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Novel names extend for how long preschool children sample visual information

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ABSTRACT

Known words can guide visual attention, affecting how information is sampled. How do novel words, those that do not provide any top-down information, affect preschoolers' visual sampling in a conceptual task? We proposed that novel names can also change visual sampling by influencing how long children look. We investigated this possibility by analyzing how children sample visual information when they hear a sentence with a novel name versus without a novel name. Children completed a match-to-sample task while their moment-to-moment eye movements were recorded using eye-tracking technology. Our analyses were designed to provide specific information on the properties of visual sampling that novel names may change. Overall, we found that novel words prolonged the duration of each sampling event but did not affect sampling allocation (which objects children looked at) or sampling organization (how children transitioned from one object to the next). These results demonstrate that novel words change one important dynamic property of gaze: Novel words can entrain the cognitive system toward longer periods of sustained attention early in development.

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Introduction

There is a wide range of evidence that the words we hear guide our visual attention. When infants, children, or adults hear a known word, they look at scene elements that in some way match the word's meaning (e.g., Bobb, Huettig, & Mani, 2016; Dahan & Tanenhaus, 2005; Huettig & Altmann, 2011; Huettig & Hartsuiker, 2008; Lukyanenko & Fisher, 2016; Mani, Johnson, McQueen, & Huettig, 2013), and indeed this is the phenomenon behind one method used to study the words infants know (e.g., Bergelson & Swingley, 2012; Fernald, Zangl, Portillo, & Marchman, 2008). Known words also have effects in a variety of tasks designed to measure attentional processes (e.g., Brace, Morton, & Munakata, 2006; Kirkham, Cruess, & Diamond, 2003; Towse, Redbond, Houston-Price, & Cook, 2000; Yerys & Munakata, 2006). For example, 3-year-old children are faster at finding a visual target when cued with a relevant word compared with when cued only with a relevant picture (Vales & Smith, 2015). This phenomenon is hypothesized to reflect a mechanism, illustrated by the schematic in Fig. 1A, whereby words prompt the recall of previously learned information to yield a visual representation in working memory that guides visual attention (Vales & Smith, 2015). In brief, known words direct visual attention to scene elements by activating visual information associated with the meanings of the words. However, *novel* words also influence children's visual attention (e.g., Fulkerson & Haaf, 2003; Sloutsky & Robinson, 2008; Waxman & Braun, 2005; Waxman & Markow, 1995). Given that they are unlikely to activate previous visual information, what are the mechanisms by which novel words guide visual attention?

One way that a novel word may guide visual sampling is by its similarity to known words. For example, hearing a novel noun—for example, "That's a dax"—directs children's attention to things similar in shape (Landau, Smith, & Jones, 1988; Markman, 1989; Samuelson & Smith, 1999). In fact, there is a large literature on novel word learning by young children in which novel words are offered in sentence frames and conversational contexts, and when children hear such a novel word they are biased to attend to some specific object, event, or property that is consistent with the frame such as a noun, verb, or adjective (e.g., Brown & Bellugi, 1964; Fisher, 1996; Gleitman, 1990; Mintz, 2003; Weisleder & Waxman, 2009). For example, sentences such as "He gorped it" direct attention to transitive actions (Thothathiri & Snedeker, 2008; Yuan & Fisher, 2009). One could propose that these novel word effects work in fundamentally the same way that children understand known words (see Fig. 1B) (Colunga & Smith, 2005; Goldberg, 2006; McMurray, Horst, & Samuelson, 2012; Xu & Tenenbaum, 2007) because in many of these tasks children are shown a novel visual event, it is labeled, and how long children look at the novel event is measured. Thus, this abstract meaning account suggests that novel words direct attention toward visual properties consistent with the frame in which the novel words are inserted (e.g., shape or action above). But not all effects of novel labels are so easily explained in terms of specific perceptual properties, and in fact some have argued that words often influence attention—not directly but rather through conceptual or inferential pathways (see, e.g., Waxman & Gelman, 2009).

Here, we pursued a somewhat different idea as to how novel words may directly influence visual processing and attention (see Fig. 1C)—not by directing attention *to specific* visual information but rather by influencing how visual information is *generally sampled*. By this sampling hypothesis, words activate not just internal representations that may drive attention to specific perceptual information but also the internal networks that drive the dynamics of looking behavior (Gottlieb, Hayhoe, Hikosaka, & Rangel, 2014; Hayhoe & Ballard, 2014), changing how information is sampled regardless of any specific perceptual, semantic, or conceptual knowledge about the word. We aimed to provide direct evidence that the inclusion of a *novel* name by itself might change globally how children sample the information provided (the visual sampling hypothesis; Fig. 1C). This evidence points to a general mechanism whereby labels—especially novel ones that do not elicit previous knowledge—change how children sample visual information in systematic and important ways. Thus, it is possible that novel words may first generally entrain children's attentional system with subsequent consequences for other aspects of cognitive development.

Prior work suggests several dimensions of gaze dynamics that are malleable to contextual manipulations similar to the inclusion of a label (Gottlieb et al., 2014; Hayhoe & Ballard, 2014). These include

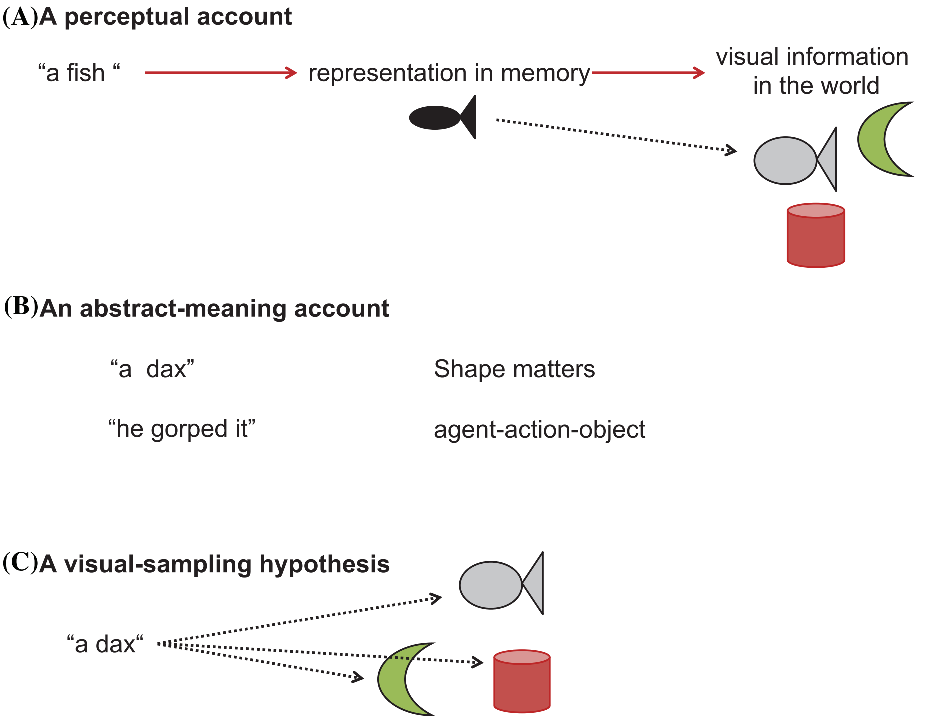

Fig. 1. Schematic representation of three ways that words influence processing across development. (A) A perceptual account posits that naming extends attention toward information that matches the representations of the labeled item in memory. (B) An abstract-meaning account posits that the name will bias attention toward visual properties consistent with the frame in which they are inserted. (C) The visual-sampling hypothesis proposes that the introduction of a name will extend attention toward all the visual information presented.

the systematicity with which elements in the pattern are sampled (Thibaut & French, 2016; Vurpillot, 1968), the duration of attention to individual elements (Mahdi, Schlesinger, Amso, & Qin, 2015; Schlesinger, Johnson, & Amso, 2015), and the underlying rules that govern how, why, and where attention shifts from one element to another (Balas & Oakes, 2015; Bonawitz, Denison, Gopnik, & Griffiths, 2014; Schlesinger, Johnson, & Amso, 2014). Here, we examined the extent to which novel names affect three key aspects of gaze dynamics, namely, whether novel names (a) attract looks to all objects, (b) reorganize the pattern of looks to objects, or (c) extend the duration of looks.

