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Categorization of Two-Dimensional and Three-Dimensional Stimuli by 18-Month-Old Infants

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Abstract

In two experiments, 18-month-olds' categorization of 3D replicas and 2D photographs of the same animals and vehicles were compared to explore infants' flexibility in categorization across different object representations. Using a sequential touching procedure, infants completed one superordinate and two basic-level categorization tasks with 3D replicas, 2D cut out photographs, or 2D images on photo cubes ("2D cubes"). For superordinate sets, 3D replicas elicited longer mean run lengths than 2D cut outs, and 3D replicas elicited equivalent mean run lengths as 2D cubes. For basic-level sets, infants categorized high-contrast animal sets when presented with 3D replicas, but they failed to categorize any of the 2D photograph sets. Categorization processes appear to differ for 3D and 2D stimuli, and infants' discovery of object properties over time while manipulating objects may facilitate categorization, at least at the superordinate level. These findings are discussed in the context of infants' representation abilities and the integration of perception and action.

Keywords

Categorization; 2D & 3D perception; dual representation

Categories structure and clarify cognition, and they allow us to respond to novel entities as if they were familiar (Bornstein, 1984; Harnad, 1987). Categorizing is thus an essential cognitive and developmental achievement, and humans categorize early in life (Bornstein, & Arterberry, 2003; see Rakison & Oakes, 2003, for a review). A common method for assessing older infants' categorization abilities is the sequential touching procedure (Mandler, Fivush, & Resnick, 1987). This procedure involves presenting infants with objects from two categories (e.g., four animals and four vehicles), and observing, recording, and analyzing their patterns of touching. The empirical observation is that, if children recognize

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a categorical distinction amongst the objects, they touch those from within a category in succession more than would be expected by chance (Mandler et al., 1987).

The objects used in the sequential touching procedure are typically 3D replicas of real-world objects, such as realistic toy animals and cars (see Figure 1A). The use of 3D replicas most likely facilitates categorization as they are highly realistic exemplars of their real object referents, and infants show equivalent categorization of real objects referents and their replicas, whether objects (phones, brushes) or fruit (lemons, pears) (Arterberry & Bornstein, 2012). 3D replicas provide a rich source of information regarding object features, information infants may use to access existing object representations or to create new categories (e.g., Arterberry & Bornstein, 2012; Horst et al., 2009; Mareschal & Tan, 2007; Rakison & Butterworth, 1998).

Not all information about objects comes from objects themselves or 3D replicas. From early life, infants have experience with two-dimensional representations of objects in picture books, on TV, and so forth. High-quality photographs of replicas also contain information in terms of object features (Fisher, Ferdinandsen, & Bornstein, 1981; Kuchuk, Vibbert, & Bornstein, 1986), although this information is only available visually (Figure 1B), rather than multimodally as with 3D objects (Figure 1A). Moreover, processing 3D stimuli involves only a one-step inference from symbol to referent. When viewing a 2D photograph of a replica, however, infants might need to perceive the image as a replica first and then make the link between the replica and its real-world referent. In other words, 2D stimuli might involve two steps of inference from symbol to referent. Both 3D and 2D stimuli require forms of mediated perception (Gibson, 1966), but 2D images of replicas likely require more mediation than 3D replicas. Of interest here was how different levels of mediation impact infant categorization. Thus, in the present study we compared infants' categorization of the same 2D and 3D stimuli in 2 experiments.

To categorize 2D images of objects, infants need some rudimentary pictorial competence (see Beilin, 1999, for a review); and it appears that this foundation may be present in the first year or two. Infants as young as 5 months of age reportedly perceive correspondences between 2D and 3D stimuli (DeLoache, Strauss, & Maynard, 1979; Dirks & Gibson, 1977), and at 18 months they can learn labels for novel objects using photographs (Ganea, Pickard, & DeLoache, 2008). By 2 to 3 years, representations (in the form of pictures or objects-on-display) encourage young children (and parents) to think about categories (Gelman, Chesnick, & Waxman, 2005). At the same time, infants do not equate pictures and referents; 9-month-olds show different manual actions to 2D and 3D stimuli (Yonas, Granrud, Chov, & Alexander, 2005), suggesting at the very least that 2D and 3D stimuli of the same objects afford different actions.

