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5-Month-Olds' Categorization of Novel Objects: Task and Measure Dependence

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Abstract

To examine key parameters of the initial conditions in early category learning, two studies compared 5-month-olds' object categorization between tasks involving previously unseen novel objects, and between measures within tasks. Infants in Experiment 1 participated in a visual familiarization / novelty preference (VFNP) task with 2D stimulus images. Infants provided no evidence of categorization by either their looking or their examining even though infants in previous research systematically categorized the same objects by examining when they handled them in 3D. Infants in Experiment 2 participated in a VFNP task with 3D stimulus objects that allowed visual examination of objects' 3D instantiation while denying manual contact with the objects. Under these conditions, infants demonstrated categorization by examining but not by looking. Focused examination appears to be a key component of young infants' ability to form category representations of novel objects, and 3D instantiation appears to better engage such examining.

As research on the content and structure of infants' category representations accumulates (e.g., Bornstein & Arterberry, 2010; Quinn & Eimas, 1996), complementary work on the actual processes involved in categorization is increasing in priority (e.g., Bornstein & Mash, 2000; Oakes & Madole, 2000). One strategy that has been fruitful in this regard is the comparison of performance outcomes between different categorization tasks (Oakes, Plummert, Lansink, & Merryman, 1996; Oakes & Ribar, 2005; Younger & Furrer, 2003). Comparing tasks enables researchers to identify the unique features of performance contexts that facilitate categorization, thereby revealing core components of the processes involved.

As one example, task discrepancies in infant performance have led to speculation that wholly different psychological processes are elicited by different tasks. Mandler (1992) contended that visual familiarization tasks index the categories that infants formulate on an exclusively perceptual basis, but object examination tasks index infants' conceptual knowledge about categories and their individual members. To investigate this distinction directly, Younger and Furrer (2003) compared 9-month-olds' performance in a visual familiarization / novelty preference (VFNP) task with two-dimensional (2D) images to their performance in an object examination (OE) task with three-dimensional (3D) objects comprising the same stimulus categories between tasks (dog and horse replicas). When stimuli were presented in a serial fashion, infants successfully categorized in the VFNP task, but not in the OE task. When the OE task was modified to enable category comparison at test, however, infants successfully demonstrated categorization. This pattern of results is difficult to account for by differences between tasks in the use of conceptual knowledge. Instead, more compelling explanations specify how different task demands (e.g., serial vs.

paired comparisons) interact with cognitive processes that are empirically attributable to infants (e.g., visual attention, comparison, and memory; see also Oakes et al., 1996).

A limitation of existing task comparisons is the stimulus domain that has been used. Researchers have employed animal categories exclusively, allowing reliance on existing familiarity with those categories during task performance. A drawback is that such knowledge contributes additional variance to the results obtained (Kovack-Lesh, Horst, & Oakes, 2008). Related studies have sidestepped this critique with novel stimulus materials. Such studies have revealed categorization of novel 2D monochromatic forms by very young infants (Mash, Quinn, Dobson, & Narter, 1998; Quinn, 1994; Turati, Simion, & Zanon, 2003; Younger & Gotlieb, 1988) and categorization of more complex 3D novel objects by infants 5 months and older (Booth, 2000; Bornstein & Mash, 2010; Horst, Oakes, & Madole, 2005; Trauble & Pauen, 2007). These results indicate that infants' categorization does not depend on preexisting knowledge about the items categorized. None of this work with novel stimuli, however, has compared infants' performance across differing tasks.

A second limitation of existing task comparisons is that they have focused on task differences without controlling for response measure differences. VFNP studies invariably report looking time, and OE studies report focused examining time. Looking time is coded as the intervals over which infants simply look at the task stimulus, whereas focused examination (henceforth used interchangeably with "examination") consists of segments within those intervals of looking that involve heightened orientation distinguished by manipulative movements for the sake of better visual regard and accompanying changes in facial expression (see Mandler, 1992; Oakes, Madole, & Cohen, 1991; Oakes & Tellinghuisen, 1994; Ruff, 1986). Examining is identified through much more stringent coding than that which is used to identify instances of looking. Examining has been of interest to researchers because it is widely held to reflect more focused attention than looking does, and a correspondingly heightened intake of information compared to looking. Thus, any differences between tasks could be due to task-demand differences or to response measure differences, or both. This confound may be unnecessary, however, because infants' behavior can be coded for both measures in both tasks. Conclusions about categorization performance clearly depend on both the specifics of the task demands in play and how performance is measured and analyzed.

