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An object's categorizability impacts whether infants encode surface features into their object representations

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Abstract

Infants encode the surface features of simple, unfamiliar objects (e.g., red triangle) and the categorical identities of familiar, categorizable objects (e.g., car) into their representations of these objects. We asked whether 16–18-month-olds ignore non-diagnostic surface features (e.g., color) in favor of encoding an object's categorical identity (e.g., car) when objects are from familiar categories. In Experiment 1 ($n = 18$), we hid a categorizable object inside an opaque box. In No Switch trials, infants retrieved the object that was hidden. In Switch trials, infants retrieved a different object: an object from a different category (Between-Category-Switch trials) or a different object from the same category (Within-Category-Switch trials). We measured infants' subsequent searching in the box. Infants' pattern of searching suggested that only infants who completed a Within-Category-Switch trial as their first Switch trial encoded objects' surface features, and an exploratory analysis suggested that infants who completed a Between-Category-Switch trial as their first Switch trial only encoded objects' categories. In Experiment 2 ($n = 18$), we confirmed that these results were due to objects' categorizability. These results suggest infants may tailor the way they encode categorizable objects depending on which object dimensions are perceived to be task relevant.

1 | INTRODUCTION

Infants are tasked with learning about the world around them as objects and people move in and out of occlusion. The ability to keep track of objects' identities as the objects move through space, and to maintain a representation of an object in the mind, allows infants to learn about and navigate the world around them even when they may not have visual access to relevant objects.

Much previous work has examined infants' use of objects' surface features (such as color, shape, or texture) to keep track of objects in the world. For example, a 5-month-old infant who observes a triangle emerge from and return behind an occluder, and who then observes a disk emerge from and return behind that same occluder, can correctly posit the existence of two objects behind the occluder (and can eventually use pattern and color to individuate objects as well; Wilcox & Baillargeon, 1998; Wilcox, 1999). However, infants are extremely limited in their ability to encode and subsequently maintain objects' surface features into their representations of objects such that hidden objects can be *identified*, not just individuated (see Kibbe, 2015, for review). For example, 6-month-old infants who observe two featurally-distinct objects (e.g., a triangle and a disk) hidden one at a time in two separate locations are able to recall the featural identity of only the last-hidden of the two objects (Káldy & Leslie, 2005; Kibbe & Leslie, 2016), while recalling only the existence, but not the surface features, of the first-hidden object (Kibbe & Leslie, 2011). Although these limits ease somewhat across infancy (Cheng et al., 2020; Káldy & Leslie, 2003; Kibbe & Applin, 2022; Kibbe & Leslie, 2013), encoding and maintaining objects' surface features in representations of objects requires sustained attention, which imposes significant limitations on object representational capacities (Cheng et al., 2019; Mareschal et al., 1999) even into adulthood (Wheeler & Treisman, 2002).

Infants also can use knowledge of objects' categories to individuate objects. Infants readily individuate objects based on category membership, and infants often fail to use objects' surface features to individuate objects when the objects are from categories infants are familiar with (e.g., infants individuate a human-like doll and a non-human-like ball, but not one human-like doll from another; Bonatti et al., 2002; see also Pauen, 2002; Surian & Caldi, 2010; Xu & Carey, 1996; Xu et al., 2004), suggesting category identity supersedes featural identity in infants' object individuation. Infants also can use objects' shared category membership to keep track of more individual objects than they otherwise could, hierarchically reorganizing a set of four objects into two sets of two objects that belong to the same category (e.g., two distinct cats and two distinct cars; Feigenson & Halberda, 2008).

Although these studies show that infants can use objects' category membership to help them keep track of *how many* objects are hidden in a given location, relatively less is known about *what* infants encode about those categorical identities into their object representations. Categories are defined by specific diagnostic features—a face has eyes, nose, and mouth in a particular configuration; a car has four wheels and a particular overall shape—and we recognize whether an object belongs to a given category based on these diagnostic features. But the *specificity* of the features—whether the car's wheels are black or red, for example—do not impact the car's ability to be categorized as a car. Do infants include diagnostic features in their object representations, and to what extent are those features represented with sufficient detail to allow infants to detect category-irrelevant changes to those features?

There is some evidence to suggest that infants may represent objects' categorical identities without specific featural information in their representations of objects. Kibbe and Leslie (2019) showed 6-month-olds two categorically-distinct objects—a human face and a non-human ball—hidden sequentially behind separate occluders. They tested infants' representation of the first hidden object (for which infants typically fail to encode surface features; Káldy & Leslie, 2005; Kibbe & Leslie, 2011, 2016) by removing the occluder hiding this object and revealing either the original hidden object, a different object from the same category, or an object from a different category. They found that infants looked longer when the object was revealed to have changed categories (e.g., a red and orange striped ball was hidden, and a human face was revealed), but failed to notice when the object changed to a different object from the same category, despite large featural changes (e.g., a red and orange striped ball was hidden, and a green and blue polka dot ball was revealed). These results suggest that infants may encode an object's categorical identity but fail to encode the specific features of the object. The results also suggest that maintaining objects' categorical identities may be less cognitively effortful than maintaining objects' featural identities.

However, Kibbe and Leslie's (2019) study was, by design, an extremely demanding scenario in which they examined 6-month-olds' representation of an object whose featural identity they typically fail to recall. Thus, it is unclear whether encoding an object's categorical identity into the object representation necessarily prompts infants to neglect surface features in their object representations, or whether this is simply more likely to happen under conditions that place extreme demands on infants' object representational resources. Indeed, previous work suggests that, as memory load increases, infants' representations of objects' categories become coarser. Zosh and Feigenson (2012) used a manual search task with 18-month-olds in which they hid one, two, or three objects inside a box. On some trials, infants reached into the box and retrieved the same object(s) that were hidden. On other trials, the experimenter surreptitiously swapped one or more of the original objects for objects from different categories, which infants retrieved from the box. They then measured infants' continued searching in the box following retrieval of the objects. If infants could track the identities of the hidden objects, they should notice when an object that had been hidden had not subsequently been removed, and search longer on trials in which objects were swapped relative to trials in which all of the original objects were retrieved. When only one or two objects were hidden, infants successfully detected changes to the object(s)' categorical identit(ies). When three objects were hidden, infants only detected large, superordinate category changes (e.g., when a solid object changed to a substance) but did not detect relatively smaller categorical changes (e.g., when a cat changed to car). These results suggest that representational load may impact the specificity of the category information stored in infants' object representations. Memory load could similarly impact the extent to which infants encode specific identity information about non-diagnostic features (e.g., whether a car is red or blue).

