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Categorization in infancy based on novelty and co-occurrence

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ABSTRACT

Abstract categories (i.e., groups of objects that do not share perceptual features, such as food) abound in everyday situations. The present looking time study investigated whether infants are able to distinguish between two abstract categories (food and toys), and how this ability may extend beyond perceived information by manipulating object familiarity in several ways. Test trials displayed 1) the exact familiarized objects paired as they were during familiarization, 2) a cross-pairing of these same familiar objects, 3) novel objects in the same category as the familiarized items, or 4) novel objects in a different category. Compared to the most familiar test trial (i.e., Familiar Category, Familiar Objects, Familiar Pairings), infants looked longer to all other test trials. Although there was a linear increase in looking time with increased novelty of the test trials (i.e., Novel Category as the most novel test trial), the looking times did not differ significantly between the Novel Category and Familiar Category, Unfamiliar Objects trials. This study contributes to our understanding of how infants form object categories based on object familiarity, object co-occurrence, and information abstraction.

1. Introduction

Grouping objects into categories is one of the most useful cognitive tools to reduce processing load and make better sense of our world. Categories can be perceptual (e.g., based on shape) or abstract (e.g., based on rules or associations with category members not sharing similar perceptual features). The vast majority of studies on categorization during infancy have focused on perceptual categorization (see Oakes & Rakison, 2019). Perceptual categories contain objects with similar features, such as shape or parts (e.g., cars tend to have a similar shape and wheels). By contrast, abstract categories contain dissimilar items within the category (e.g., a bottle of milk and blueberries do not have similar perceptual features but are both food), and yet share similar functions or intrinsic, unobservable properties. Although both types of categories are important for infant learning, abstract categories are more difficult to learn given that their criteria for membership are not immediately obvious.

Earlier research showed that toddlers in the second year of life develop a bias to group objects based on functional characteristics (e.g., things that can be driven) compared to perceptual features (e.g., things that have wheels; e.g., Rakison & Butterworth, 1998; for a review, see Rakison, 2005). Using looking time and sequential touching measures, Mandler, Fivush, and Reznick (1987) found that toddlers (14–20 months of age) could distinguish between perceptually dissimilar items based on similarity in location in the house and functions of the items (kitchen versus bathroom items). Toddlers also can flexibly use various features to categorize objects based

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on task requirements and contexts (e.g., Ellis & Oakes, 2006; Mareschal & Tan, 2007).

Despite strong evidence that toddlers can categorize items that do not share obvious perceptual features, less is known about this ability in infants. Some studies have shown that infants understand animate-inanimate distinctions, which are based on intrinsic, unobservable properties (e.g., animacy, Kibbe & Leslie, 2019; Kuhlmeier, Bloom, & Wynn, 2004; Poulin-Dubois, Lepage, & Ferland, 1996). EEG studies have found that 6- to 7-month-olds are able to distinguish animate from inanimate objects that share some perceptual features within a broad category (e.g., animals versus furniture, Grossmann, Gliga, Johnson, & Mareschal, 2009; Jeschonek, Marinovic, Hoehl, Elsner, & Pauen, 2010; Marinović, Hoehl, & Pauen, 2014; Peykarjou, Wissner, & Pauen, 2017). Young infants are also capable of understanding spatial configurations that may differ in perceptual sub-features across instances (e.g., above versus below, Quinn, Cummins, Kase, Martin, & Weissman, 1996). A recent study suggests that even 3-month-olds can distinguish when objects are the same or different across trials, even when the objects change from trial to trial (Anderson, Chang, Hespos, & Gentner, 2018): when infants were familiarized to objects that were the same, they looked longer to completely new test objects that differed across trials, but crucially they looked the same amount to completely new test objects that did not differ across trials.