The present work adopts a task comparison approach to investigate process parameters of infants' first learning about novel object categories. By extending the use of uniquely novel stimulus materials across a broader range of task conditions and response measures, any observed task differences may lend insight into the core factors guiding infants' construction of categories as initial learning is taking place. In two experiments that follow, we use the stimulus categories of our earlier work and introduce different task contexts to identify specific factors that sustain infants' learning novel object categories.

Experiment 1

In Experiment 1, we used images of novel stimulus objects and administered a VFNP task to 5-month-olds who had never previously seen the objects. In reference to our earlier study (Bornstein & Mash, 2010), this experiment was designed to test the necessity of direct perceptual access to objects' 3D structure when infants have an opportunity to categorize them for the first time.

Methods

Participants—Twenty-five infants 5 months of age ($M=20.48$ weeks, $SD=1.68$) were included in the final sample (10 girls, 15 boys). An additional 3 infants participated but were

not included due to fussiness. Infants were recruited through direct mail to parents included in purchased mailing lists, and received a \$20 gift certificate for participating.

Apparatus—The task was run using Habit 2000 software (Cohen, Atkinson, & Chaput, 2002) on an Apple Mac G4 computer with a 38-cm stimulus monitor.

Stimuli—Stimuli consisted of photographs of novel objects against a white background. The objects subtended approximately $5^\circ \times 4^\circ$ on average. The objects were constructed to comprise two novel categories (see Figure 1). They were each made of 3 wooden pieces assembled in unique configurations. Individual parts were painted with a total of 8 different colors, 4 used for each category. The shape of individual parts differed systematically between categories: Category A parts had linear contours, and Category B parts had round contours. Each category exemplar represented a unique combination of part configuration and color. Both within and between categories, the parts of each object were assembled in a similar way, but each varied with respect to the exact positioning of parts.

Each category contained a total of 8 unique exemplars. Each object was painted with 3 colors, 1 per part, and the colors did not overlap across categories. Thus, the two categories were similar in size, complexity, part configuration, and the distribution of color boundaries, but differed in the shapes and colors of the objects' parts. Although infants of 5 months typically do have experience with the shape and color variation, we consider the stimuli novel given our focus is on unified objects *per se*. The familiarization exemplars were depicted in numerous and varied orientations and viewpoints, so edge composition did not provide a single, local feature for discrimination between categories. A stationary white "+", $2.5^\circ \times 2.5^\circ$ and centered on a black background, was used as an attention-getting stimulus before each trial to center infants' looking at the stimulus display before the trial's stimulus image was presented.

Procedure—Infants were seated directly in front of the stimulus monitor at a viewing distance of approximately 36 cm in a dimly lit room. On each trial, the attention-getting image appeared first, and the experimenter observed the infant's looking behavior in the video monitor. The experimenter initiated the presentation of each trial after infants were judged to look at the attention-getting stimulus. Infants' looking at each image was coded using a corneal reflection technique. The experimenter depressed a timing key when the reflected image was superimposed over the infant's pupil, and released the key when the reflection moved off the pupil with each change in looking.

Aside from the use of the attention-getting stimulus that is necessary for VFNP tasks, the trial structure of the present task matched exactly that used by Bornstein and Mash (2010). Infants were randomly assigned to one of the two categories, A or B, for familiarization. A fixed-trials procedure was used. There were ten 20-s familiarization trials using five different exemplars from one category, followed by two 20-s test trials involving a novel image from each category. The intertrial interval varied somewhat according to the time required for the infant to reestablish looking, but generally did not exceed 3 s. The category serving as familiar was counterbalanced over infants. Previous work with these stimuli indicates that infants the same age can discriminate exemplars within categories and have no baseline preference for members of one category over those of the other (Bornstein & Mash, 2010). All coders were blind to the hypotheses of the study and condition assignment of the infants. To examine coding reliability of the primary experimenter, a second experimenter coded infants' looking time from video records for 25% of the sessions. Over each trial of the sessions coded twice, $r=.97$.

