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Linguistic labels, dynamic visual features, and attention in infant category learning

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ABSTRACT

How do words affect categorization? According to some accounts, even early in development words are category markers and are different from other features. According to other accounts, early in development words are part of the input and are akin to other features. The current study addressed this issue by examining the role of words and dynamic visual features in category learning in 8- to 12-month-old infants. Infants were familiarized with exemplars from one category in a label-defined or motion-defined condition and then tested with prototypes from the studied category and from a novel contrast category. Eye-tracking results indicated that infants exhibited better category learning in the motion-defined condition than in the label-defined condition, and their attention was more distributed among different features when there was a dynamic visual feature compared with the label-defined condition. These results provide little evidence for the idea that linguistic labels are category markers that facilitate category learning.

Introduction

The ability to form categories is an important component of human cognition that appears early in development: infants exhibit evidence of category learning during the first months of life (Quinn, Eimas, & Rosenkrantz, 1993; Younger & Cohen, 1985). There is also evidence suggesting that language may affect this process, although the mechanisms underlying the effects of language remain a matter of debate.

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Some have suggested that words accompanying category members have the special status of category markers and, as such, guide or supervise category learning during infancy (Waxman & Markow, 1995; see also Westermann & Mareschal, 2014). At the same time, others have suggested that early in development words are akin to other features, but they may become category markers during the course of development (Gliozzi, Mayor, Hu, & Plunkett, 2009; Sloutsky, 2010; Sloutsky & Fisher, 2004; Sloutsky & Lo, 1999; Sloutsky, Lo, & Fisher, 2001). As we discuss below, distinguishing between these positions has profound consequences for our understanding of the relationships between language and cognition and the nature of learning early in development.

According to the former theory, "infants embark on the task of word learning equipped with a broad, universally shared expectation, linking words to commonalities among objects" (Waxman, 2003, p. 220). As a result, words, but not other kinds of auditory input, facilitate infants' category learning by attracting attention to within-category commonalities (Waxman & Booth, 2001; Waxman & Markow, 1995), thereby effectively supervising category learning. These effects are supervisory because labels guide learning by attracting attention to commonalities.

There is some evidence consistent with this view. First, words may facilitate infants' categorization above and beyond other kinds of auditory input (Balaban & Waxman, 1997; Ferry, Hespos, & Waxman, 2010; Fulkerson & Haaf, 2003). Second, facilitative effects of words were reported at the basic level as well as at the superordinate or global level (Balaban & Waxman, 1997; Waxman & Booth, 2003; Waxman & Markow, 1995). Third, there are reports that facilitative effects of labels are specific rather than general in nature: count nouns and adjectives initially have similar effects on category learning, whereas at around 14 months of age count nouns are more likely to facilitate category learning than adjectives (Waxman & Booth, 2001). This finding suggests that count nouns may play a special role in category learning. Finally, labels may facilitate property induction above other kinds of input (Keates & Graham, 2008).

There are challenges, however, to the idea that words are category markers during infancy. First, even if words affect category learning during infancy, they do not need to function as category markers supervising learning but can instead be part of the stimulus input and influence learning in a bottom-up fashion. For example, Plunkett, Hu, and Cohen (2008) presented 10-month-old infants with a category-learning task, such that the to-be-learned category consisted of two clusters of artificial creatures (i.e., a broad category somewhat analogous to a global category encompassing cats and horses). When the category was presented in silence, participants learned two narrow categories, whereas when one common label accompanied each item, participants learned the single broad category. Although it is tempting to conclude that these results indicate that labels supervised category learning, this conclusion is unwarranted. Specifically, when Gliozzi et al. (2009) modeled data reported by Plunkett et al. (2008) using self-organizing maps, a model that assumed that labels are features and function as input rather than top-down supervisory signals was able to account for the reported pattern.

Second, findings that labels facilitate infant category learning are tenuous at best – facilitation transpires in some studies but does not transpire in others. This is because many studies compared the effects of labels with those of unfamiliar sounds but not with a silent condition. When a silent baseline was introduced (e.g., Robinson & Sloutsky, 2007), labels were not found to facilitate infants' category learning above the silent baseline.

Finally, even studies demonstrating facilitative effects of labels have generated inconsistent findings regarding the age at which labels facilitate category learning. For example, Booth and Waxman (2002) demonstrated that for an artifact category, words alone facilitated category learning only at 18 months of age, whereas at around 14 months of age words needed to be paired with object function to facilitate learning above the baseline. It was argued that both words and functions (a) indicate human agency and (b) highlight commonalities among objects. Results of this study seem to be in sharp contrast to studies where words were claimed to facilitate category learning in very young infants. In particular, Ferry et al. (2010) found evidence that labels facilitate category learning in 3- and 4-month-olds. Why do labels facilitate category learning in 3- and 4-month-olds while failing to facilitate learning in much older infants (e.g., Booth & Waxman, 2002; Robinson & Sloutsky, 2007, 2008)?

According to the label-as-feature proposal, at least early in development, words are part of input – they are features of items rather than category markers (Gliozzi et al., 2009; Sloutsky & Fisher, 2004; Sloutsky & Lo, 1999; Sloutsky et al., 2001). For example, there is evidence that early in development auditory input overshadows (or attenuates processing of) corresponding visual input (Lewkowicz, 1988a, 1988b; Napolitano & Sloutsky, 2004; Robinson & Sloutsky, 2004a, 2004b; Robinson & Sloutsky, 2008; Sloutsky & Napolitano, 2003). Therefore, under most conditions words do not facilitate infant category learning, but under some conditions they may interfere with learning.