However, one recent study suggests that infants do indeed fail to notice changes to non-diagnostic features of categorizable objects even in tasks with no response demands and minimal memory demands. Pomiechowska and Gliga (2021) showed 12-month-old infants a series of displays in which a single object (e.g., a blue shoe) moved behind an occluder and then re-emerged, and they used EEG to probe infants' representations of the objects. On some trials, the object that re-emerged was the same that was hidden (e.g., the blue shoe re-emerged), on some trials the object changed to a featurally-distinct object from the same category (e.g., a pink shoe emerged), and on the remaining trials the object changed to an object from a different category (e.g., a colorful ball emerged). They found that when objects were from familiar categories (like shoes or balls), infants detected changes to the object's categorical identity but did not detect within-category changes, as measured by EEG. When objects had clear functions but were from *unfamiliar* categories (like padlocks or staplers), infants detected both between- and within-category changes to the objects. Further, their results suggested that infants encoded the objects from familiar and unfamiliar categories differently *before the objects were hidden*, suggesting that category knowledge impacted the way infants represented objects before those representations needed to be stored in limited working memory.

While this study provides insights into the way infants' brains process categorizable objects, as measured implicitly via EEG, it is unclear how these neural signatures may play out in the way children explicitly track object identities, that is, in a task that requires infants to interact with objects.

Interacting with objects may prompt infants to encode and track objects differently than observing objects alone (Gibson & Pick, 2000; Libertus et al., 2013; Perone et al., 2008). For example, Perone et al. (2008) showed young infants an object with a function (e.g., an object that squeaked when squeezed), and found that infants could detect a change to the object's function (suggesting kind-based encoding), but only those who had robustly interacted with the object were able to reliably detect a change to the object's appearance (suggesting encoding of the objects' surface features).

Here, we asked what infants encode about categorizable objects with which they interact. We used a manual search task, because this task requires infants to physically interact with objects, and tested 16- to 18-month-old infants, since previous research showed that infants of this age can encode the *categorical* identity of a single object in a manual search task (Zosh & Feigenson, 2012). In Experiment 1, on each trial infants viewed an object from a familiar category (doll or car) that was then hidden inside of an opaque box. Infants were then allowed to reach into the box and retrieve either the original hidden object (e.g., a red car), an object from a different category (e.g., a doll), or a featurally-distinct object from the same category (e.g., a yellow car). In Experiment 2, we replaced the categorizable objects with objects that were featurally similar to the categorizable objects but were not categorizable (e.g., a block covered in red and black felt matching the colors and color configuration of the red car). To assess whether infants noticed that the object had changed, we compared infants' subsequent searching in the box when a different item was retrieved to their search when the original item was retrieved.

We predicted that, if infants encode objects' categories and not objects' specific features when objects are from familiar categories, infants should successfully detect between-category, but not within-category, changes to objects in Experiment 1. With respect to Experiment 2, if infants' behavior in Experiment 1 was driven by the *categorizability* of the objects, and not differences in the objects' overall surface features (i.e., color and pattern), we would expect a different pattern of searching in Experiment 2 compared to Experiment 1. However, we did not have strong predictions about what that pattern would necessarily be, given previous literature. On the one hand, infants may detect feature changes in Experiment 2, since previous studies found that younger infants encoded the featural identities of simple objects (e.g., Káldy & Leslie, 2003, 2005; Kibbe & Leslie, 2013, 2016, 2019). On the other hand, infants may not encode the surface features of the objects in Experiment 2, or may have difficulty detecting the changes to the objects' surface features. The previous work that showed that infants detect changes to non-categorizable objects' surface features used very simple objects (e.g., a red triangle changed to a red disk); to succeed, infants needed to bind only one or two features to their object representation. By contrast, the objects in Experiment 2 were more featurally complex, to match the color and pattern of the categorizable objects in Experiment 1. Binding this range of features to the object representation is significantly more demanding on infants' limited representational resources (Kibbe & Applin, 2022), and infants, children, and adults all have much more difficulty detecting featural changes to objects when objects are more featurally complex (e.g., defined by two or more features: Applin & Kibbe, 2021; Bays & Husain, 2008; Cheng et al., 2020; Kwon et al., 2014; Oberauer & Eichenberger, 2013; Wheeler & Treisman, 2002). Furthermore, when objects are from the same *superordinate* category (e.g., “object”) but there are no additional cues that would indicate that the objects are from distinct *subordinate* categories (e.g., features that would suggest an object's functionality; Futo et al., 2010; Pomiechowska & Gliga, 2021), infants may be less likely to encode the objects' surface features, only encoding the dimensions of the object that are relevant to its superordinate category (e.g., that it is solid, rigid, and cohesive, and not amorphous and squishy; Zosh & Feigenson, 2012). Therefore, infants may fail to detect feature changes to the non-categorizable objects in Experiment 2.

2 | EXPERIMENT 1: CATEGORIZABLE OBJECTS

2.1 | Method

2.1.1 | Participants

Eighteen 16- to 18-month-old infants (mean age = 17 months 20 days, range = 16 months 0 days–18 months 29 days; 9 girls) participated in the laboratory at Boston University. Sample size was determined prior to data collection based on Zosh and Feigenson (2012) who obtained large effect sizes ($d > 1.5$) in a study in which similar-aged infants detected a categorical change to a single object in a manual search task (their studies included $n = 16$ infants per experiment; see also Feigenson & Carey, 2003; Stahl & Feigenson, 2014, 2018; Stahl et al., 2023). An additional six infants were tested but excluded from analyses because they failed to produce the dependent measure on at least half of the trials. Infants were tested between April 2015 and February 2016. All study procedures for Experiments 1 and 2 were conducted according to guidelines laid down in the Declaration of Helsinki, with written informed consent obtained from a parent or guardian for each child before any assessment or data collection. All procedures involving human subjects in this study were approved by the Boston University Charles River Campus Institutional Review Board (Protocol #3594E: Development of working memory in social and non-social contexts).