Research on categorization in the first half year of life has relied exclusively on 2D depicted images in looking time paradigms, and researchers have concluded from these studies that infants' categorization ability is advanced. For example, using 2D color photographs Quinn and Eimas (1996) found that 3-month-old infants categorized animals, such as dogs and cats, a basic-level comparison; Arterberry and Bornstein (2001) found that this same age group also categorized animals and vehicles, a superordinate comparison; and Quinn, Doran,

Reiss, and Hoffman (2010) found that by 7 months infants categorized different breeds of cats, a subordinate-level comparison. In fact, these examples depict a competency that appears to be more advanced than the developmental story that emerges when infants' categorization is assessed using the sequential touching procedure. For example, from a sequential touching study with 12-, 18-, 24-, and 30-month-old infants Bornstein and Arterberry (2010) learned that 18-month-olds categorize at the basic level when there is high contrast between the two categories, but it is not until 30 months that infants categorize at the basic level when there is low contrast between the categories. No age group categorized at the subordinate level by sequential touching.

The difference in findings described above could be due to the fact that studies with younger infants have employed looking-time measures, such as habituation or preferential looking, and studies with older infants have used paradigms relying on infants' manual actions, such as sequential touching. A start in trying to identify the reasons for these different findings would be to assess infants' categorization at the same age, with the same task, with both 2D and 3D stimuli. This is what we do here.

The goal of the present experiments was to assess infants' categorization of 3D and 2D stimuli holding method constant. To this end, two experiments compared infants' categorization of 3D replicas to photographic stimuli. In Experiment 1 the photographic stimuli were presented as cut outs, and in Experiment 2 the same photographic stimuli were presented on 3D cubes. Thus, the object referents and categorization method were held constant, but the information afforded by the stimuli varied. To complete the comparison, two levels of categories with two kinds of objects were tested.

Experiment 1

In Experiment 1, 18-month-old infants were assessed for categorization of animals and vehicles at the superordinate and basic levels using either 3D replicas or 2D photographic cut outs (Figure 1A and B). All infants were tested with three stimulus sets that manipulated level of inclusiveness: An animal-vehicle superordinate set and two basic-level sets with high and low contrasts. For group level analyses, mean run length (successive contacts to different objects from the same category) was the dependent measure. Run length is the number of touches in a row to objects from the same category. A run can range from 1 (if the infant touches only 1 object from 1 category before touching an object from another category) to the total number of the infant's touches (if the infant touches only objects from 1 category). The mean of all run lengths is calculated and compared to chance (1.75; see Mandler et al., 1987).

Although run length provides key information regarding whether infants as a group categorize objects, run length does not indicate whether individual infants categorize objects from one or both categories. For example, one infant might touch 3 of 4 objects from category 1 but only 1 object from category 2 and still produce a high mean run length, showing an overall high level of categorization. However, this infant's categorization performance is less sophisticated than a second infant who touched all the objects in category 1 and category 2 each in a sequential manner. The first infant categorized category

1, but the infant's touching leaves in question his/her categorizing of category 2. An additional approach to evaluate categorization, therefore, is to focus on individual infants, where the question is whether and how each infant categorizes. This assessment is also based on run length, but instead focuses on the longest run within a category and whether infants touch at least three of the four exemplars.

With the 3D replicas, we expected 18-month-olds to show (a) mean run lengths greater than chance for superordinate sets and for basic-level high-contrast sets and (b) mean run lengths at chance with basic-level low-contrast sets. This pattern of results would replicate previous work by Mandler, Bauer, and McDonough (1991) and Bornstein and Arterberry (2010) that showed categorization by 18-month-olds with superordinate and basic-level categorization with high-contrast sets but not with basic-level low-contrast sets. Of central interest was infants' comparative performance with 2D representations of the same stimuli. We anticipated that mean run lengths would be shorter for the 2D photos compared to 3D replicas given the less rich information afforded by 2D relative to 3D stimuli and the additional inferential step between the image and the real-word referent object when viewing a photograph of a replica.

Method

Participants—Forty 18-month-old infants ($M_{\text{age}} = 18.43$, $SD = .31$ months; 20 boys) participated, with approximately 20 infants in each stimulus condition. Families were recruited via purchased mailing lists and came from middle-socioeconomic status households ($M = 50.73$, $SD = 15.66$, on the Hollingshead, 1975, *Four-Factor Index of Social Status*; see Bornstein, Hahn, Suwalsky, & Haynes, 2003).

Materials—Five sets of stimuli were created. A superordinate set contrasted animals (lion, pig, duck, and dolphin) and vehicles (tractor, sedan, boat, and semi-truck). Four basic-level sets included two sets for animals and two sets for vehicles. The basic-level sets manipulated the amount of contrast between the two categories. High-contrast sets had few features in common across the two categories (cows-frogs, pick up trucks-helicopters), whereas low-contrast sets shared features (dogs-horses, SUVs-panel trucks). The sets were presented as either 3D replicas or 2D photographs. Within-category discrimination of the same 3D replicas has been reported elsewhere (Blind).