Results

Looking time—Following established conventions in the literature, critical evidence for categorization involves both the generalization of looking time from familiarization to the familiar-category test stimuli and recovery of looking time to the novel-category test stimuli across both stimulus categories. Looking time was analyzed with an ANOVA involving familiar category (A, B) as a between-subjects factor and three planned contrasts of trial block means, each described separately below.

The first contrast, Habituation, compared the mean of first 2 familiarization trials to the mean of last 2 familiarization trials. This contrast was significant, $F(1, 23)=8.36$, $p=.008$, $\eta^2_p=.27$, with looking times decreasing between familiarization blocks (see Table 1).

A Generalization contrast compared the mean of the last 2 familiarization trials to the familiar test trial. This contrast was not significant, $F(1, 23)=0.50$, $p=.49$, revealing infants' generalization of looking time from the end of familiarization to a completely novel member of that same category.

Finally, a Discrimination contrast compared the familiar test trial to the novel test trial. This contrast was also not significant, $F(1, 23)=0.19$, $p=.67$, revealing no indication of infants' exclusion of the novel-category test stimulus from their familiar category. Unlike their counterparts in the previous research who participated in an object examination task, infants provided no evidence of categorizing the same stimulus objects when looking at them on a 2D image plane.

Examining time—The present task and reported data differ from those of Bornstein and Mash (2010) not only in stimulus domain (objects vs. images), but also in the coding of behavior. The earlier study reported more stringently coded focused examination, whereas the present data represent looking time more inclusively. This difference introduces the possibility that infants may categorize novel objects and their images similarly when dependent measures are equivalent between tasks. To equate the tasks on outcome measures for further comparison, the video records were recoded in an attempt to investigate focused examination in infants' looking at the 2D image displays. Fifty percent of the sessions were coded by a 2nd coder. Over each trial of the sessions coded twice, $r=.91$. Focused examination was not observed in sufficient quantity, however, to test statistically (Table 2).

Discussion

Despite their robust demonstration of categorizing novel stimulus objects in an earlier OE task, infants the same age in the present study did not categorize the same objects when seeing them depicted as 2D images on a stimulus monitor in a VFNP task. This systematic difference in task outcome was observed despite task equivalence in category structure, exposure time, visual angle in stimulus regard, and laboratory conditions.

This analysis does not exhaust the range of possible dependencies, however, because the two tasks under comparison differ in at least two additional and rather substantial ways: stimulus domain (images vs. solid objects) and manual contact (looking vs. handling). We therefore conducted a second experiment to examine the role of these factors in the task differences observed.

Experiment 2

In Experiment 2, instead of 2D images we presented infants with the actual objects depicted in the Experiment 1 images. Unlike the OE task used previously (Bornstein & Mash, 2010), however, the objects were barred from infants' reach by a rigid transparent barrier. Thus,

infants had visual access to the 3D structure of the objects but no manual contact with them. If infants in the previous OE task outperformed those in the 2D VFNP task of Experiment 1 because of their multimodal experience with the objects during familiarization, their performance should be undermined by the contact barrier. If infants in the OE task outperformed those in the 2D VFNP task due specifically to the 3D visual information available in the task, the barrier should not restrict object categorization.

Methods

Participants—Twenty-eight infants aged 5 months ($M=22.10$ weeks, $SD=1.15$) were included in the final sample (13 girls, 15 boys). An additional 4 infants participated but were not included due to fussiness or experimenter error. Infants were recruited and remunerated as in Experiment 1.

Stimuli—Stimuli consisted of the novel objects depicted in the images used in Experiment 1. The objects were approximately $7.5 \times 5 \times 5$ cm in size, so at viewing distance during the task subtended approximately $5^\circ \times 4^\circ$ in the picture plane, matching the visual size of the object images used in Experiment 1.