The context in which we did so was a relational match-to-sample task, in part because naming has been shown to influence performance in this task. For example, in Kotovsky and Gentner’s (1996) task, children were introduced to cards depicting a set of three elements arranged according to a specific spatial relationship. On each trial, children were shown a standard card showing an array of circles—for example, little–big–little—and asked to find a match from two answer choices: circle–star–circle and star–circle–circle. The correct choice is a unique relational match, that is, the card depicting circle–star–circle. Kotovsky and Gentner (1996) found this to be an extremely difficult task for 4-year-olds, with most children not systematically selecting the relational match. In general, without perceptual training and/or other support from task structure, this is a very hard task for preschool children (Christie & Gentner, 2010, 2014; Loewenstein & Gentner, 2005; Simms & Gentner, 2013; Son, Smith, & Goldstone, 2011) and is particularly so when the relational target choice has no object similarities with the standard as in the example described above. However, a number of studies have shown that arbitrary, noniconic, and (at least initially) contentless novel labels often help preschool children to perform better in this task even if children are still not completely successful (Kotovsky & Gentner, 1996; Loewenstein & Gentner, 2005; Namy & Gentner, 2002; Rattermann, Gentner, & DeLoache, 1990; Son et al., 2011). These novel labels—in a sentence form indicating a name (e.g., "This is a dax")—seem unlikely to change behavior through abstract meanings associated with the sentence frame because names usually direct attention to individual object properties such as shape (Dahan & Tanenhaus, 2005; Huettig & Altmann, 2011; Huettig & Hartsuiker, 2008; Imai & Gentner, 1997; Lupyan & Spivey, 2010a, 2010b; Samuelson & Smith, 1999) and not to the relations among the objects in an array. Explanations of the effects of labeling on children's abilities to make relational matches are often in terms of a process of "comparison" (e.g., Christie & Gentner, 2010, 2014; Gentner, Anggoro, & Klibanoff, 2011; Gentner & Medina, 1998; Gentner & Namy, 1999). This could be a process strictly internal to match-to-sample task demands engaged when presented with multiple scene elements. Or, it could be about the dynamics of looking behavior itself, that is, the gaze dynamics involved in seeking information from multiple elements in a scene. Thus, relational learning is a productive initial domain in which to investigate the sampling hypothesis. Testing the sampling hypothesis also requires a task that (a) is challenging for children so as to limit a possible confounding link between behavioral success and looking behavior and (b) minimizes the possibility of learning during the task but also (c) involves relevant goals in which manipulations of labels are unlikely to influence success in the task through meaning or through learning over the course of the experimental trials. These properties allowed us to test the sampling hypothesis at a pre-expertise stage where children, although engaged in the task, could not use their knowledge acquired during the task or any linguistic frame to guide their visual sampling. The classic Kotovsky and Gentner (1996) task meets these goals. In our task, only two items (rather than three items as in the usual preschool studies described above) instantiated a relation (sameness). Moreover, and as in the original Kotovsky and Gentner study, there were no item-level similarities between the standard and relational match choice because these are known to make the task easier for preschoolers. In addition, we made the distractor items visually similar to the items in the standard, which is likely to increase the difficulty of the task (see, e.g., Graham, Namy, Gentner, & Meagher, 2010) (see Appendix B).

We used three conditions. The No Label condition used a spoken general sentence frame but no labeling. This provides a test in which naming, and not speech, influences children's visual sampling. In addition, we included two label conditions. In the Constant Label condition, children heard the same label on all trials (e.g., "See this dax"). In the Changing Label condition, children heard a different label on each trial. Previous research has used tasks in which a new label is presented on each trial (e.g., Christie & Gentner, 2010) as well as tasks in which the label is consistent throughout the task (e.g., Christie & Gentner, 2014; Gentner et al., 2011). Comparing children's visual sampling when no label is presented and when a label is presented, in either form, allowed us to test whether it is the novelty of a name or a naming event more generally that influences looking behavior.

The task structure, as shown in the left panel of Fig. 2, offered two phases that presented different sampling challenges. During the first phase, children were presented with a single array of two spatially close and identical shapes. Because the two shapes within this array were sufficiently close (<1 degree of visual angle), this array (the standard) constituted a single target for visual attention. Thus, the main sampling questions for this phase concerned how long and how often children fixated the standard. During the second phase, the standard continued in view and two choice arrays were also presented: the target and the distractor. There were now three potential visual targets: the standard, the target showing the matching relation, and the distractor showing a pair of unrelated shapes. Visual sampling during this second phase offered more complex sampling possibilities, including duration and number of fixations to each of the three pairs of shapes as well as patterns of switching among them. The principal dependent measure, continuously measured throughout all trials, was visual sampling operationalized as eye gaze.

Method

Participants

A total of 48 children (M_{age} = 54 months, range = 35–68; 28 girls) were randomly assigned to one of three conditions: No Label (n = 16), Constant Label (n = 16), or Changing Label (n = 16). This wide age

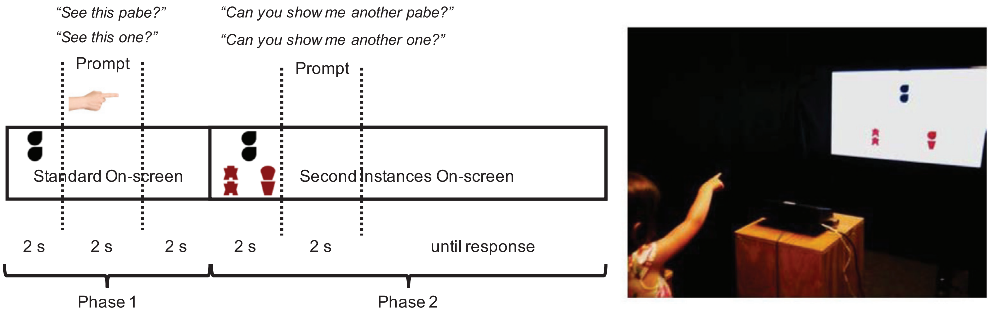

Fig. 2. Left panel: Structure of a single trial in the task. During Phase 1, children were presented with an instance on the top half of the screen, and then the prompt was presented (varying depending on label condition). The beginning of Phase 2 was defined by the appearance of two new instances at the bottom of the screen; the item from Phase 1 remained on the screen. A new prompt was presented 2 s after the new instances were introduced, asking children to choose the other item that matched the top one (exact prompt varied by condition). Right panel: Child completing one trial of the task.

range matches previous research using the match-to-sample task (e.g., Christie & Gentner, 2010, 2014; Gentner et al., 2011); there were no significant age differences among the No Label (M = 55 months, SD = 6), Constant Label (M = 53 months, SD = 10), and Changing Label (M = 50 months, SD = 8) conditions, $F(2, 45) = 1.22$, $p = .304$, $\eta^2_G = .05$.

An additional 21 children were recruited, but their data were not analyzed due to failure of eye-tracker calibration (n = 9), inability to complete the task (n = 3), significant eye-tracking data missing (n = 8; see Results section for details), or experimenter error (n = 1). Children had no known developmental disorders, they were reported to have normal or corrected-to-normal visual acuity, and English was their main or only language. Parental consent was obtained for all participants in compliance with the institutional review board of the research institution. These children were recruited from a database of families maintained for research purposes that is broadly representative of the local population: 84% European American, 5% African American, 5% Asian American, 2% Latino, and 4% other and consisting of predominantly working- and middle-class families.

Apparatus and procedure

Children were seated approximately 211 cm from a 55-inch LED screen. A free-standing Tobii X120 eye tracker (Tobii Technology, Stockholm, Sweden) was used to capture children's eye movements at a 60-Hz sampling rate. E-Prime software (Psychology Software Tools, Pittsburgh, PA, USA) was used to control stimuli presentation and to record eye gaze data. Before starting the main experiment, children completed a 9-point eye-tracking calibration. The calibration was repeated until satisfactory calibration was achieved or until children demonstrated signs of tiredness. Immediately following calibration, children completed three trials of familiarization to the structure of the task where they were asked to find known objects in natural scenes on the screen (e.g., finding the telephone in a picture of a room) and completed four trials with the same structure as the test trials. In these familiarization trials, the objects were known and the correct match was also an object match (e.g., children were presented with a ball as standard and asked to pick the item that matched, either another ball or an umbrella; see Appendix A for stimuli used during the familiarization trials). Feedback was given to children during this familiarization phase if children did not understand the task.

Each of the eight trials consisted of an initial phase followed by a second phase (see left panel of Fig. 2). During Phase 1 of each trial, children saw a same-relation instance on the top half of the screen (standard item; see Appendix B for all stimuli used in the experiment). A prerecorded spoken phrase oriented children to this instance. The phrase that children heard differed across the three conditions. In the No Label condition, children heard "See this one?" or "This is one" (for each child, each unique phrase was used in half of the trials with order randomized). In the Constant Label condition, children heard the name of the instance (e.g., "See this [dax]?" or "This is a [dax]") sampled randomly from a list of eight possible names (dax, ryke, fode, pabe, zup, kiv, mell, and cheem). Children heard the same name on all eight trials. In the Changing Label condition, children heard a different name on each trial (sampled randomly without replacement from the list of eight names).