3D replicas: Small naturalistic three-dimensional scale models were used to create the 5 sets of stimuli (see Figure 1A for an example). Each set contained four replica objects from two categories. The objects averaged $9.46 \times 4.32 \times 4.47$ cm.

2D photographic cut outs: High-resolution digital photographs were taken of the 3D replicas against a homogeneous gray background. The images were printed on paper, cut out of the gray background, and laminated. The same image appeared on both sides of the cut out. The mean size of the depicted objects was 5.47 by 3.15 cm. Small clear adhesive bumpers were affixed to the cut out, allowing the cut out to sit .3 cm off the table to afford ease of grasping by infants.

Procedure—Infants received three trials, and all infants received the superordinate animal-vehicle set. Infants also received either two animal basic-level sets or two vehicle basic-level sets. Half of the infants were tested with 3D replicas, and the other half were tested with 2D cut outs. The order of presentation of each set was determined randomly, as was assignment to the animal or vehicle basic-level sets and stimulus condition.

The infant sat at a small table, and the experimenter sat opposite the infant. A camera positioned behind the experimenter focused on the infant's head and torso and recorded the infant's actions with the objects. On each trial, the experimenter randomly positioned eight replicas or photographs (cut outs), four from each category, on a presentation board. After moving the board within easy reach of the infant, the experimenter gave the standard prompt, "These are for you to play with." Infants were allowed to manipulate the stimuli in any way they wished for 2 min with no further prompting. If an infant did not touch any of the stimuli after 10 s, the experimenter repeated the original prompt; if the infant lost interest during the session, the experimenter encouraged the infant's attention back to the stimuli by saying, "These are for you to play with." If a stimulus fell off the table, the experimenter (or parent) unobtrusively replaced it onto the tray.

Videorecords were coded in a random order by a single coder who was naive to the hypotheses of the study. For each set, the order in which the infant touched the stimuli was coded. Touches were calculated with replacement, and a stimulus could be touched more than once, except for two touches of the same stimulus in succession. A touch was also recorded if the infant used one stimulus intentionally to contact another (e.g., touched the truck with the pig). Finally, if the infant touched a stimulus and then touched the same stimulus less than 10 s later without touching another stimulus in the interim, only one touch was recorded (Starkey, 1981). After 10 s a touch to the same object was counted as the first touch of a new run. A second coder coded a random sample of 25% of the sessions to obtain a measure of coding reliability for sequential touching: Mean agreement was 90% (*range* = 86–94%). Scoring yielded the total number of touches and the order of stimulus and categories sequentially touched in each set of stimuli.

Results and Discussion

Infants were required to complete at least two out of three sets; all infants completed all three sets. An analysis of outliers identified two infants whose mean run lengths were more than 2 *SDs* above the *M*. Mean run length and number of touches for outliers were excluded only from analyses in which they exceeded the criterion. One 2D cut out outlier was excluded from the superordinate analyses, and one 3D replica outlier was excluded from the basic-level analyses.

Infants' mean numbers of touches and mean run lengths for each set in the 3D replica and the 2D cut out conditions are shown in Tables 1 and 2. Run lengths to the 3D replica stimuli ranged from 0–8, 1–6, and 1–6 for the superordinate, basic-level high-contrast, and basic-level low-contrast sets, respectively. Mean numbers of runs for each set, respectively, were 6.55 (*SD* = 4.32), 7.90 (*SD* = 3.93), and 7.25 (*SD* = 2.75). Run lengths to the 2D cut out stimuli ranged from 0–8, 1–5, and 1–9 for the superordinate, basic-level high-contrast, and basic-level low-contrast sets, respectively. Mean numbers of runs for each set, respectively,

were 7.90 ($SD = 4.03$), 7.90 ($SD = 3.29$), and 7.75 ($SD = 2.99$). Preliminary analyses examined effects of gender; as no differences between girls and boys were found, the following analyses were conducted collapsing across gender (here and in Experiment 2).

Infants' mean run length for each set was compared to chance performance (1.75). The resulting t -values are also shown in Tables 1 and 2. With 3D replicas, infants showed run lengths significantly greater than chance to the superordinate set and the basic-level high-contrast animal set, but not to other sets. Mean run lengths did not exceed chance for any of the 2D cut out sets. These results suggest that infants categorized 3D replica animals and vehicles at the superordinate level and animals at the high-contrast basic-level but not in any other sets, including none of the 2D cut out sets.