Of course, even if words start out as features, they may become category markers later in development (e.g., Deng & Sloutsky, 2012). For example, Deng and Sloutsky (2012) used a variant of Yamauchi and Markman's (1998, 2000) category learning paradigm to teach preschoolers and adults two novel categories. During training, the category label correlated perfectly with a pattern of motion, which is a highly salient visual feature (see Egeth & Yantis, 1997, for a review), whereas the rest of the category features were probabilistic. At test, the label was pitted against the pattern of motion and participants needed to predict one of the features of a test item. The researchers found that unlike many adults, who relied on a category label, children relied on the salient feature despite the fact that their memory for the label was as good as that of adults. These results raised interesting questions. If a visual feature that is a part of input has a greater effect on category learning than a label, what makes the label a category marker? And if words are not category markers for preschoolers, how can they be category markers for infants?

In sum, there are two theoretical positions regarding the role of words in category learning that differ with respect to the underlying mechanism and a developmental trajectory. Distinguishing between these possibilities and understanding the mechanisms underlying the effect of words on category learning is of critical importance for understanding cognitive development. If from early in development words function as category markers supervising learning, top-down effects may play a significant role in early cognitive development. In addition, given that supervision results in the ability to learn substantially more complex categories than unsupervised learning (Rumelhart, 1989), if words are supervisory signals for infants, our construal of what infants can and cannot learn will be subject to substantial revision.

Effects of words and other features on category learning during infancy: potential mechanisms

Although the reviewed evidence is controversial with respect to the idea that labels are category markers, none of the reviewed studies directly examined the mechanisms hypothesized by each theoretical position. At the same time, each position gives divergent predictions as to how words should affect category learning in comparison with other features. According to the label-as-category-marker position, attracting attention to commonalities is the mechanism via which labels facilitate category learning (e.g., Waxman, 2003). Therefore, when labels are presented, category learning should be accompanied by some form of attention optimization (Blair, Watson, & Meier, 2009; Hoffman & Rehder, 2010)—diffused attention early in learning, followed by shifting attention to within-category commonalities. Furthermore, attention optimization when labels are present should be greater than in no-label conditions, and this attention optimization should lead to better category learning.

In contrast, according to the label-as-feature position, (a) labels should not attract attention to commonalities and (b) due to possible auditory overshadowing effects, labels should either interfere with infant category learning or not affect it at all. Furthermore, there is evidence that successful category learning in 6- to 8-month-old infants is accompanied not by increased attention to commonalities (which is often the case in adults) but rather by broader exploration of features and, thus, more broadly distributed attention (e.g., Best, Yim, & Sloutsky, 2013). This prediction is based on a substantial body of literature demonstrating that distributed attention (with shorter individual fixations and frequent gaze shifts) is generally associated with better learning during infancy (e.g., Bronson, 1991; Colombo, Mitchell, Coldren, & Freeseman, 1991; Jankowski, Rose, & Feldman, 2001; Rose, Feldman, & Jankowski, 2003). There is also evidence that distributed attention is not merely associated but actually *leads* to better learning. In one study (Jankowski et al., 2001), researchers introduced a peripheral dynamic cue (a dynamic engager appearing in various parts of the screen) to induce shorter fixations, multiple gaze shifts, and thus a more distributed pattern of attention in 5-month-old infants. Results indicated that training resulted in more distributed attention (compared with no training) and in more efficient learning of presented items. This finding suggests that dynamic visual features (especially those that appear peripherally) may encourage distributed attention, thereby facilitating learning. Given that successful category learning during infancy is also accompanied by distributed attention (e.g., Best et al., 2013), it is possible that such dynamic visual features may also affect infant category learning.

Why do dynamic visual features encourage distributed attention? In contrast to static visual features that maintain their salience throughout the trial, dynamic visual features become highly salient only during the period when they are dynamic. As a result, if a dynamic visual feature is presented peripherally, at a very minimum participants would need to move their gaze from the point of their initial fixation to the moving part and then, when the motion ceases, to the point of their final fixation. Each of these gaze shifts may be accompanied by short fixations (and thus attention) to multiple regions of the stimulus (see Jankowski et al., 2001, for a discussion).

Therefore, compared with labels, these dynamic visual features may result in more gaze shifts, more distributed attention, and better and more robust learning. This prediction contrasts sharply with that of the label-as-category-marker position, which predicts that labels facilitate category learning by attracting attention to commonalities. The goal of the current research was to test both predictions by using a combination of eye-tracking and a more traditional novelty preference paradigm.

Overview of the current study

The study reported here presents two experiments designed to examine the effects of labels and dynamic visual features on category learning during infancy. Experiment 1 included two between-participants conditions: a label-defined condition and a motion-defined condition. In both conditions, infants were familiarized with exemplars from one category and then tested with the prototype of this category and that of the contrast category. Infants saw the same testing stimuli in both conditions, with neither label nor motion being presented during testing. Experiment 2 was aimed at further comparing the effects of labels with a silent control condition. In both experiments, eye gaze data were collected. Recall, that, according to the label-as-category-marker position, labels should (a) facilitate category learning compared with the other conditions and (b) lead to greater attention to commonalities than in the other two conditions. In contrast, according to the label-as-feature view, (a) because of auditory overshadowing, labels should not facilitate category learning and (b) more robust category learning may be accompanied by more distributed attention.

Experiment 1

Method

Participants

A total of 51 infants (30 girls and 21 boys) ranging in age from 8 to 12 months (M = 10 months 11 days, SD = 1 month 20 days) were recruited. Of the original sample, 10 infants were excluded from the analyses (2 due to fussiness and 8 for not looking at a single test trial).

Apparatus

A Tobii T60 eye-tracker with a sampling rate of 60 Hz was used to collect eye gaze data. The eye-tracker was integrated into a 17-inch computer monitor and located on a table inside a booth enclosed by black curtains. A trained experimenter monitored the experiment using Tobii Studio gaze analysis software installed on a 19-inch Dell OptiPlex 755 computer outside the booth. A video stream displaying participants' activities was projected onto a 9-inch black and white Sony SSM-930 CE television for the experimenter's online monitoring. Two Dell speakers were located behind a black curtain on each side of the eye-tracker.