1.1. The present study

The present study investigated whether infants categorize objects that do not share similar perceptual features, but rather share similar functions in the real world (food versus toys). One way of forming abstract categories could be via tracking co-occurrence statistics (e.g., Wu et al., 2013, see also Mandler et al., 1987). Infants are capable of tracking objects' co-occurrence statistics by 8 months of age (Fiser & Aslin, 2002). For example, if infants were shown apples, avocado, and carrots repeatedly, where apples and avocado were always in the same spatial configuration (i.e., apples were always on top of avocado), but the placement of carrots varied trial to trial, infants can distinguish scenes where apples were on top of avocados (i.e., familiarized scenes) from novel scenes where apples were on top of carrots (n.b. Fiser and Aslin used basic shapes in their study, such as circles and triangles). The present study investigated whether the fact that apples, avocado, and carrots are all presented simultaneously could help infants group these perceptually distinct objects into the same category. Apples, avocado, and carrots may co-occur on an infant's dinner plate, suggesting that they all have a similar function. By linking together unique objects based on their co-occurrence, the learner can extend the category beyond the perceptual features of the category exemplars. This process is related to infants' ability to track feature co-occurrences related to a particular set of objects (e.g., using the presence of wheels and shape to distinguish cars from other objects; Baumgartner & Oakes, 2011; Madole, Oakes, & Cohen, 1993; Wu, Gopnik, Richardson, & Kirkham, 2011; Younger & Cohen, 1985)

Given that perceptual features play an important role in infant categorization (French, Mareschal, Mermillod, & Quinn, 2004; Horst, Oakes, & Madole, 2005; for an overview, see Oakes & Rakison, 2019), a secondary aim of this study was to investigate how abstract categorization may interact with perceptual novelty when different pairings of objects are presented during test trials. In particular, given infants' ability to track object co-occurrence, test trials with objects that are within the same object category as the familiarized items but did not co-occur during familiarization trials may be considered novel to infants, thus resulting in longer looking times to those test trials than test trials that match the familiarization trials (i.e., familiar objects in familiar pairings). Perceptual novelty also could play a role in infants' looking time when novel items from the familiarized category are displayed. However, if infants can engage in abstract categorization, then they would look longer when shown objects from the untrained category compared to the familiarized category, even when shown novel objects from the familiarized category. In the present study, co-occurrence provided an additional way for infants to group objects based on functionality, and we investigated whether infants can go beyond co-occurrence information to consider novel objects in the same functional category as more similar to familiar objects within the same category compared to novel objects from a different functional category. The ability to distinguish between these two abstract categories (i.e., novel objects, familiar category vs. novel objects, novel category) then would rely on infants' prior knowledge acquired before the experimental session. This contrast required us to include objects that are generally familiar to infants (e.g., food and toys).

2. Methods

2.1. Participants

Thirty-eight healthy infants ($M = 10$ months, 9 days (10.30), $SD = 1.91$, range: 7 months, 2 days to 13 months, 26 days; 22 females, 16 males) composed the final sample. We included a wide age range (7- to 13-month-olds) to examine the possibility of age effects on abstract categorization. Prior studies suggest that the ability to form real-world categories may be absent until approximately 14 months of age, but other categorization, object individuation, and statistical learning studies (e.g., Fiser & Aslin, 2002; Kidd, Piantadosi, & Aslin, 2012; Kirkham, Slemmer, & Johnson, 2002; Mareschal & Johnson, 2003; Wilcox, 1999; Xu, Carey, & Quint, 2004) have demonstrated these abilities that could be useful for abstract categorization are present by at least 7 months of age. Eight additional infants participated but were excluded from the final analyses due to fussiness and not completing the study, one was excluded due to an excessive number of trials displayed due to software issues, and another five infants were excluded due to incomplete age information. We used the SIMR package in R to calculate the power of our analysis performed via (generalized) linear mixed effects models and found that our model had a power of 93% with a 95% confidence interval [86.11, 97.14] (Green & MacLeod, 2016). The majority of the infants were White/Caucasian. Infants were given $10 and a t-shirt or tote bag for their participation. All primary caregivers provided written consent for their infants to take part in the study, and this study was carried out in accordance with APA ethical standards.