The standard item size was 120 × 197 pixels and was presented for a total of 6 s. Children started by seeing the standard item for 2 s in silence. After this time, an animated hand pointed at the image and the verbal prompt was presented. The standard item remained on the screen for an additional 2 s after the end of the prompt. Then, during Phase 2 of each trial, two more items appeared on the bottom half of the screen: one different-relation instance (distractor item) and one same-relation instance (target item), with position on the screen counterbalanced across trials. Both instances had the same size as the standard item (120 × 197 pixels). Each trial consisted of a new instance of the standard, target, and distractor. After 2 s, children were asked to point to a bottom instance that was "the same kind of thing" (No Label) or "another [dax]" (Constant Label and Changing Label). Our main interest was in the distribution of gaze prior to response. Children could take as long as they needed to respond. The verbal prompts used throughout this experiment were recorded by a female native English speaker at a sample rate of 44.1 kHz. An experimenter controlled the experiment outside of children's view and advanced to the next trial when children responded.

Data processing

Eye-tracking data were analyzed using custom code written in R (R Core Team, 2013; code and data available from https://osf.io/mfqfd/).

The eye-tracking raw data were initially preprocessed through a blink filter in which loss of pupil for 12 or fewer samples was considered a blink; in these conditions, the location of the pupil was interpolated from the available data. When more than 12 samples were missing, no gaze was recorded for that period. We defined an area of interest (AOI) as an area around each of the items on the screen (120 × 197 pixels). A look longer than 80 ms within these areas was considered a fixation on the item (Bojko, 2009; Juhasz, Liversedge, White, & Rayner, 2006; Salvucci & Goldberg, 2000). Total looking duration was computed by summing the duration of all fixations on the AOI from its onset. A switch between AOIs was defined as a shift from one or more fixations in one AOI to one or more fixations in another AOI.

To confirm the difficulty of the task, children's pointing responses were coded. Children's pointing responses were coded online by the experimenter running the study; two additional independent offline coders, blind to condition, coded all participants' data. Agreement between the two offline coders was high (93%, Cohen's kappa = .868, $z = 16.2$, $p < .0001$). Agreement among the three coders was also high overall (Fleiss's kappa = .828, $z = 26.8$, $p < .0001$). To define the final response code (left or right), we used the code on which at least two coders agreed.

Analyses plan

The main results of interest in this study come from analyses of the visual sampling behavior in the three conditions. To this end, we calculated several measures of visual sampling and compared children in each of the three conditions on these. Unless stated otherwise, in all the analyses presented below, we start by comparing the three conditions using a one-way analysis of variance (ANOVA). When appropriate, follow-up analyses using planned contrasts examined the effect of using a novel label as well as the effect of degree of novelty of the word (constant label vs. changing label).

We analyzed sampling measures that describe the frequency of children's sampling (rate of fixation) and the duration of each sampling episode (mean fixation duration, proportion of time looking, and duration of longest fixation). During the second phase, when more than one item was available, we also analyzed measures of sampling organization (different types of transitions between two successive items) and how children allocated their sampling (first item fixated, last item fixated, and item fixated the longest). In addition, we also analyzed commonly used preference measures between the repeated standard item and the recently introduced target and distractor items in terms of difference in total looking time and mean fixation duration. Summaries of the results for all the measures analyzed for the first and second phases are presented in Tables 2 and 3, respectively, in the Results section. Each measure for which presenting a label or the type of label presented significantly influenced children sampling behavior is identified with an asterisk (see Results section for details). We did not, however, analyze how visual sampling influenced, or was influenced by, task performance. There were two main reasons for this. First, testing the sampling hypothesis requires a task where conceptual knowledge is not a factor and where learning over the duration of the task is unlikely to take place; otherwise, any differences in visual attention could be the result of activating previously acquired information that the label cued rather than the label per se. Second, because we successfully achieved this goal of a difficult task with no learning (see below), any apparent correlations between visual sampling and learning measures would likely be spurious.

Results

To confirm that this task was indeed difficult for young children, we analyzed the proportion of correct pointing responses (likelihood of pointing to the target during the second phase) and the corresponding response time. A descriptive summary of these measures can be found in Table 1.

As expected, children performed poorly overall in selecting the target in all three conditions. Children made similar choices whether they heard a constant label (M = 55% target choices), a changing label (M = 62% target choices), or no label (M = 53% target choices), $F(2, 45) = 1.27$, $p = .290$, $\eta^2_G = .053$. Children who heard a different label on each trial selected the target more often than expected by chance, $t(15) = 2.75$, $p = .015$, $d = 0.69$, although we note that this condition did not differ reliably from the other two conditions. Time taken to respond, as measured by the time the online coder pressed the computer key to register children's response, also did not differ among conditions, $F(2, 45) < 1$, $p = .479$, $\eta^2_G = .032$ (see Table 1). This pattern of results is consistent with previous research showing that this task is complex and hard for preschoolers. To verify that learning throughout the task did not differ across the three experiment conditions (which could be a main force guiding differential sampling; see Introduction), we compared performance for the first three trials of the task with that for the last three trials of the task.[1] We found no main effect of task part, $F(1, 45) < 1$, $\eta^2_G = .019$, or condition, $F(2, 45) < 1$, $\eta^2_G = .014$, and no interaction between task part and condition, $F(2, 45) < 1$, $\eta^2_G = .018$. Thus, the task met our goals of being challenging for children this age, not showing improvement across trials and not showing any overall difference in performance (i.e., emerging knowledge) across the conditions. Against this backdrop of equivalent response performance, we can ask how novel labels influenced children's visual sampling during the two phases of the task.

Phase 1: Children fixate items longer when they hear a label

Table 2 presents a summary of children's sampling behavior during Phase 1. To foreshadow, we found that novel labels changed *how long* children sampled the visual information presented (the standard during this phase) but not *how often* they sampled it. Moreover, labels extended looks toward the standard item through the duration of Phase 1, not just immediately after hearing the novel label.

Overall, children fixated the standard 0.49 times per second (SD = 0.11), and this rate of fixation did not differ among conditions, $F(2, 45) < 1$, $\eta^2_G = .040$. Similar results were found for number of fixations, $F(2, 45) < 1$, $\eta^2_G = .042$ (see Table 2). Even though all children fixated the standard at the same rate, children in different conditions sampled the information differently by spending different amounts of time in *each* fixation. As shown in Fig. 3, hearing a label had a significant impact on mean fixation duration during Phase 1, $F(2, 45) = 3.65$, $p = .034$, $\eta^2_G = .139$. Planned contrasts show that children who heard either a constant or changing label showed similar mean fixation durations, $t(45) = 0.34$, $p = .733$. Importantly, fixations from children in either of those groups were longer than fixations from children who did not hear a label, $t(45) = 2.68$, $p = .010$. Analyses of the proportion of time looking at the standard instance and the duration of the longest fixation on the standard instance show similar patterns (see Table 2).

[1] A similar pattern of results is found when we use trial as a continuous independent variable. However, because not all children contributed data to all trials and for consistency with subsequent analyses, here we report the analyses contrasting the first three and last three trials.

Table 1
Performance measures in the task for the three groups.

Measure	No Label	Constant Label	Changing Label
Proportion relational choices	0.53 (0.17)	0.55 (0.23)	0.62 (0.18)
Time to respond (s)	1.6 (1.5)	1.5 (1.6)	1.5 (2.6)

Note. Values are means (and standard deviations).

Table 2
Measures of visual sampling during Phase 1 of the task for the three groups.

Measure	No Label	Constant Label	Changing Label
Number of fixations	3.06 (0.82)	2.82 (0.37)	3.11 (0.62)
Rate of fixation (fixations/s)	0.50 (0.13)	0.46 (0.06)	0.51 (0.11)
Proportion time looking*	0.47 (0.12)	0.58 (0.05)	0.58 (0.11)
Mean fixation duration (ms)*	1065 (158)	1338 (231)	1300 (411)
Duration longest fixation (ms)*	1838 (306)	2103 (256)	2183 (487)

Note. Values are means (and standard deviations). An asterisk (*) indicates a measure for which a statistically significant effect of label was found.

Planned contrasts confirmed overall longer looking times and longer longest fixation when children heard a label (either constant or changing) than when no label was presented, $t(45) = 3.92$, $p = .0003$ and $t(45) = 2.73$, $p = .0008$, respectively, and no difference between the two label conditions for any of the measures, $ps > .540$. Overall, these analyses suggest that novel labels change children's visual sampling by extending the duration of individual looks.

We calculated the average duration of each fixation across trials and ordered children's individual looks starting after the beginning of the verbal prompt for each condition. We used multiple regression analysis to predict mean fixation duration using the numbered fixation and label condition as predictors. As shown in the right panel of Fig. 4, overall, the duration of children's looks decreased with each fixation, $b = -0.353$, $t(340) = -7.14$, $p < .0001$. We see longer fixation durations when children heard a label compared with when they did not hear a label, $b = 0.217$, $t(45) = 4.39$, $p < .0001$. Note that when we compare differences in fixation duration for fixations *before* the prompt is presented (see left panel of Fig. 4), we see no difference among the three conditions, $F(2, 87) < 1$, $\eta^2_G =$ .003. Thus, hearing a novel label results in overall longer looks compared with when no labels are heard. In addition, throughout Phase 1, the two label conditions show numerically longer fixations than the No Label condition (see Fig. 4). This suggests that the effect of labels is not due only to a robust influence on any one trial. In brief, labels extend the duration of all fixations even beyond the first one.