Materials and design

The materials were colorful drawings of artificial creatures and the novel labels "Flurp" and "Jalet" (see Fig. 1A). The creatures had five features varying in color and shape and consisted of two categories. As shown in Table 1, the categories had a family resemblance structure that was derived from two prototypes (A0 and B0) by modifying the values of one of five features: head, antennae, hands, body, or feet. We used these novel categories to ensure that none of the infants was familiar with these categories prior to the experiment and all participants needed to learn these categories de novo. Another advantage of these stimuli is that they have been extensively tested in previous work with preschoolers (Deng & Sloutsky, 2012, 2013).

There were two between-participants conditions: a label-defined condition and a motion-defined condition. In the label-defined condition the label presented during training was the same for all of the exemplars, whereas in the motion-defined condition the pattern of motion presented during training was the same. To create a dynamic visual feature, the feet were animated using Macromedia Flash MX software. For all Flurps the feet stretched up and down, whereas for all Jalets the feet moved sideways. Because the goal was to examine effects of labels and dynamic visual features on category *learning*, neither labels nor patterns of motion were presented at test.

Procedure

Infants were seated on parents' laps approximately 60 cm away from the eye-tracker. Parents were instructed not to interact with infants and to avoid speaking or pointing. Prior to the experiment, infants completed a 5-point calibration sequence. The calibration consisted of dynamic kitten images accompanied by a "bouncing" sound appearing in different locations on the screen.

The experiment proper consisted of 20 familiarization and 4 test trials. The trials were mixed and pseudo-randomly assigned to four blocks, with each block consisting of 5 familiarization trials followed by 1 test trial (see Fig. 1B for the overall sequence in a block). On each familiarization trial, infants saw a creature generated from the same category (one of the categories shown in Table 1) on a white background lasting for 8000 ms and heard a phrase starting at the onset of each trial. A subset of infants studied Category A, whereas the rest of the infants studied Category B. In the label-defined condition the phrase (e.g., "Look! This is a Flurp") was presented at the beginning of each trial and lasted for approximately 2800 ms, whereas in the motion-defined condition the phrase did not include the label (e.g., "Look at this one!"). The feet of the creature started moving after the phrase ended, and the motion lasted for 3000 ms. The onset of motion was approximately the same as that of the label in the label-defined condition (i.e., 2300 ms into the trial).

Each test trial lasted for 8000 ms and presented a pair of items—the prototype of the studied category and the prototype of the non-studied category, with the left–right position of each prototype counterbalanced across test trials. Note that neither prototype was presented during training. These test items (which were the same across the conditions) were different from training trials in that they were presented without either label or motion. A dynamic bouncing ball was presented between trials within each block, whereas a short and task-irrelevant cartoon video was presented between blocks to maintain engagement of infant participants. All gaze data were recorded by the computer using Tobii Studio gaze analysis software.

Results and discussion

Gaze data were exported using Tobii Studio gaze analysis software. For each stimulus, seven areas of interest (AOIs) for fixations were defined: ellipses (ranging in visual angle from 2.4° by 2.4° to 3.8° by 5.7°) surrounding each feature of the creatures. Given that hands, feet, and antennae appeared in pairs, each pair was treated as a single AOI, which resulted in five AOIs used for data analyses: head, body, hands, feet, and antennae (see Fig. 1C for AOIs). The gaze durations were weighted by the area of each AOI. The analyses focused on (a) looking time at familiarization, (b) novelty preference score based on the proportion of looking time to the prototype of the novel category as compared with the total looking time to both of the prototypes at test, and (c) patterns of attention during test and familiarization based on the proportion of looking time to different features and the number of gaze shifts between AOIs.

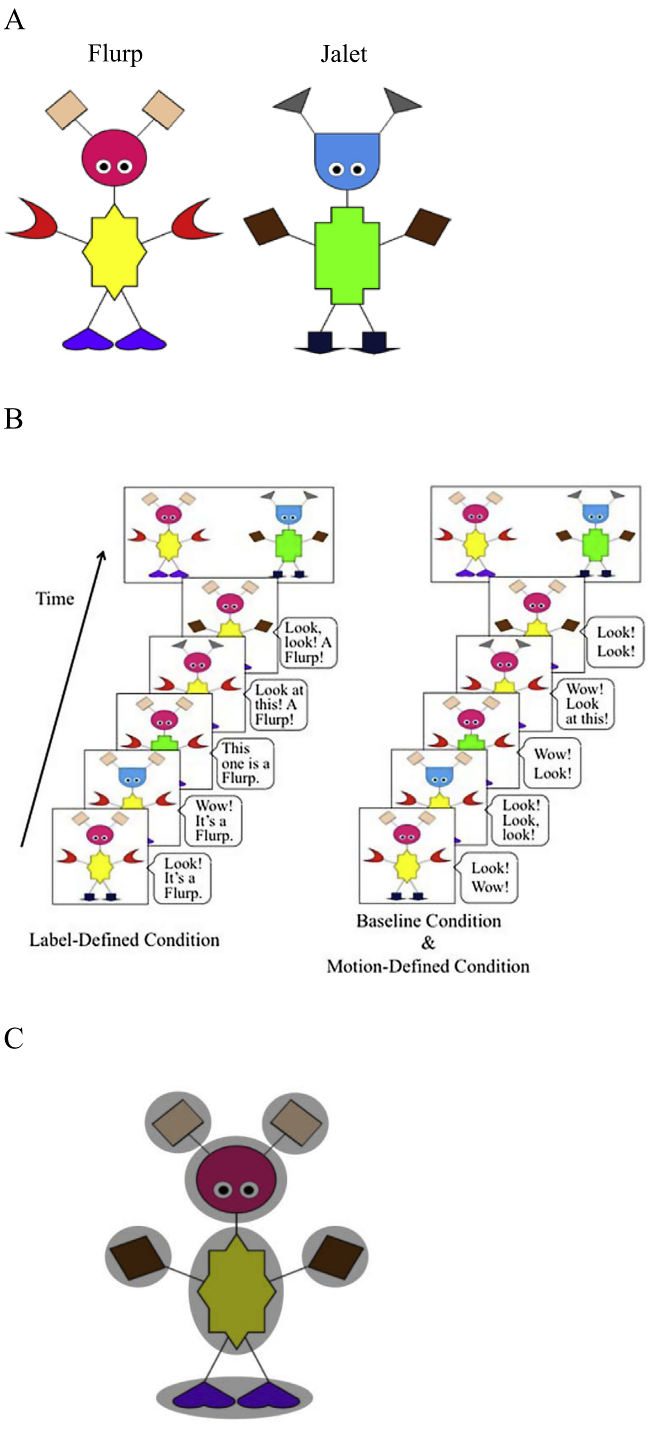

Fig. 1. Example stimuli. (A) Prototypes of stimuli from Categories A and B. (B) Procedures used in this study. (C) Areas of interest (AOIs) shown as gray ellipses.