2.1.2 | Materials

An opaque black box (10 inches wide X 5 inches tall X 16.5 inches deep) made of foam core and lined with black felt was used to hide and retrieve objects. The front face of the box had an opening (5.25 inches wide X 3 inches tall) that was covered with light blue spandex that had a horizontal slit. Infants could reach their hand(s) into the slit but could not see the contents inside the box. The back of the box had an opening that was covered with a black felt flap that allowed the experimenter to surreptitiously swap objects that were hidden inside.

Colorful plastic keys were used in the warm-up trials to get infants accustomed to the procedure. Four unique objects were hidden/retrieved from the box in the test trials: two dolls (2.5 inches tall) and two cars (2.5 inches wide). One doll had brown hair, a green shirt, and tan pants; the other doll had blonde hair, a white shirt with a pink heart, and pink pants. One car was blue with a red stripe down its center; the other car was solid yellow with black windows (Figure 1). These four objects were all similar to each other in texture (smooth and shiny) and overall shape and size (rounded rectangular), but each differed from each other in their perceptual features (color and pattern). Across categories (dolls vs. cars) the objects differed in orientation (vertical vs. horizontal).

2.1.3 | Procedure

Infants were seated in a low high-chair at a child-sized table, with their caregiver seated in a chair behind them and to their right. The experimenter knelt next to the table to the infants' left. Two cameras captured infants' search times (one located above, one located behind the infant and to the left).

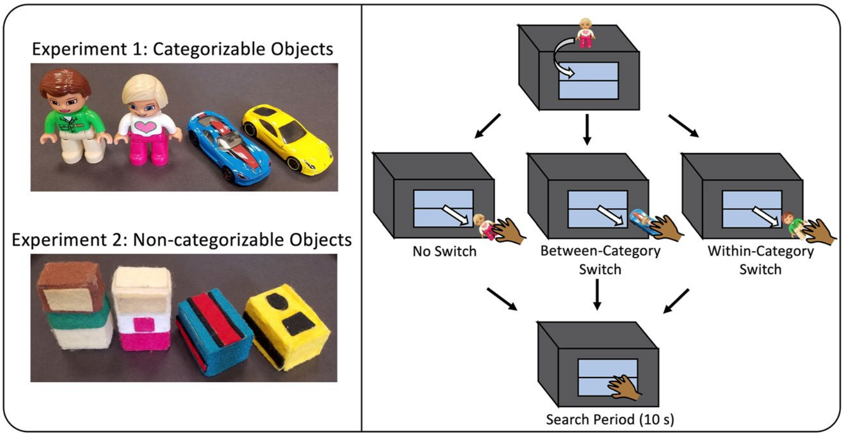

FIGURE 1 The left panel shows the categorizable objects used in Experiment 1 and their non-categorizable counterparts from Experiment 2. The right panel is a schematic of the study design of Experiment 1. Infants watched the experimenter hide one object, and then were able to retrieve one object from the box (either the same object that was hidden, a different object from a different category, or a different object from the same category). We then measured infants' search time in the box following the removal of the object.

Warm-up trials

Each infant received two identical warm-up trials. The experimenter placed the colorful plastic keys on top of the box while saying, "Look at this!" She then circled the keys with her pointer finger while saying, "Watch this!" She then lifted the keys and said, "In we go!" as she hid them in the box through the slit in the front. She then asked, "What can you find?" and pushed box toward the infant so that they could reach inside. Infants then retrieved the keys and the experimenter removed them from view. If infants were hesitant to retrieve the object, the experimenter encouraged them to reach inside until they did so (e.g., by saying, "What's in there?" or by reaching in into the box, pulling the keys out of the opening slightly, and then returning them to the box and again encouraging the infant to search).

Test trials

Infants completed eight test trials in which the experimenter hid a single object inside of the box, and infants reached inside to retrieve an object. Infants completed three types of test trials: No-Switch trials, Between-Category-Switch trials, and Within-Category-Switch trials. Each Switch trial was paired with a No-Switch trial, such that the object that was hidden on each trial was the same (e.g., the yellow car) but the object that the infant retrieved varied (e.g., the yellow car in a No-Switch trial, the blue car in a Within-Category-Switch trial). Thus, infants completed two Between-Category Switch trials and two Within-Category-Switch trials, each paired with a No-Switch trial (for a total of four No-Switch trials).

In No Switch trials, the experimenter placed one object (e.g., the yellow car) on top of the box while saying, "Look at this!" She then circled the object with her pointer finger while saying, "Watch this!" The object was visible for approximately 5 s before being hidden. She then lifted the object and said, "In we go!" as she hid it in the box through the slit in the front. To equate the hand motions in No Switch trials with those that would be used in the Switch trials (in which the object was surreptitiously switched for a different object through the opening at the back of the box), the experimenter pushed the object all the way to the back of the box, and slid it back to the front of the box, while her other hand rested inside the concealed opening in the back of the box. Doing so ensured that hiding and retrieving objects appeared exactly the same to the infants regardless of whether an object was switched on a given trial. She then asked, “What can you find?” and pushed the box toward the infant so that they could reach inside. The infant then retrieved the same object that was hidden (e.g., the yellow car), which the experimenter immediately took from them and placed under the table. A ten-second measurement period followed, during which the experimenter looked down to avoid influencing the infants' searching behavior. Infants were allowed to freely search the box during that time. Infants were considered to be searching if their hand was inside the box past the knuckle closest to their palm. If infants were still searching after the 10 seconds passed, the experimenter allowed the infant to continue searching until they pulled their hand out of the box.