Phase 2: Children fixate items longer, and less often, when they hear a novel label

Table 3 presents a summary of children's sampling behavior during Phase 2. To foreshadow, in addition to an overall preference to sample the new items introduced during this phase (target and distractor), we found that presenting a label extended *how long* children sampled visual information and decreased *how many times* children sampled each item. Presenting a label did not influence how children *allocated* sampling time among the standard item and the target and distractor items, either overall or in terms of where to look first or last; it also did not influence how children *organized* their sampling from one item to the next. Hearing a label did, again, extend the duration of individual looks.

Children looked more often at novel items

We started by investigating how children allocated their sampling time between the item they had already seen (the standard) and the novel information presented (target and distractor). The results show that children fixated familiar and novel items a different number of times, $F(2, 90) = 20.45$, $p < .0001$, $\eta^2_G = .236$. Overall, children fixated the new information (the target and distractor; $M = 0.22$, $SD = 0.07$) more often than the old information (the standard; $M = 0.15$, $SD = 0.07$), $t(135) = 6.27$, $p <$

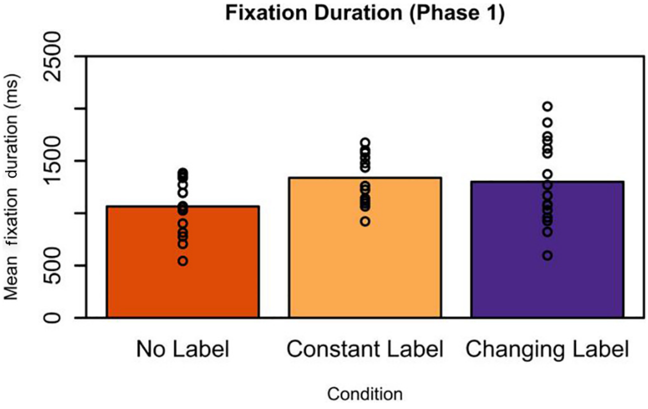

Fig. 3. Mean fixation durations on the standard item for the three conditions during Phase 1. Bars represent group averages, whereas points represent mean fixation durations for individual children in each group.

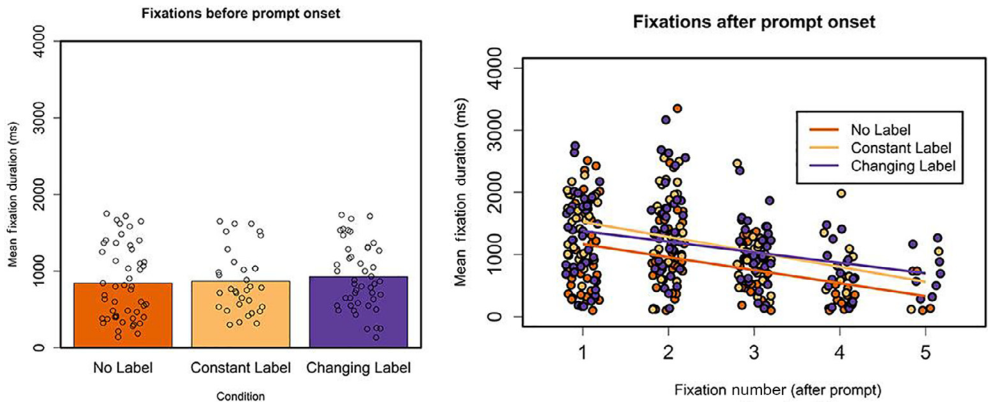

Fig. 4. Left panel: Mean fixation duration for fixations before the onset of the prompt during Phase 1. Individual points represent data from individual trials for each condition. Bars represent the average fixation duration per condition. Because most participants fixated the items only one or two times before the label onset, and not consistently across conditions, we did not analyze data across fixations. Right panel: Mean fixation duration for Fixations 1–5 after the prompt onset during the initial study phase of Phase 1. Individual points represent data from individual trials. Lines represent the best-fitting regression lines for each condition. As can be seen by the reduction of individual points across fixations, for most trials children had fewer than three fixations on the initial instance. Because only one trial (in the Changing Label condition) had six fixations, this fixation count was excluded from analysis.

.0001, and they fixated both the target and distractor items equally often, $t(135) = 1.58$, $p = .116$, with no interaction between novelty of the object and label condition, $F(4, 90) < 1$. This suggests that children were engaged with the task in all conditions.

Children looked longer at novel items

Children's fixation duration also depended on the type of item, similar to what we saw when analyzing the rate of fixation above, $F(2, 90) = 7.79$, $p = .0008$, $\eta^2_G = .11$. Overall, children fixated the new information ($M = 699$, $SD = 239$) longer than the old information ($M = 515$, $SD = 315$), $t(135) = 4.10$, $p <$ .001, and they fixated the two new items equally long, $t(135) = 1.58$, $p = .116$. We found no interaction between the novelty of the object and label condition, $F(4, 90) = 1.24$, $p = .300$, $\eta^2_G = .03$, indicating that

Table 3
Measures of visual sampling during Phase 2 of the task for the three groups.

Item	No Label	Constant Label	Changing Label
Difference in proportion time looking between instances (standard – target/distractor)			
–	0.03 (0.12)	0.08 (0.10)	0.07 (0.10)
Difference in mean fixation duration between instances (standard – target/distractor)			
–	41 (330)	282 (351)	231 (527)
Rate of fixation (fixations/s)[*]			
Distractor	0.24 (0.06)	0.21 (0.04)	0.20 (0.05)
Target	0.25 (0.07)	0.23 (0.07)	0.24 (0.08)
Standard	0.18 (0.09)	0.13 (0.06)	0.15 (0.04)
Proportion time looking[§]			
Distractor	0.13 (0.04)	0.15 (0.04)	0.16 (0.05)
Target	0.14 (0.05)	0.15 (0.05)	0.17 (0.05)
Standard	0.11 (0.09)	0.07 (0.06)	0.09 (0.07)
Mean fixation duration (ms)[*]			
Distractor	574 (212)	695 (238)	840 (255)
Target	576 (213)	690 (179)	820 (219)
Standard	575 (213)	411 (231)	599 (426)
Duration of longest fixation (ms)[*]			
Distractor	1233 (414)	1338 (414)	1545 (447)
Target	1198 (393)	1330 (361)	1513 (377)
Standard	1461 (414)	1229 (688)	1672 (892)
Proportion of longest fixations (out of total number of trials)			
Distractor	0.32 (0.20)	0.36 (0.17)	0.32 (0.18)
Target	0.31 (0.19)	0.31 (0.19)	0.33 (0.15)
Standard	0.37 (0.29)	0. 37 (0.29)	0.35 (0.25)
Proportion of first fixations (out of total number of trials)			
Distractor	0.24 (0.15)	0.21 (0.13)	0.16 (0.11)
Target	0.23 (0.16)	0.24 (0.11)	0.24 (0.14)
Standard	0.53 (0.17)	0.54 (0.19)	0.60 (0.16)
Proportion of last fixations (out of total number of trials)			
Distractor	0.42 (0.21)	0.30 (0.23)	0.28 (0.21)
Target	0.38 (0.24)	0.44 (0.26)	0.49 (0.23)
Standard	0.19 (0.30)	0.25 (0.30)	0.24 (0.26)
Rate of transitions (transitions/s)			
Overall	0.12 (0.06)	0.09 (0.06)	0.10 (0.07)
Standard <_> distractor/target	0.09 (0.03)	0.06 (0.03)	0.07 (0.04)
Distractor <_> target	0.17 (0.05)	0.15 (0.06)	0.15 (0.08)

Note. The standard is the instance that was presented during Phase 1 and instantiated the sameness relation. This instance remained on the screen during Phase 2. The distractor is the new item that did not instantiate sameness, whereas the target is the item that instantiated the sameness relation. Transitions indicate consecutive looks from one item to the other. Overall transitions indicates all type of transitions, whereas standard <_> distractor/target indicates transitions from/to the standard from/to the distractor or target. Similarly, distractor <_> target indicates transitions between the two new items on the screen. Values are means (and standard deviations) for the groups. An asterisk ([*]) indicates a measure for which a statistically significant effect of label was found. A section mark ([§]) indicates a marginally significant effect of label found ($p < .07$).

the introduction of a label did not modulate the extension in fixation duration for novel items. Again, this suggests that children were engaged with the task similarly across conditions.