Procedure—Infants sat on their parent's lap facing a wheeled presentation table, and the table was rolled toward the participants passing over their legs and stopping just short of the infant's abdomen. The table had a 50×70 cm sheet of rigid transparent Plexiglas attached to the near edge (from infant's perspective) of the table, and tilting slightly back toward far edge at a fixed 70° angle. A $40 \times 60 \times 5$ cm panel of white rigid styrofoam was vertically attached to the tabletop between the stimulus location and the experimenter. Stimuli were placed at infants' midline under the Plexiglas sheet near the table's edge so infants could view, but not touch or handle them, at the same distance used previously by Bornstein and Mash (2010). Except for the visibility of one arm during stimulus placement, the experimenter was hidden from infants' view by the styrofoam panel.

The trial structure of the task matched exactly that of Experiment 1 and Bornstein and Mash (2010), comprising a familiarization phase and a test phase. Five objects from one stimulus category were randomly assigned for familiarization. During familiarization, the experimenter presented one object at a time to the infant, using a count-down timer to mark 20-s intervals. At the end of 20 s, the experimenter retrieved the object from under the Plexiglas sheet then presented the next object. Except for the one being presented, the remaining objects were hidden from the infant's view. Using a fixed-trials procedure, each object was presented twice over the course of 10 familiarization trials in an order uniquely randomized for each infant. Two test trials were then administered in the same fashion. In one test trial a previously unseen member of the familiar category was presented, and in the other test trial a randomly selected member of the novel category was presented. The order in which the test trials were administered (novel category first or second) was counterbalanced over infants. The categories serving as familiar and novel were randomly assigned and counterbalanced over infants.

Each session was video recorded, and infants' examination of stimulus objects was coded from the video records. Coders made two passes through each session, beginning by coding all looking at the stimuli. In the second pass, infants' focused examination was coded. Following Ruff (1986), focused examination was defined as clearly discerned looking that is specifically directed toward the object just presented. To be coded as examination, each instance of discerned looking had to occur within a sustained period of looking (i.e., not a quick glance) and had to be accompanied by a change in facial expression that was interpreted as an indication of concentration. As typically reported with use of this

technique, the nature of specific expressions of examining varied considerably across infants. Despite the variability, coders were able to reliably identify intervals of examining for each infant.

Because infants were unable to handle or even touch the objects, however, manipulative aspects of examination were not present. Although manual contact with the transparent screen occurred during many instances of examination, it did not consistently distinguish examining and so was not used as a criterion. All coders were blind to the hypotheses of the study and condition assignment of the infants. As before, video records were coded both for looking time and for examining time, with 50% of the sessions coded by a 2nd coder. For looking, coding judgments correlated $r=.96$ over trials between coders, and for examining, judgments correlated $r=.93$.

Results

Looking time—As in Experiment 1, looking was analyzed with an ANOVA involving familiar category (A, B) as a between-subjects factor and three planned contrasts of trial block means. The Habituation contrast compared the mean of first 2 familiarization trials to the mean of last 2 familiarization trials. This contrast was significant, $F(1, 26)=7.29$, $p=.012$, $\eta^2_p=.22$, with looking time decreasing between familiarization blocks (see Table 1). The Generalization contrast compared the mean of the last 2 familiarization trials to the familiar test trial. This contrast was not significant, $F(1, 26)=0.70$, $p=.41$, revealing infants' generalization of looking time at the end of familiarization to a completely novel member of that same category. Finally, the Discrimination contrast compared the familiar test trial to the novel test trial. This contrast was also not significant, $F(1, 26)=2.23$, $p=.15$, revealing no indication of infants' systematic exclusion of the novel-category test stimulus from their familiar category.

Examination time—The Habituation contrast in the analysis of examination was not significant, $F(1, 26)=2.47$, $p=.13$, indicating relatively limited decline in examining through the familiarization phase. The Generalization contrast also was not significant, $F(1, 26)=2.95$, $p=.11$, revealing infants' generalization of examining time at the end of familiarization to a completely novel member of that same category. This analysis did reveal a significant Discrimination contrast, $F(1, 26)=7.02$, $p=.010$, $\eta^2_p=.21$, with examination of the novel-category test stimulus exceeding that of the familiar-category test stimulus (Table 2).