In Between-Category-Switch trials, the experimenter placed an object on top of the box and hid it inside in the same manner as on No Switch trials. However, when she hid the object inside, she surreptitiously swapped it with a different object from a *different category* through the concealed opening in the back of the box and secretly removed the originally-hidden object from the back of the box. When the infant reached into the box, they retrieved an object that was different from the one that was hidden, which belonged to a different category (e.g., the yellow car was hidden and the doll with the green shirt was retrieved). The measurement period followed exactly as in the No-Switch trials.

In Within-Category-Switch trials, the retrieved object was a different object from the *same category* as the one that was hidden (e.g., yellow car hidden, blue car with red stripe retrieved). Each trial was followed by a ten-second measurement period as in the Between-Category-Switch and No-Switch trials.

A trained observer measured infants' search times on each trial. All search times also were coded for reliability by a second, independent observer. Inter-observer agreement was high ($r = 0.96$). Data for Experiments 1 and 2 are available at https://osf.io/f69hr/.

Counterbalancing

Trial order was counterbalanced across infants: half of the infants completed a Between-Category-Switch trial pair first, followed by a Within-Category-Switch trial pair; the other half of infants completed a Within-Category-Switch trial pair first, followed by a Between-Category-Switch trial pair, and the order of the trials within each pair was counterbalanced (e.g., a switch, no-switch pair followed by a no-switch, switch pair; for a total of 8 test trials). Infants completed two trial pairs in which a doll was hidden (two No-Switch trials, one Between-Category-Switch trial, and one Within-Category-Switch trial) and two trial pairs in which a car was hidden (two No-Switch trials, one Between-Category-Switch trial, and one Within-Category-Switch trial). Which object was hidden on which trial was counterbalanced across infants.

2.2 | Results

Analyses were conducted on infants' mean search times computed across the two trials of each type (Between-Category-Switch trials and their No-Switch counterparts; Within-Category Switch trials and their No-Switch counterparts). We submitted infants' mean search times to a repeated measures ANOVA with Category Switch Type (Between-Category or Within-Category) and Trial Type (No Switch or Switch) as within-participants factors and Order (Between-Category trial pair first or

Within-Category trial pair first) as a between-participants factor. We observed no main effect of Category Switch Type (F [1, 16] = 0.838, p = 0.373, et2p = 0.050) or Order (F [1, 16] = 3.575, p = 0.077,

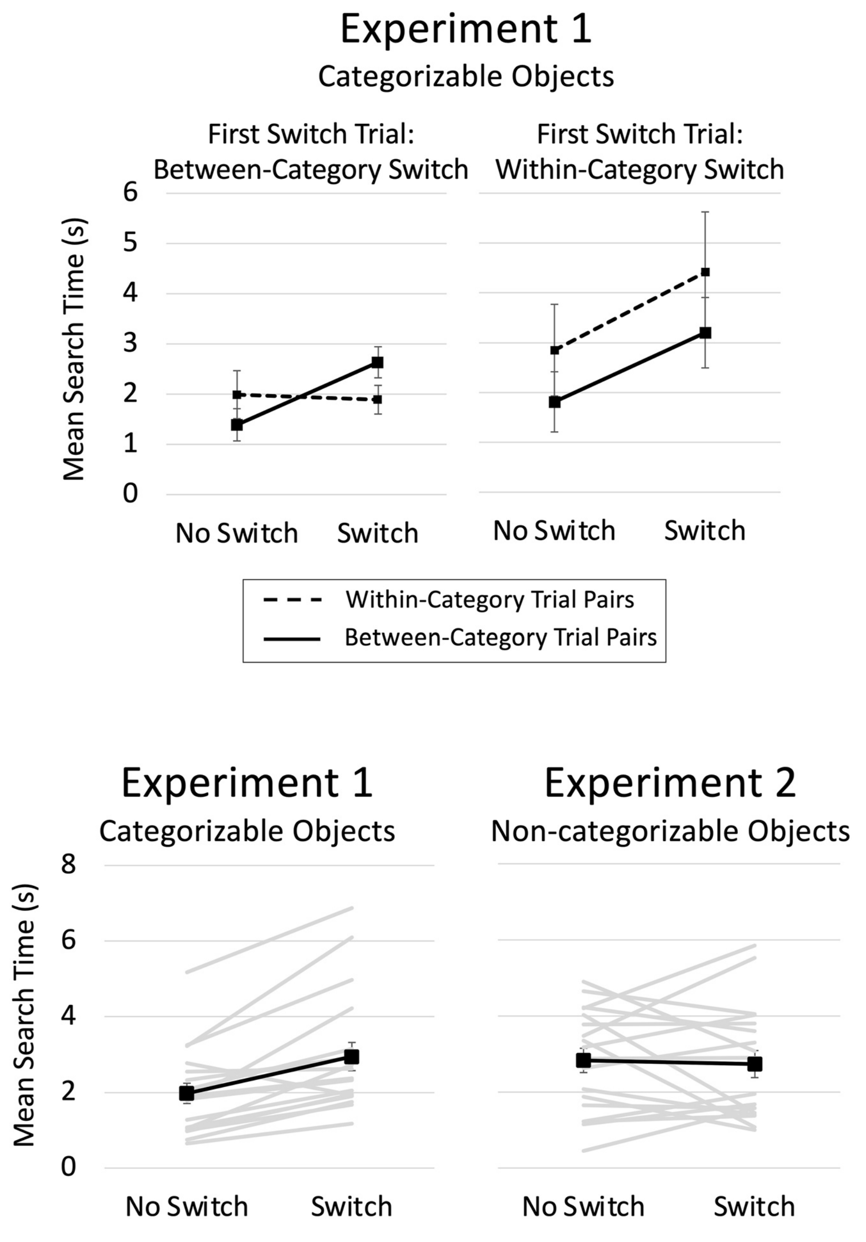

FIGURE 2 Top panel shows infants' mean search times in Experiment 1 (Categorizable Objects) for all trials as a function of Order. The top left panel shows mean search times in Within-Category-Switch trials, Between-Category Switch-trials, and their paired No-Switch trials for infants whose first Switch trial was a Between-Category Switch. The top right panel shows mean search times in Within-Category-Switch trials, Between-Category Switch-trials, and their paired No-Switch trials for infants whose first Switch trial was a Within-Category Switch. Bottom panel shows individual children's mean search times (light gray bars) and overall mean search times (black bars) across No Switch and Switch trials in Experiment 1 (Categorizable Objects) and Experiment 2 (Non-categorizable Objects). Error bars in all plots show ±1 SEM.

eta2p = 0.183), but we did observe a significant main effect of Trial Type (F [1, 16] = 32.610, p < 0.001, eta2p = 0.671) subsumed under a significant Order X Trial Type interaction (F [1, 16] = 6.336, p = 0.023, eta2p = 0.284; no other interactions were significant, all F > 2.6, all p > 0.30). This result is illustrated in Figure 2, top panel.