Children made fewer fixations when they heard a label

Children's rate of fixation across all three available items depended on the label condition, $F(2, 45) = 3.69$, $p = .032$, $\eta^2_G = .050$. Planned contrasts indicate that, overall, children who heard a label made fewer fixations than children who did not hear a label, $t(135) = 2.63$, $p = .001$, and this did not depend on the relative novelty of the label, $t(135) = 0.35$, $p = .725$ (see Table 3). Thus, in a more complex situation where several items are available for sampling, we see two important sampling trends, namely that (a) children prefer to sample information they have not already sampled during the previous phase and (b) hearing a label reduces the number of sampling events.

Children looked longer when they heard a label

Fig. 5 shows that the duration of each fixation varied depending on the label condition, $F(2, 45) = 9.15$, $p = .0005$, $\eta^2_G = .10$. Planned contrasts show that children who heard a label fixated longer than children who did not hear a label, $t(135) = 2.56$, $p = .012$. The kind of label also influenced how long children fixated instances, with children who heard a changing label fixating longer than those who heard a constant label, $t(135) = 2.97$, $p = .004$. A similar pattern of results was found when we analyzed proportion of time looking and duration of longest fixation, similar to what we saw for Phase 1 (see Table 3).

Thus, contrary to what we saw during Phase 1 with only one item available, during the second phase—when more items were available—whether children heard a constant label or a different label in each trial influenced children's sampling behavior. The contribution of changing labels emerged over the task. We compared the mean fixation duration for the three conditions during the first three trials with the mean fixation duration during the last three trials of the task.[2] As shown in Fig. 6, there is no main effect of part of the task, $F(2, 45) = 1.35$, $p = .250$, $\eta^2_G = .008$, but there is an interaction between label condition and part of the task (first three trials vs. last three trials) on mean duration of fixations during Phase 2, $F(2, 45) = 3.28$, $p = .047$, $\eta^2_G = .038$. A series of planned contrasts showed that during the first part of the task there was no difference in the duration of fixations between the label conditions and the No Label condition, $t(45) = 1.32$, $p = .193$, or between the two label conditions, $t(45) = 1.33$, $p = .192$. Conversely, by the end of the task, there was an effect of label on fixation duration compared with no label, $t(45) = 3.04$, $p = .004$, as well as an effect of the relative novelty of the label, $t(45) = 2.66$, $p = .011$. Thus, the effect of labels—and the bigger effect of changing versus constant labels—increased over the course of the task.

Labels did not influence sampling organization

We also analyzed how children organized their sampling by looking at the sequence of fixations. For each trial, we calculated the number of transitions between items defined by successive fixations. We defined the rate of transitions as the number of transitions per second. There were three main transition types: overall number of transitions between any object on the screen and any other object on the screen, transitions between the standard item and one of the new items (distractor or target), and transitions between the distractor and the target. The results of these analyses are presented in Table 3. We found no systematic effect of labels on how children organized their sampling among available objects. Similar results were found when looking at which object was fixated first, last, and for the longest period of time during Phase 2 (see Table 3).

Discussion

The findings presented here provide clear support for the sampling hypothesis, positing that novel words influence information seeking in ways that have direct effects on the dynamics of gaze. The sampling hypothesis, along with the results presented here, suggests that words affect visual attention in ways that extend beyond biases with respect to specific visual content and, thus, speak to how the presence of words can potentially influence visual attention in novel tasks with novel visual content. This is an important contribution to our understanding of how words influence processing early on in cognitive development.

The sampling hypothesis is new; therefore, there is much left unanswered by this first study, including whether there are similar or different effects on looking behavior across different tasks and sentential frames. We analyzed several measures of visual sampling—duration and frequency of looks, organization of looks, and switching among items. These measures, although not exhaustive,

[2] A similar pattern of results is seen when looking at the change across all trials using trial number as a factor; however, because some children did not contribute data on all trials, the change between the first three and last three trials presented here includes a maximum number of children, increasing the power of our analysis.

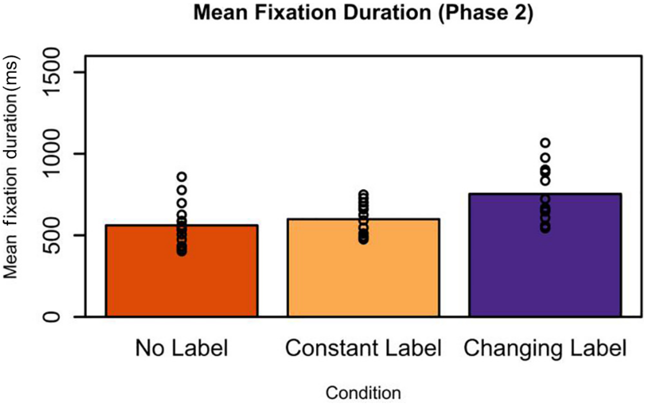

Fig. 5. Mean fixation durations on the items presented during Phase 2 (standard, target, and distractor) for the three conditions. Bars represent group averages, whereas points represent mean fixation durations for individual children in each group.

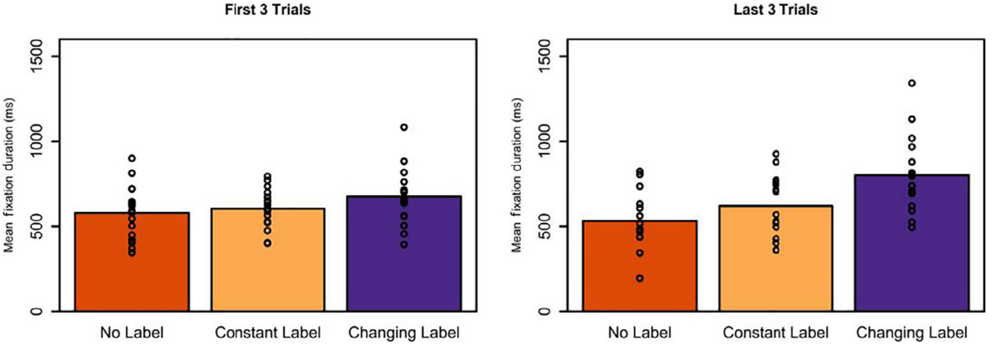

Fig. 6. Mean duration of fixations on the items presented during Phase 2 (standard, target, and distractor) for the first three trials of the task (left panel) and the last three trials of the task (right panel). Bars represent group averages, whereas points represent fixation durations for individual children in each group.

speak to a broad range of possibilities as to how novel verbal labels might influence visual sampling. The current findings show that, at least in the context of sentence frames indicating a naming event and at least for preschoolers in a relational matching task, the effect of a novel name is rather specific: It *extends the duration of individual fixations*.

During Phase 1 of the current experiment, just the standard was present and this phase asked for no decision making, just the pickup of visual information for later comparison with the choice stimuli. The simplicity of the visual task during this first phase, thus, offers the most straightforward evidence for the sampling hypothesis. During this phase, both with new novel names on each trial and with the same repeated novel name on each trial, the duration of individual looks to the visual information was longer than when children heard equivalent carrier sentences but no novel names. Moreover, hearing a novel name continued to extend individual durations throughout the second phase of this task when children were presented with multiple items to sample.

The observed effect of novel names on the durations of individual looks is consistent with one of the earliest reports of labeling effects on visual attention. Baldwin and Markman (1989) reported that 12-month-old infants looked longer at objects during a play period if the objects had been labeled beforehand. Here, with the added precision of contemporary eye-tracking methodology, we found that novel names specifically extended the duration of fixations that preschoolers made immediately after they heard the name when those preschoolers were presented with pairs of geometric shapes. Moreover, these effects on the duration of looks were not limited to the first look after the heard name but rather persisted over a series of multiple looks. This suggests a mechanism that operates generally and not a momentary increase in arousal from multimodal presentation.

Because the No Label condition also used spoken words that directed children to look at the items in a way that is equivalent to the two conditions that labeled the standard object, these observed effects must be due to the properties of the naming event itself, which include *a novel word* form, the sentence frame specifying that *word form as a noun* and the *speech act as a naming event,* and the *prosodic properties of natural labeling events*. The current experiment provides no information on which of these (or possibly other) components of the naming event contributed to the extension of individual looks. What these results do tell us is that novel naming events, because of some or all of their typical components, altered children's gaze dynamics.