Table 1
Category structure used in training.

Category A							Category B						
Stimulus	Head	Body	Hands	Feet	Antennae	Label/ Motion	Stimulus	Head	Body	Hands	Feet	Antennae	Label/ Motion
A1	1	1	1	1	0	1	B1	0	0	0	0	1	0
A2	1	1	1	0	1	1	B2	0	0	0	1	0	0
A3	1	1	0	1	1	1	B3	0	0	1	0	0	0
A4	1	0	1	1	1	1	B4	0	1	0	0	0	0
A5	0	1	1	1	1	1	B5	1	0	0	0	0	0
A0	1	1	1	1	1	1	B0	0	0	0	0	0	0

Note. The value 1 = any of five dimensions identical to "Flurp" (see Fig. 1). The value 0 = any of five dimensions identical to "Jalet" (see Fig. 1). A0 and B0 are prototypes of each category.

Looking time at familiarization

To ascertain whether the levels of engagement with the stimuli were comparable across the conditions, we compared accumulated looking time to the stimuli on familiarization trials in the label-defined condition with that in the motion-defined condition. The accumulated looking time data were submitted to a 4 (Block: 1 vs. 2 vs. 3 vs. 4) by 2 (Condition: label-defined vs. motion-defined) mixed analysis of variance (ANOVA), with block as a within-participants factor and condition as a between-participants factor. Results revealed a main effect of block, $F(3, 117) = 37.26$, $MSE = 0.02$, $p < .01$, $\eta_p^2 = .296$, with infants' accumulated looking time decreasing through blocks. However, infants' accumulated looking time did not differ between the label-defined and motion-defined conditions ($p = .52$). These results indicated that infants exhibited comparable levels of engagement across the two conditions.

To further examine whether stimuli became more familiar during the course of learning, we compared the average looking time on the first three and last three familiarization trials in the label-defined condition with that in the motion-defined condition (see Fig. 2). These data were submitted to a 2 (Trial: first three vs. last three) by 2 (Condition: label-defined vs. motion-defined) mixed ANOVA, with trial as a within-participants factor and condition as a between-participants factor. There was a main effect of trial, $F(1, 39) = 57.78$, $p < .001$, $\eta_p^2 = .597$, with infants in both conditions decreasing looking during familiarization, paired-samples $ps < .001$. There was a significant trial by condition interaction, $F(1, 39) = 4.62$, $p = .038$, $\eta_p^2 = .106$. The interaction indicated that infants in the label-defined condition started with longer looking on the first three trials than those in the motion-defined condition, independent-samples $t(31.7) = 2.44$, $p = .021$, $d = 0.75$, whereas there was no difference in the last three trials, $p = .629$. Therefore, infants in the label-defined condition exhibited somewhat greater familiarization than infants in the motion-defined condition.

Novelty preference

To examine how labels or patterns of motion affected infants' categorization, a novelty preference score was calculated for each test trial. Because there was only one test trial per block, we averaged test trials for Blocks 1 and 2 and for Blocks 3 and 4 (see Fig. 3). The data in Fig. 3 were submitted to a 2 (Block: 1–2 vs. 3–4) by 2 (Condition: label-defined vs. motion-defined) mixed ANOVA, with block as a within-participants factor and condition as a between-participants factor. There was a significant main effect of condition, with infants having higher novelty preference scores in the motion-defined condition, $F(1, 39) = 5.78$, $MSE = 0.12$, $p = .021$, $\eta_p^2 = .129$. Neither the effect of block ($p = .079$) nor the interaction ($p = .325$) reached significance.

In addition, infants in the motion-defined condition exhibited above-chance novelty preference in Blocks 3 and 4, one-sample $t(19) = 2.87$, $p = .010$, $d = 0.64$, but not in Blocks 1 and 2, $p = .949$, whereas in the label-defined condition novelty preference was not different from chance in either block, both $ps > .251$. Therefore, after four blocks of training, participants in the motion-defined condition exhibited evidence of category learning, whereas participants in the label-defined condition failed to learn.

Distributions of individual novelty preference scores by condition are presented in Fig. 4. As shown in this figure, during the first half of training (Blocks 1–2) there were comparable numbers of participants exhibiting novelty preference in either condition, whereas during the second half of training (Blocks 3–4) there were more participants exhibiting novelty preference in the motion-defined condition. To perform statistical analyses, we identified participants with novelty preference scores of 55%[1] or higher as "learners" while identifying the rest as "non-learners." For Blocks 1 and 2, in the label-defined condition there were 4 of 21 learners (19%) and in the motion-defined condition there were 7 of 20 learners (35%), which was not statistically different, $\chi^2(1, N = 41) = 1.33$, $p = .249$. However, for Blocks 3 and 4, there were 13 of 20 learners (65%) in the motion-defined condition, which exceeded the number of learners in the label-defined condition (7 of 21, 33.3%), $\chi^2(1, N = 41) = 4.11$, $p = .043$. Therefore, despite the fact that there was no advantage for the motion-defined condition during familiarization, there was greater evidence of category learning in this condition than in the label-defined condition.