Inspection of Figure 2 suggests that infants' ability to detect any switch to an object's identity depended on whether infants saw within- or between-category changes first. We followed this up with exploratory pairwise comparisons within each Order. When infants completed a Within-Category-Switch trial pair first, they searched longer on both types of Switch trials compared to No-Switch trials (Between-Category M [*switch*] = 3.2 s, M [*no switch*] = 1.81 s, t [7] = −2.931, p = 0.022; Within-Category M [*switch*] = 4.41 s, M [*no switch*] = 2.85 s, t [7] = −2.293, p = 0.056). When infants observed a Between-Category-Switch trial pair first, they searched longer on Between-Category-Switch trials compared to paired No-Switch trials (Between-Category M [*switch*] = 2.64 s, M [*no switch*] = 1.39 s, t (9) = −2.794, p = 0.021), and searched similarly on Within-Category-Switch trials and paired No-Switch trials (Within-Category M [*switch*] = 1.89 s, M [*no switch*] = 1.99 s, t [9] = 0.262, p = 0.799).

2.3 | Discussion

In Experiment 1, we predicted that infants, when presented with categorizable objects, would be more likely to encode an object's category rather than the object's specific features, and would thus be more likely to detect a categorical change to an object (e.g., car hidden, doll retrieved) than a featural change to an object (e.g., yellow car hidden, blue car retrieved). However, the results of Experiment 1 painted a more nuanced picture of the way objects' categorizability impacts infants' encoding of object identities. When infants experienced within-category changes first, they detected changes to objects' identities, regardless of whether those changes were to objects' categories (as in the Between-Category trials) or whether those changes were non-diagnostic changes to objects' features (as in the Within-Category trials). When infants saw between-category changes first, infants did not successfully notice changes to object identities (although exploratory analyses suggested that these infants may have detected categorical changes to objects). These results suggest that infants may encode the non-diagnostic features of categorizable objects, but may only prioritize doing so when the objects' non-diagnostic features appear to be task-relevant (i.e., when infants' first experience with a "switch" is a within-category change), and this type of encoding may persist for the duration of the task. By contrast, when objects' non-diagnostic features do not appear to be task-relevant (i.e., when infants' first experience with a "switch" is a between-category change), infants do not appear to encode non-diagnostic features into their object representations.

In Experiment 2, we created new stimuli that had similar surface featural properties as the objects in Experiment 1, but were no longer from recognizable categories. We asked what infants encode about featurally complex objects when objects are not categorizable. Further, by constructing the stimuli to match the surface featural properties of the objects in Experiment 1, Experiment 2 acted as a control condition for Experiment 1: it allowed us to determine whether the results of Experiment 1 were truly driven by objects' categorizability, or whether the pattern of results we obtained was due differences in the surface-featural properties of the stimuli.

3 | EXPERIMENT 2: NON-CATEGORIZABLE OBJECTS

3.1 | Method

3.1.1 | Participants

Eighteen 16- to 18-month-old infants (mean age = 17 months 15 days, range = 16 months 5 days–18 months 28 days; 10 girls) participated in the laboratory at Boston University. Sample size was selected to match the size of the sample used in Experiment 1. An additional six infants were excluded due to failure to produce the dependent variable on at least half of the trials (4), fussiness (1), or experimenter error (1). All infants were tested between September 2015 and April 2016.

3.1.2 | Materials

The materials were identical to those in Experiment 1, except for the objects used in the test trials. Four unique blocks (2 inches X 1.5 inches X 1 inch) were perceptually matched to the dolls and cars used in Experiment 1: A vertical block with a brown top, green middle, and tan bottom; a vertical block with a tan top, white middle, and pink bottom; a horizontal blue block with a red stripe; and a horizontal yellow block with black patches (Figure 1). Critically, as in Experiment 1, these four objects were all similar to each other in texture (fuzzy and matte) and in overall shape (rectangular), but each differed from each other in their perceptual features (color and pattern). Also as in Experiment 1, the objects differed in their orientations across pairs (the doll-matched objects were a vertical rectangular shape while the car-matched objects were a horizontal rectangular shape). While the outer contours of the objects in Experiment 1 were somewhat more complex than in Experiment 2, they were matched on overall shape, orientation, color, and placement of pattern to the objects in Experiment 1; however, the objects in Experiment 2 were not from recognizable categories.

3.1.3 | Procedure

The procedure was identical to that of Experiment 1 in which infants completed eight test trials, except that we used non-categorizable objects that were perceptually matched to the categorizable objects from Experiment 1. To match Experiment 1, the objects that were perceptually matched to the dolls were placed on top of the box in an upright position, and the objects that were perceptually matched to the cars were laid flat (illustrated in Figure 1, left panel) before being hidden inside the box. Infants completed four No-Switch trials, each paired with a Switch trial that was perceptually matched to Experiment 1: in Between-Category-Matched Features trials, infants retrieved objects that were perceptually matched to the Between-Category-Switch trials from Experiment 1 (e.g., the yellow and black horizontal block was hidden and the green, brown, and tan vertical block was retrieved), and in Within-Category-Matched Features trials, infants retrieved objects that were perceptually matched to the Within-Category-Switch trials from Experiment 1 (e.g., the yellow and black horizontal block was hidden, and the red and blue horizontal block was retrieved). Trial order was counterbalanced as in Experiment 1.

A trained observer measured infants' search times on each trial. All search times also were coded for reliability by a second, independent observer. Inter-observer agreement was high ($r = 0.95$).