2.2. Stimuli

The entire object set used in this study consisted of 16 images (8 food items, and 8 toys). The food items were a blue bottle, a half-peeled banana, carrot puree, blueberries, fusilli pasta, Cheerios, two strawberries, and a watermelon slice (Fig. 1). The toys consisted of a brown knitted monkey, a yellow and green bear rattle, an orange car, a blue plush caterpillar, a beige knitted baseball, a wooden duck, a red Lego brick, and a rainbow ring set. These stimuli were chosen based on items infants are likely familiar with, and items from one category were matched to items from the other category by general shape and color.

2.3. Design and procedure

Infants' gaze was recorded with a Tobii 1750 eye-tracker (www.tobii.com), and all stimuli were presented on the standard 17-inch monitor built into the eye-tracker. All audio stimuli were presented from external speakers. Infants sat on the caregiver's lap throughout the experimental session. The session started with the standard 5-point infant calibration procedure using Tobii Clearview. All infants were successfully calibrated to at least 4 points. Then infants were shown a familiarization phase (18, 27, or 40 trials) and a test phase (4 trials). To investigate potential looking time effects due to familiarization length, the present study included three groups of infants that were presented with different numbers of familiarization trials. Eighteen infants ($M = 8.90$ months, $SD = 1.10$, range: 7.07–10.63 months) were shown 18 familiarization trials, 12 infants ($M = 11.47$ months, $SD = 1.85$, range: 8.07–13.87 months) were shown 27 familiarization trials, and 8 infants ($M = 11.75$ months, $SD = .98$, range: 10.10–12.83 months) were shown 40 familiarization trials. During the familiarization phase, infants were exposed to pairs of either food or toy items. Six out of the possible eight items (see Fig. 1A) in the category were displayed during familiarization to the infant in nine pairings (e.g., if the items in a category were assigned letters A through H, an example of nine stimulus pairings would be: AD, AE, AF, BD, BE, BF, CD, CE, CF). These nine pairings were repeated randomly throughout the familiarization phase (see sample familiarization trials in Fig. 1B). Infants who were presented 40 familiarization trials viewed these combinations at least four times each.

During the test phase, infants were shown four trials in a random order within and across participants: a pair they had seen previously during familiarization (e.g., AD; Familiar Category, Familiar Objects, Familiar Pairing), a pair they had not seen during familiarization but had seen across pairs (e.g., BC; Familiar Category, Familiar Objects, Unfamiliar Pairing), a pair of items from the same category, each item of which had not been seen during familiarization (e.g., GH; Familiar Category, Unfamiliar Objects, Unfamiliar Pairing), and a pair of items from the other category (Unfamiliar Category, Unfamiliar Objects, Unfamiliar Pairing). Note that AD, BC, and GH were all from the familiar category but were exemplars of that category based on different types of prior experience in the experimental setting. The fourth type of test trial contained objects that were novel on all three dimensions (Category, Object, Pairing), thereby serving as a baseline measure of category discrimination. Test trial position was considered as a variable in our analyses because temporal distance from the familiarization trials may influence looking time (e.g., a need for more trials to distinguish familiarization from test trials, fatigue for later trials, etc; Kidd et al., 2012).

All familiarization trials were displayed for up to 4.2 s or until the infant looked away for 1 s, and test trials were shown up to 10 s or until infants looked away for 1 s. Each trial began with an attention getter in the center of the screen, consisting of a face smiling and speaking to the infant, saying "Hi baby, look at this!" This attention getter was looped until infants looked to the screen for at least one second.