To directly compare infants' performance between the 3D replica and 2D cut out conditions, two ANOVAs were conducted. First, for the superordinate mean run lengths, a one-way ANOVA with condition (3D replica, 2D cut out) as a between-subjects factor was conducted (see Figure 2). The analyses revealed a marginal main effect for condition, $F(1, 37) = 3.88$, $p = .056$, partial $\eta^2 = .12$; infants showed marginally longer mean run lengths to the 3D replica than to the 2D cut out superordinate sets. For the basic-level mean run lengths, a second a $2 \times 2 \times 2$ ANOVA was conducted with condition (3D replica, 2D cut out) and category (animal, vehicle) as between-subjects factors and contrast (high, low) as a within-subjects factor (see Figure 3). The analyses revealed a significant Condition by Category interaction, $F(1, 35) = 5.10$, $p = .030$, partial $\eta^2 = .13$, and a significant Contrast by Condition by Category interaction, $F(1, 35) = 6.21$, $p = .018$, partial $\eta^2 = .15$. No other main effects or interactions were found.

Tests for simple effects explored the three-way interaction. Two ANOVAs were conducted with condition and category as factors at each level of contrast. For the high-contrast sets, a main effect for category, $F(1, 36) = 7.53$, $p = .009$, partial $\eta^2 = .17$, and a Condition by Category interaction emerged, $F(1, 36) = 8.41$, $p = .006$, partial $\eta^2 = .19$. This interaction was due to significantly longer mean run lengths to animals than vehicles in the 3D replica condition, $F(1, 18) = 11.51$, $p = .003$, partial $\eta^2 = .39$ ($M = 2.33$, $SD = .54$ for animals; $M = 1.54$, $SD = .49$ for vehicles), but not in the 2D cut out condition, $F(1, 18) = .02$, ns ($M = 1.65$, $SD = .29$ for animals, $M = 1.68$, $SD = .40$). For the low-contrast sets, no main effects or interactions were found, all F s $< .83$, ns .

It is possible that the difference in categorization performance between the 3D and 2D conditions is attributable to differential amounts of activity toward 3D replicas versus 2D cut outs. This question was addressed through analyses of the mean number of touches (Tables 1 and 2). For the superordinate set, a one-way ANOVA with condition (3D replica, 2D cut out) as a between-subjects factor revealed no main effect, $F(1, 38) = .11$, ns . For the basic-level sets, a $2 \times 2 \times 2$ ANOVA with condition (3D replica, 2D cut out) and category (animal, vehicle) as between-subjects factors and contrast (high, low) as a within-subjects factor also revealed no main effects or interactions, all F s < 2.97 , ns . Thus, infants engaged with the 3D replica and 2D cut out stimuli equally often, as indexed by their numbers of touches.

To evaluate individual infants' categorization, a procedure outlined by Mandler et al. (1987; see also Arterberry, Bornstein, & Haynes, 2011) and a Monte Carlo program developed by Dixon, Woodard, and Merry (1998) were used. Based on the longest run length and whether the infant touched 3 or 4 different objects from the same category in the set, a probability judgment was calculated regarding whether each individual infant categorized. Infants can be classified as either single or dual categorizers. Single categorizers met the criteria for one of the two categories in the set, whereas dual categorizers met the criteria for both categories in the set. In this experiment, dual categorizers were rare. As can be seen in Table 3, at least one infant categorized at each level, with the exception of 2D cut outs of vehicles (helicopters and panel trucks). Consistent with the findings based on mean run length, more individual categorizers were found in the 3D than in the 2D condition. For 6 out of the 10 categories, percentages for 3D replicas exceeded those for 2D cut outs, the percentages were equal for one category (cows), and for 3 categories percentages were greater for 2D cut outs than 3D replicas.

In summary, infants categorized 3D replicas in superordinate and basic-level high-contrast animal sets. In contrast, categorization of 2D photographic cut out images was poor: No mean run length exceeded chance, and mean run length was marginally significantly lower for 2D cut outs compared to 3D replicas for the superordinate sets. Infants engaged with the 3D replicas and 2D cut outs similarly in that there was no difference in the mean numbers of touches among the conditions. Categorizer classification percentages also showed more categorizers in the 3D replica than the 2D cut out conditions, however, this analysis also showed that for some infants categorization of 2D cut outs is possible.