3.2 | Results

We submitted infants' mean search times to a repeated measures ANOVA with Feature Type (Between-Category-Matched Features or Within-Category-Matched Features) and Trial Type (No Switch or Switch) as within-participants factors and Order (Between-Category-Matched Features Trial Pair First or Within-Category-Matched Features Trial Pair First). This analysis revealed no main effect of Feature Type (F [1, 16] = 0.417, p = 0.527, eta2p = 0.025), no main effect of Trial Type (F [1, 16] = 0.049, p = 0.827, eta2p = 0.003), and no interaction between Perceptual Control Type and Trial Type (F [1, 16] = 0.242, p = 0.630, eta2p = 0.015); infants searched equally during the search period regardless of whether they had retrieved the same object or a perceptually distinct object from the box (Figure 2). We also observed no main effect of Order (F [1, 16] = 0.396, p = 0.538, eta2p = 0.024) and no Order X Trial Type interaction (F [1, 16] = 0.728, p = 0.406, eta2p = 0.044), suggesting infants searched similarly regardless of which block they completed first.

3.2.1 | Experiments 1 and 2 compared

We conducted an omnibus repeated measures ANOVA with Category Type (Between-Category/Between-Category-Matched Features or Within-Category/Within-Category Matched Features) and Trial Type (No Switch or Switch) as within-participants factors and Experiment (1 or 2) and Order (Between trial pair first or Within trial pair first) as between-participants factors. We observed no main effect of Category Type (F [1, 32] = 1.248, p = 0.272, eta2p = 0.038) and no main effect of Experiment (F [1, 32] = 0.437, p = 0.513, eta2p = 0.013). We did observe a main effect of Trial Type (F [1, 32] = 7.414, p = 0.01, eta2p = 0.188) subsumed under a significant Trial Type × Experiment interaction (F [1, 32] = 9.644, p = 0.004, eta2p = 0.232). Infants' search patterns differed significantly between the two experiments, with infants' showing differential search times across Trial Types in Experiment 1 but not in Experiment 2 (see Figure 2, bottom panel).

The main effect of Order did not reach statistical significance (F [1, 32] = 3.057, p = 0.09, eta2p = 0.087), nor did the interaction between Trial Type and Order (F [1, 32] = 4.074, p = 0.052, eta2p = 0.113). There was a significant 4-way interaction between Category Type, Trial Type, Experiment, and Order (F [1, 32] = 4.346, p = 0.045, eta2p = 0.120). While four-way interactions are difficult to interpret, this likely reflects that the order effect observed in Experiment 1 was not observed in Experiment 2. No other interactions were significant (all $F < 1$).

3.3 | Discussion

In Experiment 2, we hid complex, featurally-distinct objects that were not from distinct, familiar categories. The objects were constructed to match the overall surface-featural configurations of the objects in Experiment 1, but without the diagnostic features that made those objects recognizable as cars or dolls (i.e., wheels, faces). We found that infants failed to respond to surface featural changes to the objects. We also found that infants' searching patterns in Experiment 1 were significantly different from their searching patterns in Experiment 2. These results suggest that infants' searching behaviors in Experiment 1 were likely driven by the objects' categorizability rather than the objects' overall surface features. We discuss the broader implications of the results of both experiments in the General Discussion.

4 | GENERAL DISCUSSION

In two experiments, we asked how objects' categorizability impacts what infants encode in their representations of objects. On each trial, infants observed one object that was then hidden inside of an opaque box, and infants were allowed to reach into the box and retrieve one object. In Experiment 1, objects were from familiar categories, and infants retrieved either the object that had originally been hidden inside the box (doll or car; No-Switch trials), an object from a different category (e.g., doll hidden, car retrieved; Between-Category switch), or a perceptually distinct object from the same category (e.g., red car hidden, yellow car retrieved; Within-Category switch). Experiment 2 proceeded similarly to Experiment 1, except objects were constructed to be similar in general surface features to the objects from Experiment 1 but did not have features that were diagnostic of distinct categories. To examine how infants encoded the objects, we compared infants' continued searching in the box on switch and no switch trials.

In Experiment 1, we observed an order effect. Infants whose first switch trial was a Within-Category-Switch detected both within- and between-category changes to objects, as evidenced by their longer search times on all switch trials compared to no-switch trials. That is, infants who first saw a within-category change to an object detected changes to both non-diagnostic and diagnostic features of the objects. By contrast, infants whose first switch trial was a Between-Category switch trial did not readily detect changes to object features (although an exploratory analysis suggested they detected changes to object categories). In Experiment 2, when objects were not from familiar categories, but were perceptually matched in color, pattern, form, size, and orientation to the objects in Experiment 1, infants failed to respond to any changes to the objects' identities.

Our results suggest that the categorizability of objects impacts the way infants encode object features. Specifically, infants may tailor the way they encode the features of categorizable objects depending on the requirements of the task at hand. When objects' features are relevant for the task, infants may encode those features, even when objects are from recognizable categories, and may subsequently persist in this encoding strategy. When objects' surface features did not appear relevant for the task, infants failed to encode non-diagnostic features of categorizable objects, again persisting in this approach for the duration of the task.

In Experiment 2, we found that when objects were *not* from familiar categories, infants failed to detect feature changes to those objects. These results are consistent with previous work across the lifespan that has shown that it is more difficult to represent or detect changes to the specific features of visually complex non-categorizable objects (e.g., abstract shapes made up of conjunctions of different features; Applin & Kibbe, 2021; Bays & Husain, 2008; Cheng et al., 2020; Kwon et al., 2014; Oberauer & Eichenberger, 2013; Wheeler & Treisman, 2002), and is consistent with work that suggests that infants are less likely to notice featural changes to objects from the same superordinate category (Bonatti et al., 2002; Zosh & Feigenson, 2012). However, these results also diverge somewhat from Pomiechowska and Gliga (2021), who found that 12-month-old infants noticed both within- and between-category changes to objects from unfamiliar categories, as measured by their EEG responses. We speculate that infants in Experiment 2 may not have noticed the featural changes to the objects because the objects did not have the kinds of features that showed that they were *from* distinct categories. In Pomiechowska and Gliga (2021), the objects from unfamiliar categories had distinct shapes that hinted at their function (e.g., a padlock). These unique, function-related shapes may have prompted infants to encode the objects' affordances (Booth & Waxman, 2002; Futó et al., 2010; see also Diesendruck & Bloom, 2003; Kenderla et al., 2023) and then notice when those features changed. By contrast, in our Experiment 2, the affordances of the objects did not vary (by design; to correspond to Experiment 1), while function-irrelevant surface features did vary. This aspect of the stimuli may be particularly relevant in a manual search task that required infants to reach for and grasp objects. Future work would examine the conditions under which infants encode and store the surface features of unfamiliar objects, and whether some features may be prioritized in infants' object representations as "function-relevant", even when objects are not from familiar categories.