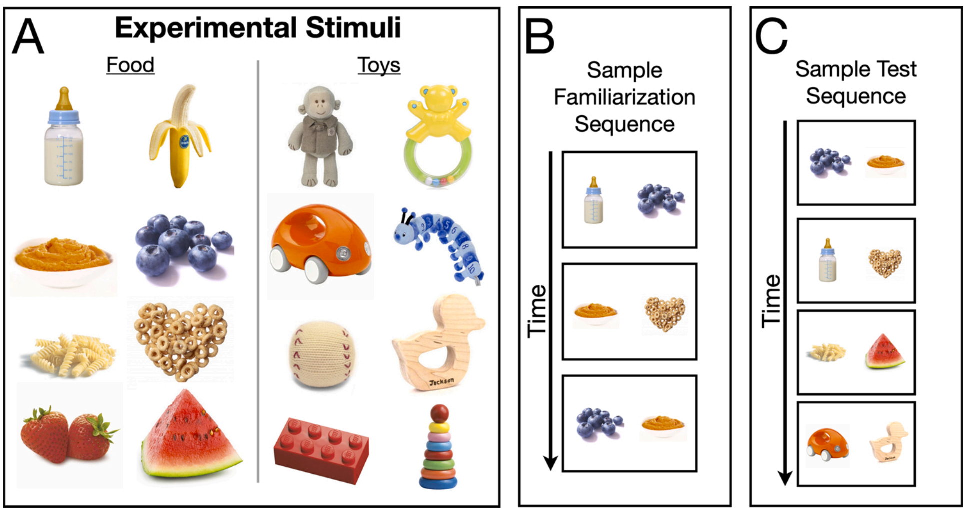

Fig. 1. A-C. The stimuli used in the present study (A), a sample sequence of familiarization trials (B), and a sample sequence of test trials (C).

2.4. Data processing and reduction

Automatic detection algorithms were used to determine both the central fixation and look away criteria. Looking time for each trial was measured from the onset of the trial (i.e., when looking to the attention getter met criterion) to the beginning of the look away that ended the trial and triggered the attention getter for the next trial. For analyses, averaged looking times were computed for familiarization trials and each test trial type. Any fixation to the computer screen during a trial counted towards the looking time measure for that trial. We did not assess separate looking times to the two stimuli on the screen, but rather used on-screen looking as a global measure of visual processing of the two category exemplars (food or toys).

3. Results

The main objective of our study was to determine whether the four test trial types differed among each other in terms of looking time in the predicted sequence (i.e., longest looking time for Novel Category to shortest looking time for Familiar Category, Familiar Objects, Familiar Pairings), while controlling for other variables. Fig. 2 depicts the mean looking times during the four different test trials.

3.1. Trend analysis

To investigate the overall relationship among looking times during the four test trials with increasing novelty, a trend analysis was used to compare linear, quadratic, and cubic regression models. We found a linear relationship (i.e., a linear change) among the four test trials, which indicated a difference of -0.544 among the conditions, $p < .001$. Neither the quadratic nor cubic models provided a good fit, $p > .542$. Because this analysis only indicates an overall linear effect, to investigate the differences among the different test trial types, we used linear mixed effects models, detailed in the next section.

3.2. Linear mixed effects models

We employed linear mixed effects models for our analyses because these models take into account the dependence among repeated measurements for a subject. In addition, they include fixed effects (“average participant”) and random effects (the difference between a particular participant from the average participant). The final set of predictors included age, training category (food vs. toys), test trial type (1: Familiar Category, Familiar Objects, Familiar Pairing; 2: Familiar Category, Familiar Objects, Unfamiliar Pairing; 3: Familiar Category, Unfamiliar Objects, Unfamiliar Pairing; 4: Novel Category), number of familiarization trials (18, 27, or 40), and test trial position (whether it was presented first, second, third, or fourth). Since fatigue may have influenced how long the infants looked at the screen during the test trials (which were presented after familiarization trials), order of the four test trials was taken into consideration. All predictors except age were categorical variables. In addition, by including the interaction between order and the test trial type, we could observe how the order in which each trial appeared affected looking time. The analyses were performed using standardized scores (i.e., z scores). In our analysis, we started with the model that had the highest level of interaction among all predictors, and then predictors were systematically removed to find the optimal model. Results from the model with significant variables and the smallest Akaike Information Criterion (AIC, a measure of model fit) are presented in Table 1.