The information gained while manipulating replicas may account for the difference in performance between 3D replicas and 2D cut outs. Consider exploring a replica vehicle. As an infant holds it, the infant can feel and see the different parts. As the infant turns it over or shifts it from one hand to the other, different views and different information (e.g., doors on one side, wheels on the bottom, smooth surface on top) are revealed. With a static photograph, only one view is presented, and as the infant turns it over or shifts it from one hand to the other, no new information is revealed. In addition to being afforded more information when exploring a 3D replica compared to a 2D cut out, infants also need only make one inferential step between the replica and the real-word object it represents. The photographs used in this study, in contrast, require two steps – from photograph to replica and then from replica to real-word object. In Experiment 2 we attempt to disentangle the manipulation from levels of inferential steps.

Experiment 2

In Experiment 2, we explored the role of manipulation, and the unfolding of information during manipulation, in infants' categorization while still requiring infants to make two inferential steps when viewing photographs. In other words, the purpose of Experiment 2 was to compare infants' categorization of two sets of stimuli (3D replicas and 2D photographs) that afforded different views during their engagement with objects. To this end, the photographic images of the replicas were placed on 3D cubes, creating a six-sided object that had a different and appropriate view of the same object on each side (Figure 1C). As in

Experiment 1, of interest was infants' comparative categorization of 3D replicas and 2D representations on the photo cubes ("2D cubes") of the same stimuli. If the discovery of information via manipulation facilitates the inferential process, then infants' categorization of both 3D replicas and 2D cubes should be equivalent. Alternatively, it is possible that even with discovery of information via manipulation infants are unable to make the two inferential steps needed when attempting to categorize the 2D cubes. Also, it is possible that the inferential process with the assistance of discovery of information via manipulation may be easier at some category levels than others.

Method

Participants—Twenty-one 18-month-old infants (M age = 18.51, SD = .32 months; 12 boys) participated. Families were recruited via purchased mailing lists, and they all came from middle-socioeconomic status households (M = 44.03, SD = 10.63, on the Hollingshead, 1975, *Four-Factor Index of Social Status*; see Bornstein et al., 2003).

Materials

2D cube stimuli: High-resolution digital photographs of each side, front, back, top, and bottom of the 3D replicas were used to create photo cubes (see Figure 1C). The cubes were assembled such that each side depicted one view point (e.g., front, sides, top, back, or base). The images were printed on heavy paper, and the paper was folded into a solid around a Styrofoam cube and taped closed. The mean size of the cubes was $8.67 \times 5.14 \times 4.88$ cm.

Procedure—The procedure was the same as in Experiment 1 except that infants received 2D photo cubes on each trial.

Results and Discussion

Infants were required to complete at least two out of three sets; 16 infants completed all three sets. All available data were included in the analyses. An analysis of outliers identified infants whose mean run lengths were more than 2 SD s above the M . Mean run length and number of touches for outliers were excluded only from analyses in which they exceeded the criterion. One 2D cube outlier was excluded from the superordinate analyses, and one 2D cube outlier was excluded from the basic-level analyses.

Infants' mean numbers of touches and mean run lengths for each set in the 2D cube condition are shown in Table 4. Infants' mean run length for each set was compared to chance performance (1.75). The resulting t -values are also shown in Table 4. Run lengths to the 2D photo cube stimuli ranged from 0–11, 1–8, and 1–15 for the superordinate, basic-level high-contrast and basic-level low-contrasts sets, respectively. Mean number of runs for each set, respectively, were 8.66 (SD = 5.36), 9.15 (SD = 5.34), and 9.88 (SD = 5.22). Mean run lengths did not exceed chance for any of the 2D photo cube sets.

To directly compare infants' performance between 3D replica (from Experiment 1) and 2D photo cube conditions, two ANOVAs were conducted. First, for the superordinate mean run length, a one-way ANOVA with condition (3D replica, 2D cube) as a between-subjects factor revealed no significant main effect, $F(1, 38) = .63$, ns . Infants showed equally long

run lengths to the 3D replica and 2D cube superordinate sets (see Figure 2). For the basic-level run lengths, a second $2 \times 2 \times 2$ ANOVA was conducted with condition (3D replica, 2D cube) and category (animal, vehicle) as between-subjects factors and contrast (high, low) as a within-subjects factor (see Figure 4). The analyses revealed a significant Contrast by Condition by Category interaction, $F(1, 30) = 7.72$, $p = .009$, partial $\eta^2 = .21$. No other main effects or interactions were found.