It is important to note that the contrasting results of Experiments 1 and 2 do not suggest that infants will *always* fail to respond to changes to the features of complex objects when objects are not from familiar categories. It is likely that manipulating the conditions under which infants viewed the objects from Experiment 2 could impact the probability that infants would detect changes to those objects (e.g., by cueing infants to attend to some of the features; Ross-Sheehy et al., 2011). Instead, the contrast between Experiments 1 and 2 show that, under identical conditions with perceptually-matched stimuli, infants' ability to detect feature changes was dependent upon the categorizability of the objects and to what extent non-diagnostic changes to categorizable objects' features were task-relevant.

We used infants' search time in a manual search task to examine how an object's categorizability impacts whether infants' encode the object's surface features into their object representations. To succeed, infants needed to recognize that the object that they removed from the box was not the same object that went into the box, infer that the original hidden object must still be in the box, and search accordingly. One important upshot of this task is that it mimics (albeit in a highly controlled way) the ways in which infants of this age may interact with objects in daily life. Infants must keep track of objects as adults move those objects around, or as they themselves switch between toys or drop objects from their highchairs or car seats. Depending on an infant's goal, different features of objects may be relevant to those goals (e.g., do they want to play with *a* car, or *that* car?). In Experiment 1, we found that infants appear to be sensitive to such task-induced shifts in the relevance of object features. When the task appeared to require tracking *this object*, infants could do so and continued to do so even when they could succeed by tracking objects' categories alone. When the task appeared to require tracking *a kind of* object, infants encoded objects' categories and not features. To be clear, we are not suggesting that infants are perceiving the objects differently in different contexts. Instead, category information is impacting what they choose to encode or maintain in their representations of objects once the objects are no longer in view. Future work would examine the conditions under which infants flexibly encode objects based on task-relevant dimensions, and the extent to which infants' ability to interact with the objects in the task influences that flexibility.

Together, our results provide new insights into how infants encode categorizable objects. At least under the conditions tested here, 16–18-month-old infants encoded categorizable objects' categorical identities when objects' categories are the relevant dimension in the task, and encoded categorizable objects' non-diagnostic features (like a car's color) when such features are the relevant dimension in the task, and they persist with these specific types of encoding even when the task-relevant dimension changes. Interestingly, previous work suggested that objects' categorical identities can be encoded and maintained in the object representation more cheaply than objects' surface featural identities, which require sustained attention to encode and maintain (Cheng et al., 2019; Kibbe & Leslie, 2019; Mareschal et al., 1999; Wheeler & Treisman, 2002). Our results suggest that infants are not "beholden" to categorical encoding whenever objects are categorizable, but may instead allocate limited representational resources in a more flexible way, encoding surface features when those features are task-relevant, and not encoding surface features when those features are not task-relevant.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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REFERENCES

Applin, J. B., & Kibbe, M. M. (2021). Young children monitor the fidelity of visual working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *47*(5), 808–819. https://doi.org/10.1037/xlm0000971

Bays, P. M., & Husain, M. (2008). Dynamic shifts of limited working memory resources in human vision. *Science*, *321*(5890), 851–854. https://doi.org/10.1126/science.1158023

Bonatti, L., Frot, E., Zangl, R., & Mehler, J. (2002). The human first hypothesis: Identification of conspecifics and individuation of objects in the young infant. *Cognitive Psychology*, *44*(4), 388–426. https://doi.org/10.1006/cogp.2002.0779

Booth, A. E., & Waxman, S. (2002). Object names and object functions serve as cues to categories for infants. *Developmental Psychology*, *38*(6), 948–957. https://doi.org/10.1037/0012-1649.38.6.948

Cheng, C., Kaldy, Z., & Blaser, E. (2019). Focused attention predicts visual working memory performance in 13-month-old infants: A pupillometric study. *Developmental Cognitive Neuroscience*, *36*, 100616. https://doi.org/10.1016/j.dcn.2019.100616

Cheng, C., Kaldy, Z., & Blaser, E. (2020). Coding of featural information in visual working memory in 2.5-year-old toddlers. *Cognitive Development*, *55*, 100892. https://doi.org/10.1016/j.cogdev.2020.100892

Diesendruck, G., & Bloom, P. (2003). How specific is the shape bias? *Child Development*, *74*(1), 168–178. https://doi.org/10.1111/1467-8624.00528

Feigenson, L., & Carey, S. (2003). Tracking individuals via object-files: Evidence from infants' manual search. *Developmental Science*, *6*(5), 568–584. https://doi.org/10.1111/1467-7687.00313

Feigenson, L., & Halberda, J. (2008). Conceptual knowledge increases infants' memory capacity. *Proceedings of the National Academy of Sciences*, *105*(29), 9926–9930. https://doi.org/10.1073/pnas.0709884105

Futó, J., Téglás, E., Csibra, G., & Gergely, G. (2010). Communicative function demonstration induces kind-based artifact representation in preverbal infants. *Cognition*, *117*(1), 1–8. https://doi.org/10.1016/j.cognition.2010.06.003

Gibson, E. J., & Pick, A. D. (2000). *An ecological approach to perceptual learning and development*. Oxford University Press.