The results in Table 1 show that, despite a wide age range in the study, age did not significantly impact looking time, $p = 0.993$, and

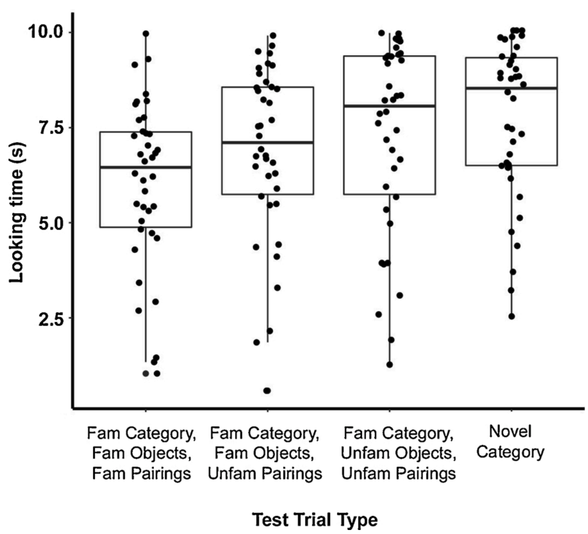

Fig. 2. Looking times in seconds for the four test trial types.

Table 1
Results of the linear mixed effects model.

Predictor	Estimate	Standard Error	95 % CI	p- value
Intercept	7.787	1.892	(4.036, 11.537)	0.000
Age	0.003	0.198	(-0.403, 0.406)	0.993
Familiar Category, Unfamiliar Objects, Unfamiliar Pairing	−0.366	0.422	(-1.202, 0.470)	0.387
Familiar Category, Familiar Objects, Unfamiliar Pairing	−0.727	0.433	(-1.585, 0.131)	0.096ˆ
Familiar Category, Familiar Objects, Familiar Pairing	−1.555	0.428	(-2.404, -0.706)	0.000*
2nd test trial	−0.106	0.425	(-0.949, 0.737)	0.803
3rd test trial	−0.508	0.432	(-1.363, 0.348)	0.242
4th test trial	−0.503	0.430	(-1.357, 0.350)	0.245
27 familiarization trials	0.746	0.934	(-1.159, 2.651)	0.431
40 familiarization trials	0.066	1.033	(-2.042, 2.173)	0.950
Familiarization stimuli: Toys	0.912	0.747	(-0.612, 2.436)	0.231
27 fam trials * toys	−3.109	1.191	(-5.537, -0.681)	0.014*
40 fam trials * toys	−1.180	1.509	(-4.258, 1.897)	0.440

Note: X*Y indicates an interaction. *p < .05, ˆp<.10.

therefore was not considered as a factor in subsequent analyses. Importantly, looking times to Novel Category test trials (reference group) and Familiar Category, Familiar Objects, Familiar Pairing test trials were significantly different from each other, $p < .001$, and infants were estimated to spend 1.555 s more looking at the Novel Category test trials than the test trials with objects identical to those presented during familiarization. There was also a marginal difference between Novel Category and Familiar Category, Familiar Objects, Unfamiliar Pairing, $p = .096$, but no significant difference between Novel Category and Familiar Category, Unfamiliar Objects, Unfamiliar Pairing. Because the results presented in Table 1 only compare each trial type to the reference group (Novel Category), we performed additional tests in order to examine differences among all test trials (Table 2). In addition, given the interaction based on familiarization trial number and familiarization item type, we explored the differences among all familiarization groups by performing additional tests (Table 3).

Table 2 shows that infants distinguished between Familiar Category, Familiar Objects Familiar Pairings and Familiar Category, Unfamiliar Objects, Unfamiliar Pairings, $p = 0.005$, spending 1.188 s more looking at Familiar Category, Unfamiliar Objects, Unfamiliar Pairings than at Familiar Category, Familiar Objects, Familiar Pairings. There was a marginal difference between Familiar Category, Familiar Objects, Familiar Pairings and Familiar Category, Familiar Objects, Unfamiliar Pairings, $p = .051$. Infants looked 0.828 s longer during Familiar Category, Familiar Objects, Unfamiliar Pairings test trials than Familiar Category, Familiar Objects, Familiar Pairings test trials, although this difference was only marginally significant.