Patterns of attention

We also examined how attention was distributed among different features of the stimuli on test trials (recall that neither labels nor motion was presented during these trials). Because there was no main effect of block ($p = .54$), the data were collapsed across blocks and results are presented in Fig. 5. There was a significant main effect of feature, $F(4, 156) = 112.04$, $MSE = 2.39$, $p < .001$, $\eta_p^2 = .742$. Neither the interaction nor the main effect of condition was significant ($ps > .117$). These results suggest that the difference in novelty preference between the label-defined and motion-defined conditions did not stem from patterns of attention at test.

Similar analyses were conducted to examine the patterns of attention on familiarization trials (see Fig. 6). The proportion of looking time to each feature was calculated within each trial (8000 ms) and then averaged across five familiarization trials within each block. These data were submitted to a 5 (Feature: head vs. body vs. hands vs. feet vs. antennae) by 4 (Block: 1 vs. 2 vs. 3 vs. 4) by 2 (Condition: label-defined vs. motion-defined) mixed ANOVA, with feature and block as within-participants factors and condition as a between-participants factor. Because there was no effect of block ($p = .155$), data were collapsed across the four blocks. There was a feature by condition interaction, $F(4, 156) = 30.95$, $MSE = 0.391$, $p < .001$, $\eta_p^2 = .442$. Infants accumulated more looking to the head in the label-defined condition compared with the motion-defined condition, independent sample $t(39) = 4.94$, $p < .001$, $d = 1.54$, whereas they looked significantly longer at the feet in the motion-defined condition than in the label-defined condition, independent sample $t(20.74) = 7.71$, $p < .001$, $d = 2.46$.

Although greater attention to the feet in the motion-defined condition might not be surprising, it was nevertheless associated with better learning. Note that feet motion was introduced approximately 2000 ms into the trial and ended approximately 3000 ms before the end of the trial. Given that participants spent most of the time looking at the head, it is likely that they moved their gaze at least twice: first from the head to the feet and then back from the feet to the head. Therefore, participants in the motion-defined condition were likely to have more gaze shifts, and this more distributed pattern of attention may have led to better category learning.

To examine this possibility, we further analyzed the number of fixation shifts between AOIs after the onset of label or motion during familiarization. To perform statistical analyses, we identified a fixation shift as a valid one if the looking time accumulated in the AOI before the shift and that accumulated in the AOI after the shift were at least 100 ms, respectively. The average number of valid fixation shifts within each block across the conditions is presented in Fig. 7. These data were submitted to a 4 (Block: 1 vs. 2 vs. 3 vs. 4) by 2 (Condition: label-defined vs. motion-defined) mixed ANOVA, with block as a within-participants factor and condition as a between-participants factor. Results revealed a main effect of block, $F(3, 117) = 3.92$, $MSE = 79.22$, $p = .010$, $\eta_p^2 = .091$, with the number of valid fixation shifts

[1] We also performed chi-square analyses by identifying participants with novelty preference scores of 60% or higher and 65% or higher as "learners" (which resulted in a substantial decrease in the number of learners in the label-defined condition), and results remained the same. In Blocks 1 and 2 there were comparable numbers of participants exhibiting novelty preference in either condition ($ps > .269$), whereas in Blocks 3 and 4 there were more participants exhibiting novelty preference in the motion-defined condition ($ps < .006$).

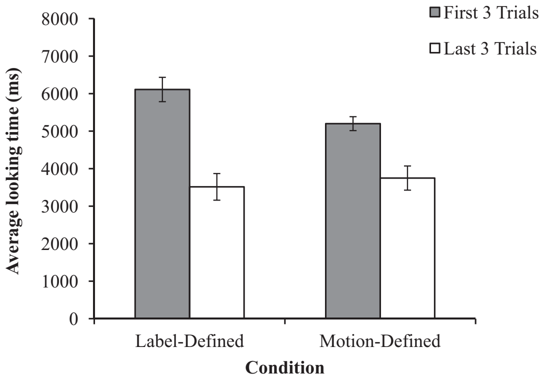

Fig. 2. Average looking times on the first three and last three familiarization trials in the label-defined and motion-defined conditions.

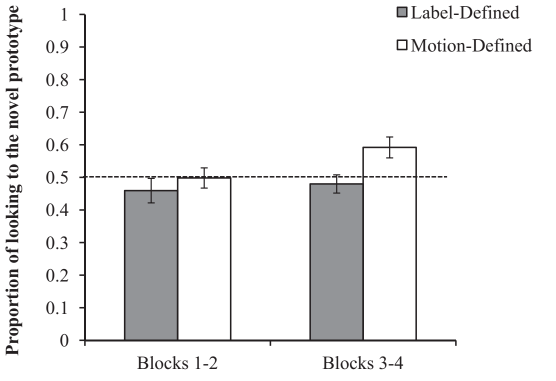

Fig. 3. Novelty preference scores on first two test trials and second two test trials in the label-defined and motion-defined conditions.

decreasing through blocks. More important, there was a main effect of condition, $F(1, 39) = 5.09$, $MSE = 442.85$, $p = .013$, $\eta_p^2 = .149$, with infants making more shifts after the onset of motion in the motion-defined condition than after the onset of label in the label-defined condition.

However, one may argue that greater attention to the head in the label condition (see Fig. 6) is indicative of the fact that labels attracted attention to commonalities, with participants optimizing attention by shifting it to the head. Another possibility is that participants in the label-defined condition merely exhibited a head bias (see Quinn, Doran, Reiss, & Hoffman, 2009, for evidence of head bias during infancy). Therefore, we deemed it necessary to directly examine these possibilities by examining whether infants exhibited focused attention after the label was introduced and whether infants differentiated the novel head from the familiar head at familiarization.