Discussion

Infants in Experiment 2 demonstrated categorization by the pattern of focused examination they expressed. While examining stimulus objects through a transparent barrier, they generalized examining time to familiar-category test stimuli and recovered examining to novel-category test stimuli. Their looking, however, did not reveal this same pattern. This difference is particularly striking in light of infants having shown a significant decrement in looking time during familiarization, a pattern that is characteristic of thorough stimulus encoding (e.g., Bornstein, 1985, Colombo, 1993).

Supplemental Analyses

The reported findings in Experiments 1 and 2 reveal task input and response measure as important variables in initial category formation. The information collected enables additional questions to be addressed, particularly about the role of manual contact in task performance, and we pursue them here with additional coding and analyses.

Looking during manipulation

Categorization of novel 3D objects was evident in Experiment 2 in infants' focused examination, but not in their looking time. These findings mesh with those of our previous study (Bornstein & Mash, 2010) with respect to examination, but we did not code looking in that study. This raises the question of whether categorization may have been evident in looking time when infants were able to handle the objects. To address this remaining question, the video records collected and analyzed by Bornstein and Mash (2010) were recoded to measure looking time during the object examination task. A second experimenter coded 25% of the sessions, and over each trial of the sessions coded twice, $r=.98$. Data were analyzed with an ANOVA involving the same three planned contrasts of trial block means used in the preceding analyses. None of the contrasts was significant: Habituation, $F(1, 24)=0.41$, $p=.42$, Generalization, $F(1, 24)=0.01$, $p=.92$, and Discrimination, $F(1, 24)=2.12$, $p=.16$ (see Table 1).

Effect of manual contact

To investigate whether manual contact may influence infants' categorization of novel 3D objects, the results of Experiment 2 were compared to those reported by Bornstein and Mash (2010). The data from that study's No Home Experience condition and appearing in Figure 2 of that report were utilized. Task performance was coded in the same manner described above in Experiment 2, with details provided in the earlier paper. We conducted ANOVAs utilizing the same planned trial contrasts used in the preceding analyses, and Task (OE, 3D VFNP) as a between-subjects factor. In the analysis of looking time, there was a significant main effect of Task, with infants in the original OE task looking more at the stimuli overall than those in the 3D VFNP task of Experiment 2, $F(1, 51)=27.85$, $p<.0001$, $\eta^2_p=.35$ (Table 1). None of the trial phase contrasts was significant: Habituation, $F(1, 51)=2.20$, $p=.14$, Generalization, $F(1, 51)=1.69$, $p=.20$, and Discrimination, $F(1, 51)=0.03$, $p=.86$ (see Table 1). There was, however, a significant interaction between Task and the Habituation contrast, $F(1, 51)=5.75$, $p=.020$, $\eta^2_p=.10$. Infants in the OE task did not look less over succeeding trial blocks, $F(1, 24)=0.41$, $p=.53$, but infants in the 3D VFNP task did decline in looking, $F(1, 27)=7.75$, $p=.010$, $\eta^2_p=.22$.

In the analysis of examining, there was a significant main effect of Task on examining time, with infants in the earlier study examining longer overall than infants in the present Experiment 2, $F(1, 51)=43.67$, $p<.0001$, $\eta^2_p=.46$ (Table 2). Both the Habituation contrast, $F(1, 51)=8.53$, $p=.005$, $\eta^2_p=.14$, and the Discrimination contrast, $F(1, 51)=31.28$, $p<.0001$, $\eta^2_p=.38$, were significant. Infants examined more in early familiarization trials than in later ones and examined novel-category stimuli at test more than familiar-category stimuli (Table 2). The Generalization contrast was not significant, $F(1, 51)=2.11$, $p=.15$. Finally, the Discrimination contrast interacted with Task, $F(1, 51)=12.21$, $p=.001$, $\eta^2_p=.19$. Analyses reported above and by Bornstein and Mash (2010) show that infants in both 3D tasks examined the novel-category stimuli more. To examine whether recovery of examining time for novel-category test stimuli differed between tasks, proportion novel-category recovery scores were calculated by dividing examination time for the novel-category stimulus into the total amount of focused examination recorded for both test stimuli. These scores were compared between tasks and found to differ, $F(1, 51)=5.00$, $p=.03$, $\eta^2_p=.09$, with greater recovery of examining time occurring with opportunity for contact ($M = 0.68$, $SD = 0.20$) than when handling was obstructed ($M = 0.57$, $SD = 0.13$).