Why should offering a name—and not merely telling children to "look" at the information—extend the *duration* of individual looks? One possibility is that this effect derives from a history of experiences in which naming events occur in the context of socially supported active direction of children's attention (e.g., by caregivers pointing to, showing, or shaking) while labeling objects or instances (see, e.g., Gogate & Bahrick, 1998, 2001; Yu & Smith, 2016). Through these experiences, the auditory, semantic, and grammatical properties that characterize naming events could become a cue that directs and sustains gaze on visual information. How could such a mechanism work? There is a large literature studying adults showing that co-occurring sounds—not necessarily speech sounds but also including tones, clicks, and music—modulate looking behavior, including duration of fixations, and enhance detection, discrimination, and memory for that information (Castelhano, Mack, & Henderson, 2009; de Haas, Cecere, Cullen, Driver, & Romei, 2013; Henderson, Weeks, & Hollingworth, 1999; Lupyan & Ward, 2013; Mammarella, Fairfield, & Cornoldi, 2007; Mills, Hollingworth, Van der Stigchel, Hoffman, & Dodd, 2011; Schellenberg, 2005; Thompson, Schellenberg, & Husain, 2001). There is also considerable neuroscience evidence that sounds automatically activate the visual cortex and in so doing modulate visual processing in multiple ways (Dorman, Watson, & Vietze, 1971; McDonald, Störmer, Martinez, Feng, & Hillyard, 2013; Song, Pellerin, & Granjon, 2013; Walker-Andrews & Lennon, 1985; Watson, 1969) and may do so in part by influencing moment-to-moment oculomotor decisions (Gleiss & Kayser, 2014; Zou, Müller, & Shi, 2012). Learned sound patterns characteristic of labeling events may affect gaze allocation through similar pathways.

To allow us to collect several data points from novices, who had a motivation to look at the materials and no relevant prior knowledge that could influence visual sampling, the task in the current study was designed to be difficult. For example, the stimuli were specifically designed to be more challenging than previous research showing behavioral differences (e.g., Christie & Gentner, 2014). Although this predictably yielded no behavioral differences among the conditions, other research has demonstrated that extended fixation durations are associated with better detection, recognition, and memory for visual information. In very young infants (1–4 months), decreases in the duration of fixations (e.g., Colombo, Mitchell, Coldren, & Freeseman, 1991) and infants' ability to disengage when a new stimulus is presented in the periphery (e.g., Johnson, Posner, & Rothbart, 1991) have been connected with greater positive cognitive outcomes (Rose, Feldman, Jankowski, & Van Rossem, 2012). However, considerable other work with newborns (Stjerna et al., 2015), infants (Lawson & Ruff, 2004; Papageorgiou et al., 2014; Ruff & Lawson, 1990), and toddlers (Rose et al., 2012) shows that extended fixation durations are associated with better ability to select and monitor behaviors to attain a goal. Thus, novel names—even in tasks such as the one we used here in which linking specific labels and objects is not the main goal—may often facilitate performance by extending the duration of looks, and these extensions in turn may be a consequence of the effect of naming on limiting competition from external distractors as a cause for terminating looks. These larger ideas are clearly conjecture at this point and require a program of research to both test and flesh them out. The main contribution of the current results is pointing to the dynamics of gaze as one pathway through which speech and novel words may influence visual processing, attention and, consequently, cognitive development.

Indeed, labels continued to extend the duration of looks as children encountered new visual information. During Phase 2, children had the original standard, the target, and the distractor to look at. If children were strategically directing their gaze and sustaining fixations in the service of the task, one might have expected labels to influence switches back and forth from the standard to the choices or between the choices. However, the effect of hearing a novel label was specific to look durations, and children who heard a repeating label as well as children who heard a changing label showed longer individual look durations compared with children who did not hear a label. Moreover, children who heard a label extended their individual look durations for all available items—the standard, the target, and the distractor—and, therefore, did not merely have longer looks to the explicitly named target but rather had longer looks to all items in the array. In addition to extending initial sampling, novel names also focused sampling by reducing the overall number of fixations on each item when several items were presented.

The effect of naming on look duration during this complex second phase was more pronounced in the Changing Label condition than in the Repeated Label condition. This difference between the two label conditions is consistent with previous evidence (e.g., Robinson & Sloutsky, 2007), indicating that novel labels prolong attentional engagement, whereas known labels capture attention faster but also result in quicker release. One route through which the degree of novelty may matter is by increasing overall arousal, which could have independent additive effects that, in conjunction with labeling, extends the duration of looks (for related ideas, see Robinson & Sloutsky, 2007; Van der Burgh, Olivers, Bronkhorst, & Theeuwes, 2008). This larger attentional engagement afforded by novel names could help to maintain effective sampling in a situation where the world is highly varied, such as for young children or older children performing a novel and challenging task.

Overall, the current results and the sampling hypothesis add a novel mechanistic framework to understand how novel labels for older children—and potentially any label for very young children—might influence visual attention that itself could influence learning. Consistent with this proposal, several experiments have shown that infants learn novel visual categories better when category instances are accompanied by novel labels compared with nonlinguistic sounds (e.g., Booth & Waxman, 2002; Ferry, Hespos, & Waxman, 2013; Fulkerson & Waxman, 2007; Robinson & Sloutsky, 2007; Waxman, 1999). Other experiments have shown that the labels used in conjunction with a set of objects guide what infants learn about those objects. For example, infants who heard no label, one label, or two labels differ in how they group the objects (Althaus & Westermann, 2016; Plunkett, Hu, & Cohen, 2008; see also Waxman & Braun, 2005). Similarly, infants who hear a novel label consistently look longer at the common properties of successive objects than at the varying properties (Althaus & Mareschal, 2014; Althaus & Plunkett, 2016). These results suggest that the infants in these experiments may have sampled the visual information differently under the different labeling conditions.

In conclusion, although there are many more questions to be answered, the current results show that words may influence the duration of children's looks. Effects of words on the dynamic properties of gaze that extend beyond specific known words and the visual properties of their referents may have potent effects on learning, problem solving, and the development of attention. If names—even novel ones—extend sustained attention, the infants and children who develop in environments with many more of those labeling experiences than others may develop more powerful mechanisms of attention and more effective information-gathering skills (see Yu & Smith, 2016, for a related hypothesis).

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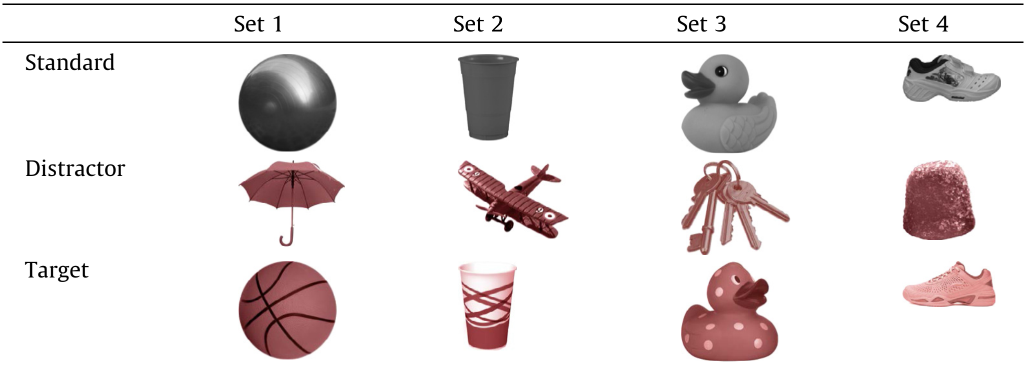
Appendix A

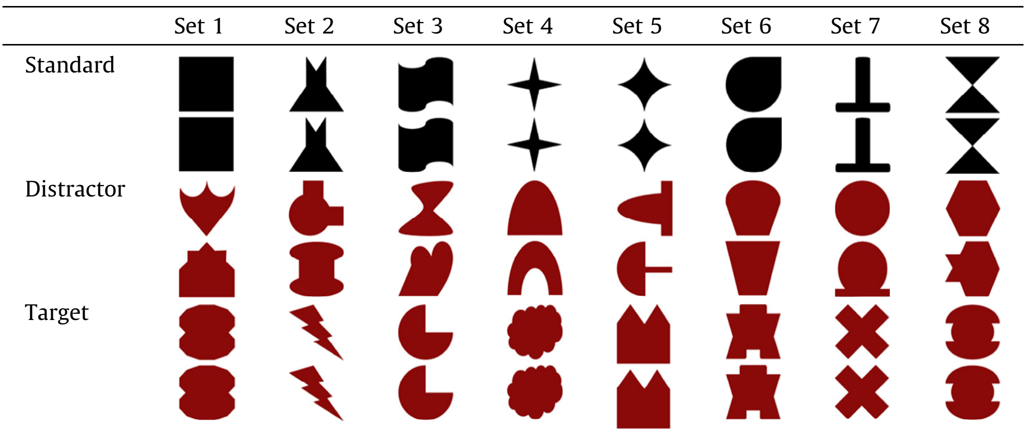
Sets of items used during familiarization trials



Note. Each set was used in a different trial.

Appendix B

Sets of items used during the experiment



Note. Each set was used in a different trial.

Appendix C. Supplementary material

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jecp.2017.12.002.

References

Althaus, N., & Mareschal, D. (2014). Labels direct infants' attention to commonalities during novel category learning. *PLoS ONE, 9*(7), e99670.