Káldy, Z., & Leslie, A. M. (2003). Identification of objects in 9-month-old infants: Integrating 'what' and 'where' information. *Developmental Science*, *6*(3), 360–373. https://doi.org/10.1111/1467-7687.00290

Káldy, Z., & Leslie, A. M. (2005). A memory span of one? Object identification in 6.5-month-old infants. *Cognition*, *97*(2), 153–177. https://doi.org/10.1016/j.cognition.2004.09.009

Kenderla, P., Kim, S.-H., & Kibbe, M. M. (2023). Competition between object topology and surface features in children's extension of novel nouns. *Open Mind*, *7*, 93–110. https://doi.org/10.1162/opmi_a_00073

Kibbe, M. M. (2015). Varieties of visual working memory representation in infancy and beyond. *Current Directions in Psychological Science*, *24*(6), 433–439. https://doi.org/10.1177/0963721415605831

Kibbe, M. M., & Applin, J. B. (2022). *Tracking what went where across toddlerhood: Feature-location bound object representations in 2-to 3-year-olds' working memory*. Child Development.

Kibbe, M. M., & Leslie, A. M. (2011). What do infants remember when they forget? Location and identity in 6-month-olds' memory for objects. *Psychological Science*, *22*(12), 1500–1505. https://doi.org/10.1177/0956797611420165

Kibbe, M. M., & Leslie, A. M. (2013). What's the object of object working memory in infancy? Unraveling 'what' and 'how many'. *Cognitive Psychology*, *66*(4), 380–404. https://doi.org/10.1016/j.cogpsych.2013.05.001

Kibbe, M. M., & Leslie, A. M. (2016). The ring that does not bind: Topological class in infants' working memory for objects. *Cognitive Development*, *38*, 1–9. https://doi.org/10.1016/j.cogdev.2015.12.001

Kibbe, M. M., & Leslie, A. M. (2019). Conceptually rich, perceptually sparse: Object representations in 6-month-old infants' working memory. *Psychological Science*, *30*(3), 362–375. https://doi.org/10.1177/0956797618817754

Kwon, M. K., Luck, S. J., & Oakes, L. M. (2014). Visual short-term memory for complex objects in 6-and 8-month-old infants. *Child Development*, *85*(2), 564–577. https://doi.org/10.1111/cdev.12161

Libertus, K., Gibson, J., Hidayatallah, N. Z., Hirtle, J., Adcock, R. A., & Needham, A. (2013). Size matters: How age and reaching experiences shape infants' preferences for different sized objects. *Infant Behavior and Development*, *36*(2), 189–198. https://doi.org/10.1016/j.infbeh.2013.01.006

Mareschal, D., Plunkett, K., & Harris, P. (1999). A computational and neuropsychological account of object-oriented behaviours in infancy. *Developmental Science*, *2*(3), 306–317. https://doi.org/10.1111/1467-7687.00076

Oberauer, K., & Eichenberger, S. (2013). Visual working memory declines when more features must be remembered for each object. *Memory and Cognition*, *41*(8), 1212–1227. https://doi.org/10.3758/s13421-013-0333-6

Pauen, S. (2002). Evidence for knowledge–based category discrimination in infancy. *Child Development*, *73*(4), 1016–1033. https://doi.org/10.1111/1467-8624.00454

Perone, S., Madole, K. L., Ross-Sheehy, S., Carey, M., & Oakes, L. M. (2008). The relation between infants' activity with objects and attention to object appearance. *Developmental Psychology*, *44*(5), 1242–1248. https://doi.org/10.1037/0012-1649.44.5.1242

Pomiechowska, B., & Gliga, T. (2021). Nonverbal category knowledge limits the amount of information encoded in object representations: EEG evidence from 12-month-old infants. *Royal Society Open Science*, *8*(3), 200782. https://doi.org/10.1098/rsos.200782

Ross-Sheehy, S., Oakes, L. M., & Luck, S. J. (2011). Exogenous attention influences visual short-term memory in infants. *Developmental Science*, *14*(3), 490–501. https://doi.org/10.1111/j.1467-7687.2010.00992.x

Stahl, A. E., & Feigenson, L. (2014). Social knowledge facilitates chunking in infancy. *Child Development*, *85*(4), 1477–1490. https://doi.org/10.1111/cdev.12217

Stahl, A. E., & Feigenson, L. (2018). Infants use linguistic group distinctions to chunk items in memory. *Journal of Experimental Child Psychology*, *172*, 149–167. https://doi.org/10.1016/j.jecp.2018.03.005

Stahl, A. E., Pareja, D., & Feigenson, L. (2023). Early understanding of ownership helps infants efficiently organize objects in memory. *Cognitive Development*, *65*, 101274. https://doi.org/10.1016/j.cogdev.2022.101274

Surian, L., & Caldi, S. (2010). Infants' individuation of agents and inert objects. *Developmental Science*, *13*(1), 143–150. https://doi.org/10.1111/j.1467-7687.2009.00873.x

Wheeler, M. E., & Treisman, A. M. (2002). Binding in short-term visual memory. *Journal of Experimental Psychology: General*, *131*(1), 48–64. https://doi.org/10.1037/0096-3445.131.1.48

Wilcox, T. (1999). Object individuation: Infants' use of shape, size, pattern, and color. *Cognition*, *72*(2), 125–166. https://doi.org/10.1016/s0010-0277(99)00035-9

Wilcox, T., & Baillargeon, R. (1998). Object individuation in infancy: The use of featural information in reasoning about occlusion events. *Cognitive Psychology*, *37*(2), 97–155. https://doi.org/10.1006/cogp.1998.0690

Xu, F., & Carey, S. (1996). Infants' metaphysics: The case of numerical identity. *Cognitive Psychology*, *30*(2), 111–153. https://doi.org/10.1006/cogp.1996.0005

Xu, F., Carey, S., & Quint, N. (2004). The emergence of kind-based object individuation in infancy. *Cognitive Psychology*, *49*(2), 155–190. https://doi.org/10.1016/j.cogpsych.2004.01.001

Zosh, J. M., & Feigenson, L. (2012). Memory load affects object individuation in 18-month-old infants. *Journal of Experimental Child Psychology*, *113*(3), 322–336. https://doi.org/10.1016/j.jecp.2012.07.005

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