Dynamics of attention. If labels attract attention to commonalities, attention may be diffused early in the trial but should become more focused on the head after the label was introduced. However, if attention to the head stems from a bias, attention after the introduction of a label should be no more focused than before. To examine the dynamics of infants' attention within familiarization trials, attention shifts were calculated every 1000 ms and then averaged across four blocks at each time point for the total duration of 8000 ms. Data between 1000 ms (i.e., after the word "Look" was introduced in both conditions) and 7000 ms (when infants' looking started to decrease rapidly) were used for analysis and are shown in Fig. 8. Results presented in this figure indicate that labels did not attract attention

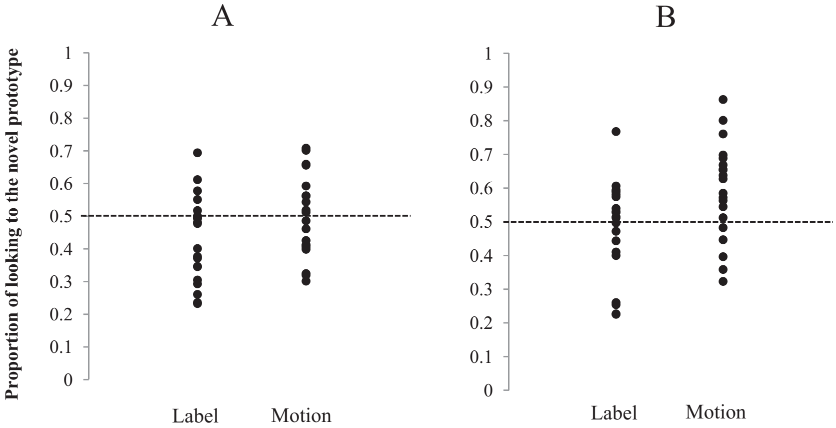

Fig. 4. Individual novelty preference scores in the label-defined and motion-defined conditions in Blocks 1 and 2 (A) and in Blocks 3 and 4 (B).

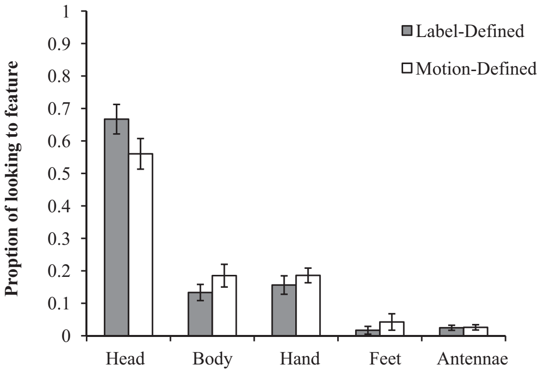

Fig. 5. Proportion of accumulated looking time to each feature averaged across four blocks at test in the label-defined and motion-defined conditions.

to commonalities (if they did, the number of shifts should have dropped rapidly after the onset of the label). In contrast, there was an increase in the number of shifts after the introduction of motion. Therefore, motion resulted in a more distributed pattern of attention and in better learning. A 6 (Time Point: 1 vs. 2 vs. 3 vs. 4 vs. 5 vs. 6) by 2 (Condition: label vs. motion) mixed ANOVA confirmed these findings. There was a main effect of condition, $F(1, 39) = 7.51$, $MSE = 34.18$, $p = .009$, $\eta_p^2 = .161$, with more shifts transpiring in the motion-defined condition than in the label-defined condition. There was also a main effect of time point, $F(5, 195) = 22.28$, $MSE = 13.57$, $p < .001$, $\eta_p^2 = .364$, with a quadratic trend showing that shifts increased early in the trial and then decreased later in the trial, $F(1, 39) = 54.94$, $p < .001$, $\eta_p^2 = .585$. In addition, there was a significant time point by condition interaction, $F(5, 195) = 5.07$, $MSE = 3.09$, $p < .001$, $\eta_p^2 = .115$. To examine the interaction, we compared the number of shifts at each time point after the introduction of the label or motion with that before the introduction (i.e., at the first time point). These pairwise comparisons with Bonferroni correction indicated that in the label-defined condition the number of shifts at the three consecutive time points after the onset of the label was comparable to that before the label (*ps* > .203), whereas in the motion-defined condition there were more shifts at the three consecutive time points after the onset of motion than before (*ps* < .010). Therefore, there was no evidence that attention became more focused after the label was introduced, but it became more distributed after motion was introduced.

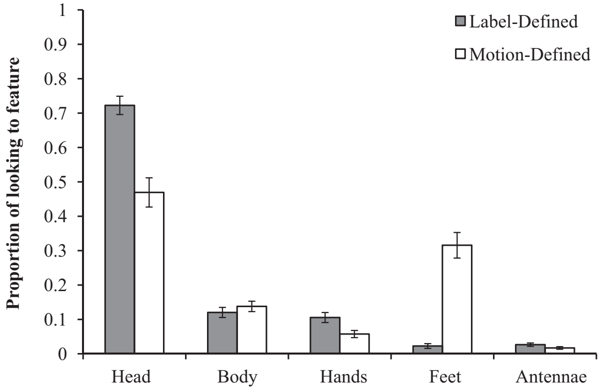

Fig. 6. Proportion of accumulated looking time to each feature averaged across four blocks at familiarization in the label-defined and motion-defined conditions.

Looking time to novel versus familiar head. To investigate whether longer looking to the head in the label condition stemmed from a head bias or from increased attention to commonalities, we examined novelty preference during familiarization. Recall that because the categories had the family resemblance structure (see Table 1), each familiarization item had one out-of-category (i.e., novel) feature. Therefore, in each training block there were four familiarization items with a given head and one familiarization item with a novel head. If labels attract attention to the common head, infants should look longer to the novel head during familiarization. However, if attention to the head stems from a head bias, infants should be interested in the head regardless of whether it is familiar or novel. To examine this, we compared infants' looking time to the novel head (i.e., the head of Item A5 or B5 as shown in Table 1) with the average looking time to the four familiar heads (i.e., the head of items A1–A4 or B1–B4 as shown in Table 1) for each block in the label-defined condition. These data were submitted to a 4 (Block: 1 vs. 2 vs. 3 vs. 4) by 2 (Head Type: novel vs. familiar) within-participants ANOVA. The results showed that infants did not differentiate the two types of head, with neither the interaction ($p = .467$) nor the main effect of head type ($p = .139$) being significant. These results suggest that looking to the head stemmed from a head bias rather than from labels attracting attention to commonalities. Similarly, infants' looking at other features did not differ when these features were familiar or novel (all $ps > .10$).