Tests for simple effects explored the three-way interaction. Two ANOVAs were conducted with condition and category as factors at each level of contrast. For the high-contrast sets, a main effect for category, $F(1, 36) = 6.04$, $p = .019$, partial $\eta^2 = .14$, and a Condition by Category interaction emerged, $F(1, 36) = 6.00$, $p = .020$ partial $\eta^2 = .14$. This interaction was due to significantly longer mean run lengths to animals than vehicles in the 3D replica condition, $F(1, 18) = 11.51$, $p = .003$, partial $\eta^2 = .39$ (this is the same result described in Experiment 1), but there was no difference in mean run length to animals and vehicles in the 2D photo cube condition, $F(1, 18) = .00$, ns ($M = 1.63$, $SD = .50$ for animals; $M = 1.63$, $SD = .47$ for vehicles). For the low-contrast sets, no main effects or interactions were found, all F s < 2.13 , ns .

A parallel set of analyses on the mean numbers of touches explored possible differences in activity between the 3D replicas and the 2D photo cubes (Tables 1 and 4). For the superordinate set, a one-way ANOVA with condition (3D replica, 2D cube) as a between-subjects factor revealed no main effect, $F(1, 38) = .54$, ns . For the basic-level sets, a $2 \times 2 \times 2$ ANOVA with condition (3D replica, 2D cube) and category (animal, vehicle) as between-subjects factors and contrast (high, low) as a within-subjects factor revealed a significant main effect for category, $F(1, 30) = 5.02$, $p = .033$, partial $\eta^2 = .14$, and a significant Condition by Category interaction, $F(1, 30) = 6.40$, $p = .017$, partial $\eta^2 = .18$.

Tests for simple effects explored the interaction. Mean numbers of touches across the two basic-level contrasts was analyzed to determine the effect of category at each level of condition. For the 3D replica condition, no difference in the number of touches to animals or vehicles emerged, $F(1, 17) = .09$, ns ($M = 13.56$, $SD = 7.42$ for animals; $M = 13.05$, $SD = 7.07$ for vehicles). For the 2D cube condition, infants made more touches to the vehicles ($M = 21.58$, $SD = 5.59$) than to the animals ($M = 13.28$, $SD = 6.63$), $F(1, 13) = 6.36$, $p = .026$, partial $\eta^2 = .33$.

As in Experiment 1, individual infants' were classified as single or dual categorizers. As can be seen in Table 3, at least one infant categorized the 2D cube sets at each level, with the exception of helicopters and dogs. Across the 10 sets, five of the 3D replica sets showed more individual categorizers than the 2D photo cube sets.

In summary, infants' infants categorized and engaged with 3D replicas and 2D cubes similarly at the superordinate level. At the basic level, categorization was superior for 3D replica high-contrast animal sets; no differences in categorization at the basic level were found for 2D cube sets. There were differences in the number of touches at the basic-level sets, with infants engaging 2D cube vehicles more than animals; however, this difference in activity did not mirror the findings with mean run length. Thus, it is unlikely that the

differences found in mean run length were due to differences in overall activity. Categorizer classification percentages were divided in that for about half of the sets more infants were identified as categorizers of 3D replicas than 2D cubes, and for the other half of the sets the reverse pattern was found.

General Discussion

The present studies investigated 18-month-old infants' categorization of 3D replicas and various 2D photographic images of those replicas to answer questions about infants' flexibility in categorization across different forms of object representation. Infants' categorization varied as a function of stimulus dimensionality (3D vs 2D) and manipulation opportunity. At the superordinate level, infants reliably categorized 3D replicas more than 2D cut out photographic images; however, there was no difference between infants' categorization of 3D replicas and 2D cubes. At the basic level, infants categorized 3D replicas of animals representing high-contrast sets but not low-contrast sets nor any of the 2D stimuli. The difference in categorization between 3D and 2D conditions cannot be explained by a difference in overall level of activity: Infants showed similar numbers of touches to the 3D replicas and the 2D photographs, with one exception. Infants engaged more with 2D cubes depicting vehicles than animals, however this finding does not explain or mirror the differences found with mean run length between 3D replicas and 2D cubes.

The findings with the 3D stimuli are consistent with previous work by Mandler et al. (1991) and Bornstein and Arterberry (2010) indicating categorization by 18-month-olds at the superordinate level and at the basic level with high-contrast stimuli. Categorization of basic-level low-contrast sets may not emerge until 30 months (Bornstein & Arterberry, 2010), an age well beyond the scope of the present study.

Even though the photographs were highly iconic, a suitable criterion for perceiving the correspondence between depicted images and their real-world referents (e.g., Ganea et al., 2008; Pierroutsakos & DeLoache, 2003), infants' mean run length did not exceed chance performance when they were presented with 2D cut out stimuli at all levels and the 2D cube stimuli at the basic level. The 2D and 3D stimuli provided similar visual perceptual information. For example, the 2D cut outs emphasized the external contours of the objects, perhaps highlighting key parts such as legs and wheels (Rakison & Butterworth, 1998), and the 2D cubes afforded infants the opportunity to gain additional information, such as different views of the objects, as infants manipulated them.