Discussion—In summary, the follow-up coding of infants' looking time in the OE task reported earlier by Bornstein and Mash (2010) provided no evidence of categorization, revealing an absence of evidence for categorization in infants' looking time across tasks. In directly comparing evidence of categorization between the tasks involving 3D objects as

stimuli, infants who could handle the stimuli clearly examined them longer, and showed greater recovery of examining time to novel-category stimuli during the test trials.

General Discussion

The task comparisons reported here were designed to examine key parameters of infants' category processing with completely novel stimulus objects. Infants in Experiment 1 provided no evidence of categorizing images of novel objects. This finding was unexpected given the performance observed by infants of the same age in a previous OE task using the same stimulus objects (Bornstein & Mash, 2010). Because infants in Experiment 1 failed to demonstrate categorization by looking or by examining, this difference cannot be attributed to measurement artifact. Reanalysis of our earlier study's results revealed categorization by examination alone, not by looking. The contrasting outcomes are not just task dependent but also measure dependent.

The robust difference between tasks appears to reveal a key advantage with 3D objects over 2D images in infants' construction of heretofore novel categories. Less clear, though, is the primary basis of this advantage. Infants in the previously reported OE task perceived objects in visual depth and had manual contact with them enabling a multimodal experience. The advantage observed with 3D objects, then, could have been due to visual depth, manual contact, or both. Experiment 2 separated the influences of manual contact from those of 3D instantiation. In this task infants examined the stimulus objects under conditions identical to those used in the original OE study except that a transparent barrier eliminated any opportunity for manual contact with the stimuli. Despite this nontrivial change, infants' pattern of performance was very similar to that observed in the original OE tasks: They categorized as indexed by examining time, but demonstrated no categorization through more inclusively coded looking time. On this basis it appears that the advantage held by 3D objects over 2D images may be attributable more to visual depth than to manual contact.

The expression of OE categorization and absence of 2D VFNP categorization observed here contrasts with the pattern reported by Younger and Furrer (2003). They observed the opposite pattern of task differences, with infants demonstrating categorization in 2D VFNP but not in OE when stimuli were presented serially as done here. Many task features were similar between these studies (e.g., trial length and number, etc.), although large differences exist in infant age and stimulus familiarity. With respect to potential age differences between 5-month-olds (seen here) and 9-month-olds (seen by Younger & Furrer), documented trends in perceptual development over the first year include improvements in the segregation of texture regions (Sireteanu & Rieth, 1992) and in sensitivity to pictorial depth cues (Granrud & Yonas, 1984). These and other related changes very likely put 9-month-olds at an advantage over 5-month-olds in the analysis of 2D images during VFNP tasks.

With respect to stimulus familiarity, it is certainly possible that the familiarity associated with known categories may support the extraction of relevant information from images and enable more efficient category construction. If so, Younger and Furrer's participants were at an advantage over infants in Experiment 1. Research examining the effects of long-term familiarity indicates that familiarity is sustained over intervals of weeks and months, and furthermore is used systematically by infants in laboratory learning tasks (Bornstein & Mash, 2010; Kovack-Lesh, et al., 2008; Shinskey & Munakata, 2003).