Overall, participants exhibited evidence of category learning in the motion-defined condition but not in the label-defined condition. This outcome is compatible with two possibilities: (a) label interfering with category learning and (b) motion facilitating category learning. To distinguish between

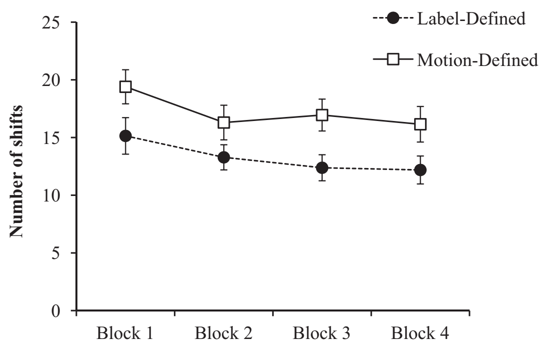

Fig. 7. Average number of valid fixation shifts within each block during familiarization in the label-defined and motion-defined conditions.

these possibilities, we needed a baseline in which neither labels nor motion was presented. If participants succeed in the baseline and exhibit patterns of attention comparable to those in the motion-defined condition, then labels interfered with learning. In contrast, if participants fail in the baseline and exhibit patterns of attention comparable to those in the label-defined condition, then motion facilitated learning. The goal of Experiment 2 was to distinguish between these possibilities.

Experiment 2

Method

Participants

A total of 23 infants (12 girls and 11 boys) ranging in age from 8 to 12 months (M = 11 months 1 day, SD = 1 month 10 days) were recruited. Of the original sample, 5 infants were excluded from the analyses due to fussiness or not looking at a single test trial.

Apparatus, materials, design, and procedure

The apparatus, materials, design, and procedure in Experiment 2 were similar to those in Experiment 1 with one critical difference, namely that neither labels nor motion patterns were introduced during training (see Fig. 1B).

Results and discussion

Similar to the data analyses in Experiment 1, five AOIs (i.e., head, body, hands, feet, and antennae; see Fig. 1C) were used and the gaze durations were weighted by the area of each AOI. The analyses focused on (a) looking time at familiarization, (b) novelty preference score based on the proportion of looking time to the prototype of the novel category as compared with the total looking time to both of the prototypes at test, and (c) patterns of attention based on the proportion of looking time to different features on test and familiarization trials.

Similar to Experiment 1, infants in Experiment 2 exhibited a drop in looking time in the last three familiarization trials compared with the first three familiarization trials, paired-sample $t(17) = 2.11$, $p = .05$, $d = 0.75$. In addition, similar to the label-defined condition, novelty preference score in Blocks 1 and 2 was not different from that in Blocks 3 and 4 ($p = .574$), and neither was different from chance ($ps > .628$). This was in contrast to the motion-defined condition, in which participants exhibited above-chance novelty preference by the second part of the experiment. Finally, patterns of attention at familiarization and test, as shown in Fig. 9, were also similar to those in the label-defined condition; infants exhibited a head bias (Bonferroni-adjusted $ps < .001$), and the proportion of looking

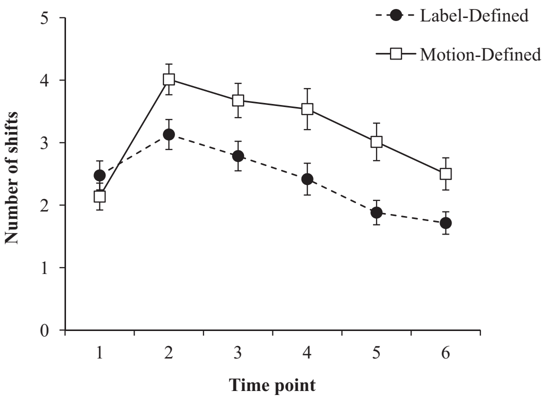

Fig. 8. Average number of valid fixation shifts averaged across four blocks at each time point within familiarization trials in the label-defined and motion-defined conditions. Each time point represents a 1000-ms time window.

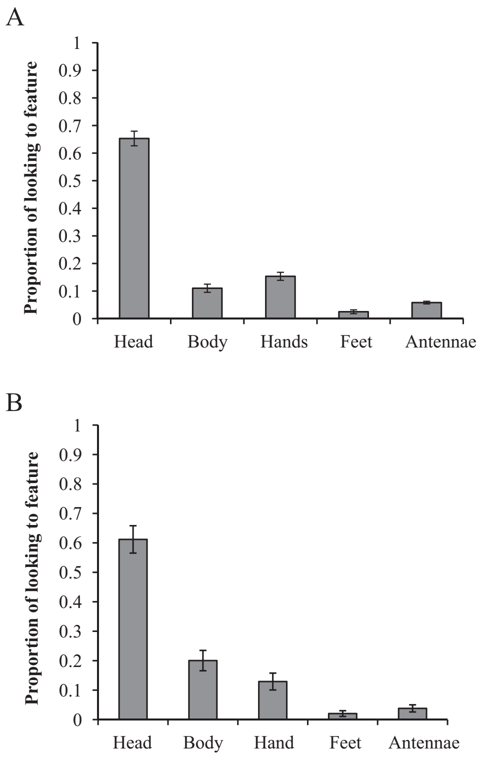

Fig. 9. Proportion of accumulated looking time to each feature averaged across four blocks at familiarization (A) and test (B) in Experiment 2.

to the head in the baseline condition did not differ from that in the label-defined condition (*p*s > .144). However, compared with the motion-defined condition, infants exhibited a stronger head bias in the baseline condition, with the proportion of looking to the head at familiarization being significantly higher (*p* = .002). Taken together, these results suggest that labels did little compared with the no-label baseline, whereas patterns of motion changed infants' patterns of attention, which resulted in better category learning.