The similarity in categorization between 3D replicas and 2D cubes at the superordinate level suggests that acquiring information during exploration is important for categorization. As infants explored the 3D replicas and the 2D cubes, different views and different information (e.g., doors on one side, wheels on the bottom, smooth surface on top) were revealed. In contrast, when exploring a cut out photograph, only one view is presented, even as the infant turns it over or shifts it from one hand to the other. Thus, revelation of information via exploration may be important. Gibson (1966) suggested that "a representative display, an image, provides stimulus information about something other than what it is" (p. 225). In other words, when looking at a picture of an object, the viewer has information for the

depicted object (e.g., color, object features), but information is also present specifying features of the picture (e.g., flat surface, uniform matte texture). In our study the opportunity to manipulate the 3D replicas and the 2D cubes may have helped infants negotiate the step between symbol and referent to facilitate categorization at the superordinate level. The opportunity to manipulate the 2D cubes did not affect categorization at the basic level.

When presented with 2D cut out photographic stimuli, infants did not guide their actions based on the category membership of the depicted objects. It is possible that infants categorized the eight photographs as members of a single set, namely cut out pictures. Photographs and other graphic images are objects in themselves (DeLoache, 1995; Gibson, 1966), and it is on this basis that infants may interact with 2D stimuli. Infants at 19 months do not comprehend that pictures have a specific orientation (Pierroutsakos, DeLoache, Ground, & Bernard, 2005) or that the depicted objects will not change despite changes in their real-world referent (Robinson, Nye, & Thomas, 1994). Alternatively, the 2D stimuli may have been novel for the infant; rarely in their daily interactions with objects would infants encounter 2D cut out images. Infants are likely, however, to have experience with cut-out like images in board books and pick up and peek wooden puzzles. Our findings, together with those of previous research, have implications for infants' understanding of objects depicted in picture books and children's developmental timetable for fully understanding pictorial representation.

Presenting infants with 3D replicas and 2D visual images allowed us also to address a perplexing question in the categorization literature: In certain circumstances, infants at younger ages show seemingly more advanced categorization performance than infants at older ages. For example, 3-month-olds show evidence of categorizing cats and dogs, a basic-level low-contrast distinction, in looking time paradigms (Quinn & Eimas, 1996), but they do not show basic-level low-contrast categorization until 30 months of age in a sequential touching procedure (Bornstein & Arterberry, 2010). Previously, all sequential touching studies were conducted with 3D objects or replicas. The present study, by directly comparing categorization of 3D replicas with their 2D images using the sequential touching procedure, reduces the number of differences between studies with younger and older infants. Nonetheless, 18-month infants in the present study did not categorize 2D cut outs, despite much younger infants doing so with looking time methods (e.g., Quinn & Eimas, 1996).

Explanations for differences in infant categorization performance as a function of methodology have focused on process. One explanation proposed that looking time measures assess perceptual categorization, a process that is based on the available perceptual information, such as key parts (Mandler, 2000). In contrast, methods involving object manipulation, such as sequential touching, assess conceptual categorization. According to this view, conceptual categorization is based on knowing what objects are and relies on what they do or the roles they play in events. Using a transfer paradigm, Arterberry and Bornstein (2002) showed that conceptual categorization is possible at 9 months of age, and it can be assessed using looking time measures; thus, conceptual categorization is possible to assess in procedures other than sequential touching.

Westermann and Mareschal (2012) proposed another explanation. They suggest that looking time measures assess online category learning, learning that is fast and is accomplished over the course of the procedure. By contrast, sequential touching methods tap background knowledge that infants bring to the experimental session. Typically infants are presented with 8 objects from two different categories and they interact with them for 2 min. As there are no “warm up”, “training”, or “learning” as there might be in a habituation or familiarization phase, infants use their existing knowledge of category membership (or not) to guide their interactions with these objects. The influence of prior knowledge on a categorization task has been documented in infants much younger than the 18-month-olds studied here: Bornstein and Mash (2010) found that 5-month-olds who were exposed to a category of novel objects for two months at home showed robust categorization in a laboratory task at the outset (i.e., in the absence of a familiarization or habituation phase).