In terms of the impact of familiarization trials and training category on test trial looking time (Table 3), the difference between the two training categories (food vs. toys) was significant when infants were shown 27 familiarization trials, but not when shown 18 or 40 familiarization trials. This result suggests that there is an optimal level of familiarization that induces discrimination performance in this familiarization-test design.

3.3. *Familiarization trials*

To investigate the potential effect of the number of familiarization trials (18, 27, or 40) on looking time during familiarization trials (average of the first three versus the last three familiarization trials), we conducted a 2 (trial position: first vs. last 3 familiarization trials) x 3 (familiarization trial number: 18, 27, or 40) repeated measures ANOVA. There was only a main effect of trial position, $F(1,35) = 51.52$, $p < .001$, $\eta^2 = .60$, and a marginal interaction, $F(2,35) = 2.56$, $p = .092$ $\eta^2 = .13$ (Fig. 3). These results suggest that looking time did decrease from the first three to the last three familiarization trials and that the number of familiarization trials may have impacted overall looking time during the first three to last three familiarization trials, justifying the inclusion of familiarization trial length in the regression model for the test trials.

Table 2
Estimates of the differences between each pair of test trial type.

Difference	Estimate	Standard Error	95 % CI	p- value
Familiar Category, Familiar Objects, Familiar Pairings – Familiar Category, Unfamiliar Objects, Unfamiliar Pairings	−1.188	0.423	(−2.018, −0.359)	0.005*
Familiar Category, Familiar Objects, Familiar Pairings – Familiar Category, Familiar Objects, Unfamiliar Pairings	−0.828	0.424	(−1.659, 0.004)	0.051ˆ
Familiar Category, Familiar Objects, Unfamiliar Pairings – Familiar Category, Unfamiliar Objects, Unfamiliar Pairings	0.361	0.424	(−0.471, 1.193)	0.395

Note: *p < .05, ˆp<.10.

Table 3
Estimates of the differences between toys and food for each number of familiarization trials.

Difference	Number of Familiarization Trials	Estimate	Standard Error	95 % CI	p- value
	18	0.912	0.747	(−0.552, 2.377)	0.222
Toys – Food	27	−2.196	0.921	(−4.002, −0.390)	0.017*
	40	−0.268	1.320	(−2.854, 2.319)	0.839

Note: *p < .05.

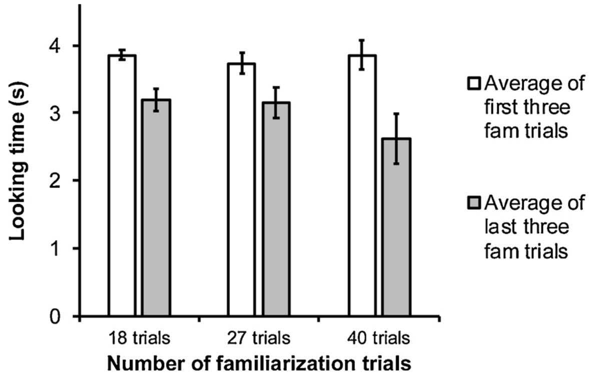

Fig. 3. Mean looking times in seconds for the familiarization trials based on number of familiarization trials shown. Error bars represent ±1 SE.

4. Discussion

This study investigated whether 7–13 month-old infants are able to distinguish between two categories of items that did not share perceptual features within a category (food and toys). Infants were familiarized to pairs of dissimilar objects from one category (e.g., bottle, banana, pasta, watermelon) and then presented with four test trial types: 1) the exact familiarized items in the same pairings that they were familiarized to (Familiar Category, Familiar Objects, Familiar Pairings), 2) the exact familiarized items in different co-occurrences (Familiar Category, Familiar Objects, Unfamiliar Pairings, 3) novel items in the same category (Familiar Category, Unfamiliar Objects, Unfamiliar Pairings), or 4) novel items in a different category (Unfamiliar Category, Unfamiliar Objects, Unfamiliar Pairings).