Althaus, N., & Plunkett, K. (2016). Categorization in infancy: Labeling induces a persisting focus on commonalities. *Developmental Science, 19*, 770–780.
Althaus, N., & Westermann, G. (2016). Labels constructively shape object categories in 10-month-old infants. *Journal of Experimental Child Psychology, 151*, 5–17.
Balas, B., & Oakes, L. (2015). Modeling infant visual preference as perceptual oscillation. In *2015 Joint IEEE international conference on development and learning and epigenetic robotics (ICDL–EpiRob)* (pp. 26–32). Los Alamitos, CA: IEEE.
Baldwin, D. A., & Markman, E. M. (1989). Establishing word–object relations: A first step. *Child Development, 60*, 381–398.
Bergelson, E., & Swingley, D. (2012). At 6–9 months, human infants know the meanings of many common nouns. *Proceedings of the National Academy of Sciences of the United States of America, 109*, 3253–3258.
Bobb, S. C., Huettig, F., & Mani, N. (2016). Predicting visual information during sentence processing: Toddlers activate an object's shape before it is mentioned. *Journal of Experimental Child Psychology, 151*, 51–64.
Bojko, A. A. (2009, July). Informative or misleading? Heatmaps deconstructed. In *International conference on human-computer interaction* (pp. 30–39). Berlin: Springer.
Bonawitz, E., Denison, S., Gopnik, A., & Griffiths, T. L. (2014). Win-Stay, Lose–Sample: A simple sequential algorithm for approximating Bayesian inference. *Cognitive Psychology, 74*, 35–65.
Booth, A. E., & Waxman, S. (2002). Object names and object functions serve as cues to categories for infants. *Developmental Psychology, 38*, 948–957.
Brace, J. J., Morton, J. B., & Munakata, Y. (2006). When actions speak louder than words: Improving children's flexibility in a card-sorting task. *Psychological Science, 17*, 665–669.
Brown, R., & Bellugi, U. (1964). Three processes in the child's acquisition of syntax. *Harvard Educational Review, 34*, 133–151.
Castelhano, M. S., Mack, M. L., & Henderson, J. M. (2009). Viewing task influences eye movement control during active scene perception. *Journal of Vision, 9*(3). https://doi.org/10.1167/9.3.6.
Christie, S., & Gentner, D. (2010). Where hypotheses come from: Learning new relations by structural alignment. *Journal of Cognition and Development, 11*, 356–373.
Christie, S., & Gentner, D. (2014). Language helps children succeed on a classic analogy task. *Cognitive Science, 38*, 383–397.
Colombo, J., Mitchell, D. W., Coldren, J. T., & Freeseman, L. J. (1991). Individual differences in infant visual attention: Are short lookers faster processors or feature processors? *Child Development, 62*, 1247–1257.
Colunga, E., & Smith, L. B. (2005). From the lexicon to expectations about kinds: A role for associative learning. *Psychological Review, 112*, 347–382.
Dahan, D., & Tanenhaus, M. K. (2005). Looking at the rope when looking for the snake: Conceptually mediated eye movements during spoken-word recognition. *Psychonomic Bulletin & Review, 12*, 453–459.
de Haas, B., Cecere, R., Cullen, H., Driver, J., & Romei, V. (2013). The duration of a co-occurring sound modulates visual detection performance in humans. *PLoS ONE, 8*(1), e54789.
Dorman, L., Watson, J. S., & Vietze, P. M. (1971). *Operant conditioning of visual fixation in infants under three intensities of auditory and visual reinforcement*. Unpublished manuscript, University of California, Berkeley.
Fernald, A., Zangl, R., Portillo, A. L., & Marchman, V. A. (2008). Looking while listening: Using eye movements to monitor spoken language. In I. A. Sekerina, E. M. Fernández, & H. Clahsen (Eds.), *Developmental psycholinguistics: On-line methods in children's language processing* (pp. 113–132). Philadelphia: John Benjamins.
Ferry, A. L., Hespos, S. J., & Waxman, S. R. (2013). Nonhuman primate vocalizations support categorization in very young human infants. *Proceedings of the National Academy of Sciences of the United States of America, 110*, 15231–15235.
Fisher, C. (1996). Structural limits on verb mapping: The role of analogy in children's interpretations of sentences. *Cognitive Psychology, 31*, 41–81.
Fulkerson, A. L., & Haaf, R. A. (2003). The influence of labels, non-labeling sounds, and source of auditory input on 9- and 15-month-olds' object categorization. *Infancy, 4*, 349–369.
Fulkerson, A. L., & Waxman, S. R. (2007). Words (but not tones) facilitate object categorization: Evidence from 6- and 12-month-olds. *Cognition, 105*, 218–228.
Gentner, D., Anggoro, F. K., & Klibanoff, R. S. (2011). Structure mapping and relational language support children's learning of relational categories. *Child Development, 82*, 1173–1188.
Gentner, D., & Medina, J. (1998). Similarity and the development of rules. *Cognition, 65*, 263–297.
Gentner, D., & Namy, L. (1999). Comparison in the development of categories. *Cognitive Development, 14*, 487–513.
Gleiss, S., & Kayser, C. (2014). Acoustic noise improves visual perception and modulates occipital oscillatory states. *Journal of Cognitive Neuroscience, 26*, 699–711.
Gleitman, L. (1990). The structural sources of verb meanings. *Language Acquisition, 1*(1), 3–55.
Gogate, L. J., & Bahrick, L. E. (1998). Intersensory redundancy facilitates learning of arbitrary relations between vowel sounds and objects in seven-month-old infants. *Journal of Experimental Child Psychology, 69*, 133–149.
Gogate, L. J., & Bahrick, L. E. (2001). Intersensory redundancy and 7-month-old infants' memory for arbitrary syllable–object relations. *Infancy, 2*, 219–231.
Goldberg, A. E. (2006). *Constructions at work: The nature of generalization in language*. Oxford, UK: Oxford University Press.
Gottlieb, J., Hayhoe, M., Hikosaka, O., & Rangel, A. (2014). Attention, reward, and information seeking. *Journal of Neuroscience, 34*, 15497–15504.
Graham, S. A., Namy, L. L., Gentner, D., & Meagher, K. (2010). The role of comparison in preschoolers' novel object categorization. *Journal of Experimental Child Psychology, 107*, 280–290.
Hayhoe, M., & Ballard, D. (2014). Modeling task control of eye movements. *Current Biology, 24*, R622–R628.
Henderson, J. M., Weeks, P. A., Jr., & Hollingworth, A. (1999). The effects of semantic consistency on eye movements during complex scene viewing. *Journal of Experimental Psychology: Human Perception and Performance, 25*, 210–228.
Huettig, F., & Altmann, G. T. (2011). Looking at anything that is green when hearing "frog": How object surface colour and stored object colour knowledge influence language-mediated overt attention. *Quarterly Journal of Experimental Psychology, 64*, 122–145.
Huettig, F., & Hartsuiker, R. J. (2008). When you name the pizza you look at the coin and the bread: Eye movements reveal semantic activation during word production. *Memory & Cognition, 36*, 341–360.