General discussion

The reported study investigated how labels and dynamic visual features affected patterns of attention and outcomes of category learning in infants. The study revealed several important findings. First, infants exhibited better category learning in the motion-defined condition than in the label-defined and no-label conditions. Second, the motion condition resulted in a different pattern of attention during category learning compared with the label condition. Third, labels failed to either facilitate category learning or attract attention to commonalities. Therefore, whereas there was little evidence of labels either affecting attention or facilitating category learning in infants, dynamic visual features did both. Specifically, the presence of the dynamic visual feature resulted in more robust learning and in more distributed attention than in the other two conditions (cf. Jankowski et al., 2001).

The role of attention in infant category learning

There is much evidence demonstrating the role of selective attention in adult category learning, and there is more recent eye-tracking evidence (Blair et al., 2009; Hoffman & Rehder, 2010) indicating that category learning in adults is accompanied by attention optimization—shifting of attention to within-category commonalities. There is also a related argument pertaining to category learning during infancy: according to the label-as-category-marker position, even during infancy labels should facilitate category learning by attracting attention to commonalities (i.e., by facilitating attention optimization). Therefore, labels are expected to facilitate category learning by affecting selective attention. However, there is evidence that makes this mechanism unlikely.

In particular, there are recent findings that successful category learning during infancy is not accompanied by attention optimization (Best et al., 2013). This finding is important given previous evidence that distributed attention (with frequent fixation shifts) may result in better learning (e.g., Bronson, 1991; Colombo et al., 1991; Jankowski et al., 2001; Rose et al., 2003). Therefore, a feature that encourages a more distributed pattern may also facilitate learning. One candidate is a dynamic visual feature, especially if it is presented peripherally. Such features may affect attention because at a very minimum participants would need to move their gaze from the point of their initial fixation to the moving part and then, when the motion ceases, to the point of their final fixation. These ideas, although consistent with the label-as-feature view, run counter to the very core of the label-as-category-marker view.

Many studies have examined the role of labels in infants' categorization, but this is the first study to demonstrate that effects of dynamic visual features on category learning are greater than those of labels. By comparing the outcome of category learning and examining the patterns of attention in the label-defined and motion-defined conditions, the current study provides novel evidence elucidating how different features may affect category learning during infancy. The results indicate that distributed attention results in successful category learning during infancy and that features that elicit more distributed attention may also lead to better learning.

What is the role of words in early category learning?

Recall that two proposals have been advanced as to the role of words in early category learning: the label-as-category-marker view and the label-as-feature view. The label-as-category-marker position makes two critical predictions. First, labels should change patterns of attention (compared with no-label baseline) by attracting attention to within-category commonalities. Second, labels should facilitate category learning above the no-label baseline. To our knowledge, the first prediction has not been tested before, and the reported study is the first such test. The results clearly indicate that labels failed to attract attention to commonalities.

In contrast to the first prediction, the second prediction has been tested extensively in previous research and generated conflicting evidence, with some studies finding facilitative effects of labels and others failing to find such effects. Two sources of supporting evidence are worth considering: (a) differential effects of labels on learning of basic-level and superordinate categories and (b) differential effects of nouns and adjectives on category learning. As we discuss below, many of these effects are inconclusive.

One of the first studies demonstrating such differential effects was the study conducted by Waxman and Markow (1995). In this study with 9- to 20-month-olds, two variables were crossed: (a) the category structure (i.e., basic level vs. superordinate) and (b) labeling condition (noun vs. no word). Results indicated that novelty preference was above chance in all conditions except for the superordinate category–no word condition. On the basis of these results, it was concluded that words facilitate infants' attention to superordinate categories, whereas labels have little effect on learning of basic-level category labels (see also Fulkerson & Haaf, 2003). In contrast, Balaban and Waxman (1997) reported facilitative effects of labels for the basic-level categories in 9-month-olds. Therefore, there is no clear evidence that words have consistently different effects for categories of different levels.

The second source of support has to do with putatively different effects of nouns and adjectives on categorization. For example, in one study with 14- and 18-month-olds (Booth & Waxman, 2009), the category structure (i.e., basic level vs. superordinate) was fully crossed with lexical category (i.e., nouns vs. adjectives). The analyses revealed greater novelty preference in the noun condition compared with the other two conditions, but only for a single time window during the third quarter of the trial. In contrast, in a similar study conducted by the same researchers with a slightly different paradigm (Waxman & Booth, 2001), 14-month-olds exhibited equivalent novelty preference in the noun and adjective conditions. Therefore, evidence for different effects of nouns and adjectives on category learning during infancy is rather weak and inconclusive.

Whereas findings used to support the label-as-category-marker position are inconclusive, the reported results contribute to the growing body of evidence suggesting that labels are similar to other features in that they are part of input rather than category markers. Data reported here include both negative and positive evidence. Negative evidence indicates that labels fail to facilitate category learning, change pattern of attention compared with the no-label baseline, or attract attention to commonalities. Although this evidence disputes the role of labels in this specific design, it does leave open the possibility that perhaps under some other condition(s) labels facilitate category learning by attracting attention to commonalities.

Positive evidence is stronger because it disputes the very core of the label-as-category-marker approach. In particular, if distributed attention results in more successful category learning during infancy, then even if labels are found to attract attention to commonalities, they are unlikely to facilitate category learning. Alternatively, if labels do not attract attention to commonalities, then little is left of the label-as-category-marker position even if labels are found to facilitate category learning. This is because if labels do not attract attention to commonalities, these putative facilitative effects of labels would not uniquely support the label-as-category-marker position. These findings are important because distinguishing between these positions is consequential for our understanding of the relationships between language and cognition and the nature of learning early in development.

Conclusion

The reported study provides negative evidence suggesting that, under current conditions, labels do not facilitate category learning and do not attract attention to commonalities. The study also provides positive evidence suggesting that dynamic visual features eliciting more distributed attention may facilitate category learning. Positive evidence has the most important implications because it points to a mechanism by which features may affect category learning during infancy.

Acknowledgments

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