Infants in both 3D tasks (Bornstein & Mash, 2010, Experiment 2) categorized the stimuli, but those afforded manual contact with the stimuli demonstrated more robust discrimination between categories. Infants who were able to handle the stimuli during the task received information about the objects through multiple sensory modes, and thus presumably

gathered more information about the objects. Moreover, amodal features of multi-modal events have been found to sustain infants' attention and learning (Bahrick, Lickliter, & Flom, 2004). Infants' processing of shape, the primary distinctive feature between the categories used here, may have benefited accordingly, because shape was both seen and felt by the infants examined by Bornstein and Mash (2010). It is also possible that the greater recovery of examining when infants could handle the stimuli is a measurement artifact. Handling may provide additional cues for coders to detect during infants' examination. This would likely result in more sensitive measurement and increase the examination observed when handling, doing so independently of the amount of processing that underlies it. Thus, the present findings indicate that manual exploration was not necessary for the initial, novel categorizations demonstrated here, but could possibly have facilitated categorization above and beyond looking alone.

Holding that categorization may be tested by different measures implies a unified basis of processing (e.g., Quinn & Eimas, 1996), and some aspects of our findings are consistent with this view. In the 2D VFNP task, we observed the same pattern of results across different measures. Across both 3D tasks, we observed the same patterns within each measure. This generalization between and within measures points toward a unified process underlying infants' performance that can be tapped in different ways.

Other aspects of the present findings, however, challenge the interpretation of absolute cohesion in categorization. Within the 3D tasks, categorization was evident in infants' examining but not in their looking. Thus, two well established and highly correlated measures (Oakes et al., 1991) diverged between different tasks using the same stimuli and trial sequence. This discrepancy calls for a more task-specific account of processing. Research motivated by the framework of embodied cognition supports a complementary, systemic view of categorization (e.g., Barsalou, 1999; Thelen & Smith, 1994). In this framework object categorization is inseparable from the varied and specific sensorimotor channels through which relevant object information has been acquired. Different tasks provide different channels of input, and so elicit different categorizations. If focused examination is the only index by which categorization is observed in some contexts, it may be the driving force behind processing in those contexts rather than a mere correlate. On the one hand, an absence of evidence for category formation in looking time is not a sufficient basis for concluding that categorization did not occur that way. On the other hand, dependence on examination in categorizing novel objects offers a parsimonious and reasonable account of the present findings. Categorization was more likely to occur when focused attention was applied during exposure to novel materials. This suggests that categorizing novel objects is a relatively effortful process for young infants compared to their performance with familiar ones (e.g., Mash, et al., 1998; Quinn, Eimas, & Rosenkrantz, 1993). Oakes and colleagues have argued that focused examination may be the component of looking that reflects active processing (Oakes, Madole, & Cohen, 1991; Oakes & Tellinghusien, 1994). That conclusion may further account for the present results when one considers that the categorization of novel materials presumably requires active processing.

In addition to categorization's dependence on focused examination in the present research, we also observed that examination only occurred with 3D objects. Focused examination thus may depend on 3D instantiation in younger infants' first encounters with novel objects. If we assume that 3D instantiation is necessary for focused examination, then it follows that direct perception is a necessary input for the formulation of category representations in new, novel stimulus domains. By some accounts, perceptual systems are optimized to specify stable layouts for the maintenance of an adaptive interface with the environment (e.g., Gibson, 1979). Kellman and Arterberry (2000) argue that development orders the emergence of different stimulus sensitivities by their ecological relevance. The factors that infants

attend to change as their functional relations with the environment change. The necessity of 3D viewing observed in the present study is consistent with the view that the development of perception accords primacy to the most functionally adaptive sources of information. The findings also suggest that 3D information is not only utilized but actually facilitates the encoding and organization of memory stores. This deduction follows from the fact that 3D information is necessary for the accurate analysis of complex shapes. In previous work using static 2D images, we found that 5-month-olds were dependent on perceiving novel objects in multiple picture-plane views in order to subsequently recognize them in a novel orientation (Mash, Arterberry, & Bornstein, 2007). Three-dimensional information also facilitates the extraction of invariants and commonalities that determine category structure (e.g., Biederman, 1987; Saiki & Hummel, 1996). The present work indicates that 5-month-olds take advantage of this information in their categorization of novel objects.