Imai, M., & Gentner, D. (1997). A cross-linguistic study of early word meaning: Universal ontology and linguistic influence. *Cognition, 62*, 169–200.
Johnson, M. H., Posner, M. I., & Rothbart, M. K. (1991). Components of visual orienting in early infancy: Contingency learning, anticipatory looking, and disengaging. *Journal of Cognitive Neuroscience, 3*, 335–344.
Juhasz, B. J., Liversedge, S. P., White, S. J., & Rayner, K. (2006). Binocular coordination of the eyes during reading: Word frequency and case alternation affect fixation duration but not fixation disparity. *Quarterly Journal of Experimental Psychology, 59*, 1614–1625.
Kirkham, N. Z., Cruess, L., & Diamond, A. (2003). Helping children apply their knowledge to their behavior on a dimension-switching task. *Developmental Science, 6*, 449–467.
Kotovsky, L., & Gentner, D. (1996). Comparison and categorization in the development of relational similarity. *Child Development, 67*, 2797–2822.
Landau, K. B., Smith, L. B., & Jones, S. S. (1988). The importance of shape in early lexical learning. *Cognitive Development, 3*, 299–321.
Lawson, K. R., & Ruff, H. A. (2004). Early focused attention predicts outcome for children born prematurely. *Journal of Developmental & Behavioral Pediatrics, 25*, 399–406.
Loewenstein, J., & Gentner, D. (2005). Relational language and the development of relational mapping. *Cognitive Psychology, 50*, 315–353.
Lukyanenko, C., & Fisher, C. (2016). Where are the cookies? Two- and three-year-olds use number-marked verbs to anticipate upcoming nouns. *Cognition, 146*, 349–370.
Lupyan, G., & Spivey, M. J. (2010a). Making the invisible visible: Verbal but not visual cues enhance visual detection. *PLoS ONE, 5*(7), e11452.
Lupyan, G., & Spivey, M. J. (2010b). Redundant spoken labels facilitate perception of multiple items. *Attention, Perception, & Psychophysics, 72*, 2236–2253.
Lupyan, G., & Ward, E. J. (2013). Language can boost otherwise unseen objects into visual awareness. *Proceedings of the National Academy of Sciences, 110*(35), 14196–14201.
Mahdi, A., Schlesinger, M., Amso, D., & Qin, J. (2015). Infants gaze pattern analyzing using contrast entropy minimization. In *2015 Joint IEEE international conference on development and learning and epigenetic robotics (ICDL–EpiRob)* (pp. 106–111). Los Alamitos, CA: IEEE.
Mammarella, N., Fairfield, B., & Cornoldi, C. (2007). Does music enhance cognitive performance in healthy older adults? The Vivaldi effect. *Aging Clinical and Experimental Research, 19*, 394–399.
Mani, N., Johnson, E., McQueen, J. M., & Huettig, F. (2013). How yellow is your banana? Toddlers' language-mediated visual search in referent-present tasks. *Developmental Psychology, 49*, 1036–1044.
Markman, E. M. (1989). *Categorization and naming in children: Problems of induction*. Mit Press.
McDonald, J. J., Störmer, V. S., Martinez, A., Feng, W., & Hillyard, S. A. (2013). Salient sounds activate human visual cortex automatically. *Journal of Neuroscience, 33*, 9194–9201.
McMurray, B., Horst, J. S., & Samuelson, L. K. (2012). Word learning emerges from the interaction of online referent selection and slow associative learning. *Psychological Review, 119*, 831–877.
Mills, M., Hollingworth, A., Van der Stigchel, S., Hoffman, L., & Dodd, M. D. (2011). Examining the influence of task set on eye movements and fixations. *Journal of Vision, 11*(8). https://doi.org/10.1167/11.8.17.
Mintz, T. H. (2003). Frequent frames as a cue for grammatical categories in child directed speech. *Cognition, 90*, 91–117.
Namy, L. L., & Gentner, D. (2002). Making a silk purse out of two sows' ears: Young children's use of comparison in category learning. *Journal of Experimental Psychology: General, 131*, 5–15.
Papageorgiou, K. A., Smith, T. J., Wu, R., Johnson, M. H., Kirkham, N. Z., & Ronald, A. (2014). Individual differences in infant fixation duration relate to attention and behavioral control in childhood. *Psychological Science, 25*, 1371–1379.
Plunkett, K., Hu, J. F., & Cohen, L. B. (2008). Labels can override perceptual categories in early infancy. *Cognition, 106*, 665–681.
R Core Team (2013). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from <http://www.r-project.org/>.
Rattermann, M. J., Gentner, D., & DeLoache, J. (1990). The effects of familiar labels on young children's performance in an analogical mapping task. In *Proceedings of the 12th annual conference of the Cognitive Science Society* (pp. 22–29). Hillsdale, NJ: Lawrence Erlbaum.
Robinson, C. W., & Sloutsky, V. M. (2007). Visual processing speed: Effects of auditory input on visual processing. *Developmental Science, 10*, 734–740.
Rose, S. A., Feldman, J. F., Jankowski, J. J., & Van Rossem, R. (2012). Information processing from infancy to 11 years: Continuities and prediction of IQ. *Intelligence, 40*, 445–457.
Ruff, H. A., & Lawson, K. R. (1990). Development of sustained, focused attention in young children during free play. *Developmental Psychology, 26*, 85–93.
Salvucci, D. D., & Goldberg, J. H. (2000). Identifying fixations and saccades in eye-tracking protocols. In *Proceedings of the 2000 symposium on eye tracking research & applications* (pp. 71–78). New York: ACM.
Samuelson, L. K., & Smith, L. B. (1999). Early noun vocabularies: Do ontology, category structure, and syntax correspond? *Cognition, 73*, 1–33.
Schellenberg, E. G. (2005). Music and cognitive abilities. *Current Directions in Psychological Science, 14*, 317–320.
Schlesinger, M., Johnson, S. P., & Amso, D. (2014). Prediction-learning in infants as a mechanism for gaze control during object exploration. *Frontiers in Psychology, 5*. https://doi.org/10.3389/fpsyg.2014.00441.
Schlesinger, M., Johnson, S. P., & Amso, D. (2015). Do infants' gaze sequences predict their looking time? Testing the sequential-learnability model. In *2015 Joint IEEE international conference on development and learning and epigenetic robotics (ICDL–EpiRob)* (pp. 162–167). Los Alamitos, CA: IEEE.
Simms, N., & Gentner, D. (2013). Encoding time and allocation of attention in analogical development. In M. Knauff, M. Pauen, N. Sebanz, & I. Wachsmuth (Eds.), *Proceedings of the 35th annual conference of the Cognitive Science Society* (pp. 1318–1323). Austin, TX: Cognitive Science Society.

Sloutsky, V. M., & Robinson, C. W. (2008). The role of words and sounds in infants' visual processing: From overshadowing to attentional tuning. *Cognitive Science, 32*, 342–365.
Son, J. Y., Smith, L. B., & Goldstone, R. L. (2011). Connecting instances to promote children's relational reasoning. *Journal of Experimental Child Psychology, 108*, 260–277.
Song, G., Pellerin, D., & Granjon, L. (2013). Different types of sounds influence gaze differently in videos. *Journal of Eye Movement Research, 6*(4), 1–13.
Stjerna, S., Sairanen, V., Gröhn, R., Andersson, S., Metsäranta, M., Lano, A., & Vanhatalo, S. (2015). Visual fixation in human newborns correlates with extensive white matter networks and predicts long-term neurocognitive development. *Journal of Neuroscience, 35*, 4824–4829.
Thibaut, J.-P., & French, R. M. (2016). Analogical reasoning, control, and executive functions: A developmental investigation with eye-tracking. *Cognitive Development, 38*, 10–26.
Thompson, W. F., Schellenberg, E. G., & Husain, G. (2001). Arousal, mood, and the Mozart effect. *Psychological Science, 12*, 248–251.
Thothathiri, M., & Snedeker, J. (2008). Give and take: Syntactic priming during spoken language comprehension. *Cognition, 108*, 51–68.
Towse, J. N., Redbond, J., Houston-Price, C. M., & Cook, S. (2000). Understanding the Dimensional Change Card Sort: Perspectives from task success and failure. *Cognitive Development, 15*, 347–365.
Vales, C., & Smith, L. B. (2015). Words, shape, visual search, and visual working memory in 3-year-old children. *Developmental Science, 18*, 65–79.
Van der Burgh, E., Olivers, C. N. L., Bronkhorst, A. W., & Theeuwes, J. (2008). Pip and pop: Nonspatial auditory signals improve spatial visual search. *Journal of Experimental Psychology: Human Perception and Performance, 35*, 1053–1065.
Vurpillot, E. (1968). The development of scanning strategies and their relation to visual differentiation. *Journal of Experimental Child Psychology, 6*, 632–650.
Walker-Andrews, A. S., & Lennon, E. M. (1985). Auditory–visual perception of changing distance by human infants. *Child Development, 56*, 544–548.
Watson, J. S. (1969). Operant conditioning of visual fixation in infants under visual and auditory reinforcement. *Developmental Psychology, 1*, 508–516.
Waxman, S. R. (1999). Specifying the scope of 13-month-olds' expectations for novel words. *Cognition, 70*, B35–B50.
Waxman, S. R., & Braun, I. (2005). Consistent (but not variable) names as invitations to form object categories: New evidence from 12-month-old infants. *Cognition, 95*, B59–B68.
Waxman, S. R., & Gelman, S. A. (2009). Early word-learning entails reference, not merely associations. *Trends in Cognitive Sciences, 13*, 258–263.
Waxman, S. R., & Markow, D. B. (1995). Words as invitations to form categories: Evidence from 12- to 13-month-old infants. *Cognitive Psychology, 29*, 257–302.
Weisleder, A., & Waxman, S. R. (2009). What's the input? Frequent frames for nouns, adjectives, and verbs: New evidence from Spanish. *Journal of Child Language, 37*, 1089–1108.
Xu, F., & Tenenbaum, J. B. (2007). Sensitivity to sampling in Bayesian word learning. *Developmental Science, 10*, 288–297.
Yerys, B. E., & Munakata, Y. (2006). When labels hurt but novelty helps: Children's perseveration and flexibility in a card-sorting task. *Child Development, 77*, 1589–1607.
Yu, C., & Smith, L. B. (2016). The social origins of sustained attention in one-year-old human infants. *Current Biology, 26*, 1235–1240.
Yuan, S., & Fisher, C. (2009). "Really? She blicked the baby?" Two-year-olds learn combinatorial facts about verbs by listening. *Psychological Science, 20*, 619–626.
Zou, H., Müller, H. J., & Shi, Z. (2012). Non-spatial sounds regulate eye movements and enhance visual search. *Journal of Vision, 12*(5). https://doi.org/10.1167/12.5.2.