The looking time results revealed an interesting interaction between novelty at both perceptual and abstract levels. Compared to the most familiar test trial (i.e., Familiar Category, Familiar Objects, Familiar Pairings), infants looked longer to all other test trials, with a significant linear trend across these four test trial types with increasing novelty. There was also a marginal difference between looking times to the Novel Category compared to the Familiar Category, Familiar Objects, Unfamiliar Pairings test trials. Although the confidence intervals suggest increased looking time with increased novelty of the test trials (i.e., Novel Category as the most novel test trial), the looking times did not differ significantly between the Novel Category and Familiar Category, Unfamiliar Objects test trials. There also was no main effect of age in test trial looking times, despite the wide age range (7–13 months), although the age distribution was older in the two conditions with 27 and 40 familiarization trials, compared to 18 familiarization trials.

One possibility as to why our results were weaker than expected is that strong biases towards perceptual differences may overshadow attention to and encoding of subtle abstract categorical differences, even in our wide age group. Perhaps the wide age group itself induced variability in the data, obscuring more subtle effects (leading to a null age effect). More subtle differences based on abstraction or function may be difficult to measure, especially with looking time measures. Perhaps EEG measures may capture subtle differences with abstract categories. Indeed, research with adults has shown that the amplitude of a particular event-related potential (N2pc ERP) can reflect sensitivity to an abstract category (e.g., healthy vs. unhealthy food based on dieting experience, Wu, Pruitt, Zinszer, & Cheung, 2017). With infants, EEG studies have demonstrated that they can distinguish between animate and inanimate objects by 6 months of age (Grossmann et al., 2009). Future work could use EEG to further explore how broadly infants in the first year can categorize objects that do not share perceptual features.

Another limitation of the study is the fact that only a few objects were included in each of the two categories, which perhaps contributed to variability in infants' familiarity with the stimuli. For example, bottles may not have been familiar to breastfed infants, although the vast majority of parents reported that their infants were familiar with bottles (but perhaps not that specific type of bottle). Relatedly, the Cherrios were displayed in a heart-shaped configuration, which may have confused infants who were not used to seeing Cheerios in that way. These issues relate to the importance of prior experience on performance, especially in categorization tasks (Hoemann et al., 2020). The present study aimed to use objects familiar to the infant to minimize novel learning about the objects' identity during the task, and thereby probe infants' abstract categorization abilities relative to perceptual novelty. Indeed, the inclusion of test trials that presented familiar items in novel pairings investigated this issue. Future research including infants' own toys or food that they eat everyday may yield stronger results than those in the present study.

The results from the present study contribute to the literature on categorization of perceptually dissimilar objects during infancy. The present study goes beyond infant categorization studies that use categories containing perceptually similar objects. We asked whether infants can transcend perceptual dissimilarity to form categories with perceptually dissimilar objects. One way of doing so may be by observing how objects co-occur (e.g., such as food on a plate or letters in a word; see Wu et al., 2013). The idea of using object co-occurrences to form categories builds on the idea of using correlations of distinct features of objects to form categories (e.g., Rakison & Poulin-Dubois, 2001). In addition to observing co-occurrences, perhaps infants can construct categories in an ad hoc manner, as adults do, based on stimulus presentation, task demands, and prior object knowledge (e.g., Barsalou, 1983; Hoemann et al., 2020). With increased cognitive, social, and motor abilities throughout the first year of life, infants become increasingly adept at forming abstract categories, where category items are perceptually dissimilar (Oakes & Rakison, 2019). By probing such mechanisms for categorization, we can better understand how infants gain efficiency with relevant objects (see Oakes & Madole, 2000).

CRediT authorship contribution statement

Rachel Wu: Conceptualization, Data curation, Formal analysis, Funding acquisition, Writing - original draft, Writing - review & editing. **Esra Kurum:** Formal analysis, Writing - review & editing. **Claire Ahmed:** Formal analysis, Writing - review & editing. **Debaleena Sain:** Formal analysis, Writing - review & editing. **Richard N. Aslin:** Conceptualization, Funding acquisition, Writing - review & editing.

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