This reasoning leads back to the question of why Younger and Furrer (2003) observed categorization of 2D but not 3D materials under the same serial-trials conditions used here. Although their findings appear on the surface to be less consistent with ecological theory, their report is not wholly at odds with such an explanation. They did not report coding or analysis of infants' looking within their OE task, so their infants may have categorized 3D objects via looking time, if not via examining time. More generally, however, a consideration of infants' differing histories between tasks may offer a more compelling reconciliation. Thelen and Smith (1994) emphasized the temporal aspects of processing in their account of category formation, arguing that relevant processes are assembled in and for the present context as a function of the past, both recent and long-term. Thus, task demands and stimulus familiarity shape task outcome through interactions among active sensory domains, specific stimulus dimensions, and specific prior experiences with the stimuli. Younger and Furrer's infants had longer postnatal histories than the infants in the present study, and they were presented with stimulus categories that were already familiar to them. They had greater visual experience, more mature visual and memory systems, larger stores of existing memories, and so on. Most likely, all of these factors were brought to bear interactively on infants' performance.

Finally, the young infants reported here categorized novel objects, but not 2D images of those same objects. As noted initially, earlier research has demonstrated the ability of young infants to categorize novel 2D forms in VFNP tasks when looking time served as the performance index. Those studies used simple, high-contrast patterns which may be one of the factors differentiating the outcome of Experiment 1. The restricted contrast sensitivity that is characteristic of early life (e.g., Banks & Salapatek, 1978) may have reduced infants' sensitivity to the category-defining features of the images used in Experiment 1. Likewise, the complexity differences between the simple patterns used in those studies and the irregular objects used presently is another factor that is likely a part of the different outcomes (e.g., Younger & Gotlieb, 1988). The images used in this research, however, are likely more representative of infants' typical visual environment, so may provide a more general characterization of task-dependent processing.

Conclusions

Most studies of infant category learning have been carried out using familiar stimulus categories, but the use of novel materials better emulates the conditions and processes through which infants' early learning occurs in natural contexts. Infants in the present experiments were faced with just such initial conditions. In this research, the stimulus categories, trial structure, exposure time, and test conditions were identical across tasks, yet categorization outcomes differed considerably. When infants first encountered objects of two novel and distinct kinds, their categorization appeared to depend on focused

examination, which in turn was dependant on 3D instantiation. Manual contact with the stimulus objects appears to have enhanced both focused examination and categorization, but was not necessary for either. Under the conditions used presently, 3D instantiation and focused examination were both necessary and sufficient for the formation of object categories in the absence of preexisting familiarity with those objects.

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Figure 1.

Examples of stimuli from categories A and B. Experiment 1 incorporated these and other similar images. In Experiment 2, the objects depicted in these images were used.

Table 1

Visual Fixation (s) by Task and Trial Block

Task	Trial Block					
	Early Familiarization		End of Familiarization		Familiar-Category Test	
	M	(SD)	M	(SD)	M	(SD)
Object examination (Bornstein & Mash, 2010) *	10.64	(5.87)	11.32	(5.54)	11.39	(5.34)
2D (image) visual familiarization / novelty preference (Experiment 1)	9.98	(4.24)	7.50	(3.55)	8.12	(5.00)
3D (object) visual familiarization / novelty preference (Experiment 2)	7.46	(5.36)	4.35	(3.30)	4.72	(3.51)

* These data are the result of recoding the video records of Bornstein & Mash's (2010) No Home Experience condition as discussed in the text.

Table 2

Focused Attention (s) by Task and Trial Block

Task	Trial Block					
	Early Familiarization		End of Familiarization		Familiar-Category Test	
	M	(SD)	M	(SD)	M	(SD)
Object examination (Bornstein & Mash, 2010) *	5.88	(4.91)	3.92	(2.87)	3.15	(2.82)
2D (image) visual familiarization / novelty preference (Experiment 1)	0.20	(0.37)	0.00	(0.00)	0.50	(2.40)
3D (object) visual familiarization / novelty preference (Experiment 2)	1.85	(1.79)	1.32	(0.61)	1.13	(0.39)

* These data were previously presented in Figure 2, Panel B of Bornstein and Mash (2010).