The discrepancy between younger and older infant performance in categorization resembles a discrepancy in the object permanence literature. When infants are tested in a search task, object permanence does not appear to be present until well into the second year of life (12–18 months; Piaget, 1954). When, however, infants are tested for their understanding of the permanence of objects using looking time as a measure, they appear to show this understanding much earlier (5 months or younger; Baillargeon, Li, Gertner, & Wu, 2010). Thus, as with the categorization literature, different results emerge based on which tasks are used - looking time versus manual action. At issue, at least for demonstrating object permanence, may be infants’ limitations in perception or cognition coupled with action. The lesson from the object permanence literature suggests that a closer look at the developmental integration of perception/cognition with action to understand infant categorization may pay dividends

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Highlights

- Explored infants' flexibility in categorization across different object representations.
- Infants completed superordinate and basic-level categorization tasks with 3D replicas, 2D cut out photographs, or 2D images on photo cubes.
- Categorization processes differ for 3D and 2D stimuli
- Discovery of object properties over time while manipulating objects may facilitate categorization at some levels.
- The findings are discussed in the context of infants' representation abilities and the integration of perception and action.

A

B

C

Figure 1.

Top view of cows and frogs that comprised the basic high-contrast animal set in (A) 3D replica, (B) 2D cut out, and (C) 2D cube conditions.

Figure 2. Mean run length for superordinate sets as a function of condition. Error bars reflect standard error of the mean.

Figure 3. Mean run length for basic-level sets comparing 3D replica and 2D cut out conditions. Error bars reflect standard error of the mean.

Figure 4. Mean run length for basic level sets comparing 3D replica and 2D cube conditions. Error bars reflect standard error of the mean.

Table 1

Numbers of touches and run lengths as a function of set type and categorization level for children tested with 3D replicas.

3D Replicas	Touches	Run Length	<i>t</i> (<i>df</i>)*	<i>p</i> <
Superordinate	13.75 (7.14)	2.49 (1.07)	3.09 (19)	.01
Basic Level High Contrast				
Animal	13.80 (3.84)	2.33 (.55)	3.32 (9)	.01
Vehicle	12.50 (6.40)	1.54 (.49)	1.38 (9)	<i>ns</i>
Basic Level Low Contrast				
Animal	13.00 (3.84)	1.55 (.32)	1.92 (8)	.10
Vehicle	13.60 (3.69)	1.86 (.71)	.49 (9)	<i>ns</i>

M(SD).

*
t-tests compare mean run length to chance, 1.75.

Table 2

Numbers of touches and run lengths as a function of set type and categorization level for children tested with 2D cut outs.

2D Cut Out	Touches	Run Length	<i>t</i> (df)*	<i>p</i> <
Superordinate	14.45 (6.30)	1.95 (.55)	1.55	<i>ns</i>
Basic Level High Contrast				
Animal	14.22 (7.25)	1.65 (.29)	1.06 (9)	<i>ns</i>
Vehicle	13.50 (7.20)	1.68 (.40)	.60 (9)	<i>ns</i>
Basic Level Low Contrast				
Animal	13.40 (6.60)	1.76 (.60)	.03 (9)	<i>ns</i>
Vehicle	12.80 (4.73)	1.73 (.63)	.12 (9)	<i>ns</i>

M(SD)

*
t-tests compare mean run length to chance, 1.75.

Table 3

Percentages of infants classified as categorizers as a function of stimulus type.

	3D Replicas	2D Cut Outs	2D Cubes
Superordinate			
Animals	45	20 ^a	9 ^a
Vehicles	25	60 ^a	33 ^a
Basic Level High			
Contrast			
Frogs	40	20	18
Cows	10	10	8
Helicopters	30 ^a	0	0
Pick Up Trucks	30 ^a	20	71
Basic Level Low			
Contrast			
Dogs	10	20	0
Horses	20	10	44
Panel Trucks	20	0	71
SUVs	20	30	29

^aOne infant was classified as a dual categorizer in that they were classified as a categorizer for both object domains in the set. For all other sets, only single categorizers were found.

Table 4

Numbers of touches and run lengths as a function of set type and categorization level for children tested with 2D cubes.

2D Cubes	Touches	Run Length	<i>t</i> (df)*	<i>p</i> <
Superordinate	15.50 (7.97)	2.13 (1.69)	1.01 (19)	<i>ns</i>
Basic Level High Contrast				
Animal	13.92 (7.68)	1.62 (.50)	.86 (11)	<i>ns</i>
Vehicle	17.25 (12.56)	1.63 (.47)	.75 (7)	<i>ns</i>
Basic Level Low Contrast				
Animal	13.78 (6.30)	1.77 (.60)	.12 (8)	<i>ns</i>
Vehicle	21.71 (7.87)	1.57 (.24)	2.02 (6)	<i>ns</i>

M(SD)

*
t-tests compare mean run length to chance, 1.75.