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Longer looks for language: Novel labels lengthen fixation duration for 2-year-old children

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Abstract

The language infants hear guides their visual attention: infants look more to objects when they are labeled. However, it is unclear whether labels also change the *way* infants attend to and encode those objects—that is, whether hearing an object label changes infants' online visual processing of that object. Here, we examined this question in the context of novel word learning, asking whether nuanced measures of visual attention, specifically fixation durations, change when 2-year-olds hear a label for a novel object (e.g., "Look at the *dax*"), compared to when they hear a non-labeling phrase (e.g., "Look at that"). Results confirm that children visually process objects differently when they are labeled, using longer fixations to examine labeled than unlabeled objects. Children also showed robust retention of these labels on a subsequent test trial, suggesting these longer fixations accompanied successful word-learning. Moreover, when children were presented with the same objects again in a silent re-exposure phase, children's fixations were again longer when looking at the previously labeled objects. Finally, fixation duration at first exposure and silent reexposure were correlated, indicating a persistent effect of language on visual processing. These effects of hearing labels on visual attention point to critical interactions involved in cross-modal learning and emphasize the benefits of looking beyond aggregate measures of attention to identify cognitive learning mechanisms in infancy.

Keywords

Word-learning; attention; labels; children; fixation duration; eye-tracking

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Introduction

From early in infancy, the language children hear guides what and how they learn about the world. Labeling objects promotes infants' success in cognitive tasks as varied as categorization (Plunkett et al., 2008; Waxman & Markow, 1995), memory (Feigenson & Halberda, 2008; LaTourrette & Waxman, 2020), and physical reasoning (Langus & Höhle, 2021). In the current study, we investigate the effect of labeling on another central cognitive process: visual attention.

It is well established that language guides young children's visual attention to both scenes and objects. For instance, when infants as young as 6 months hear a familiar object label, they preferentially attend to its referent (Bergelson & Swingley, 2012; Fernald et al., 2008). Novel labels also influence attention: when an object is given a novel label, infants attend to that object for longer than when it is shown in silence (Althaus & Mareschal, 2014; Balaban & Waxman, 1997; Baldwin & Markman, 1989). These effects of labeling on attention even persist beyond the labeling utterance: infants look more to objects for which they know a label—even if no label is uttered (Schafer et al., 1999). The same is true for newly learned labels: infants look longer to objects that were previously labeled with novel words (Baldwin & Markman, 1989; Twomey & Westermann, 2016). Beyond this increase in raw looking time, infants also show enhanced object processing and sustained attention for objects that were previously labeled (Gliga et al., 2010; McDuffie et al., 2006). Thus, labeling exerts a lasting influence on infants' attention.

This prior work has established that labels impact how *much* children attend to objects, but it remains unclear whether labels also impact *how* children attend to objects. Addressing this question requires going beyond aggregate looking to consider a more fine-grained measure: fixation duration.

Fixation durations—the length of each fixation to a scene—range in length from a hundred to several thousand milliseconds. They are affected by both exogenous (e.g., luminance) and endogenous (e.g., processing speed) properties (Rayner, 1998; Richards, 2010). Moreover, fixation durations provide a moment-by-moment index of cognitive processing. For instance, when adults attend to a visual scene and encounter an object that is inconsistent with their expectations about, or their memory of, that scene, their visual fixations become longer. This increase has been interpreted as indicating enhanced semantic or memory processing (Hollingworth et al., 2001; Loftus & Mackworth, 1978; Ryan & Cohen, 2004). Likewise, research with infants has generally found that across development, fixation duration reflects processing: short fixations indicate easier, or more efficient, object processing (Colombo et al., 1991, 1995; Jankowski & Rose, 1997; Rose et al., 2001).

This link between object processing and fixation duration provides a novel way of assessing the impact of labels on visual attention, both at the moment of labeling and afterward. While research on these questions is scant, one study reported that three- to six-year olds' fixation durations increased upon hearing labels in a paradigm in which they were tasked with identifying relations (i.e., same/different) between pairs of shapes (Carvalho et al., 2018). This increased fixation duration is consistent with the possibility that labeling objects results in more elaborate object processing. Nevertheless, because children's accuracy in this relational task did not surpass chance levels, this result cannot reveal any cognitive consequences of the change in fixation durations.

In the current study, we directly test the hypothesis that labeling objects alters young children's looking patterns during word learning. In contrast to previous work, we examined straightforward and unambiguous word-learning contexts. We also focused on 2-year-olds because at this age, children are rapidly expanding their vocabularies. Our paradigm was designed to assess the effect of labels on fixation duration and examine any lasting cognitive effects of labeling on attention. Children were presented with a series of unique novel objects, each paired with either a unique novel label or a non-labeling phrase. Next, we tested children's retention of the label-object pairings. Finally, children viewed the same series of objects again, but this time in silence. This design allowed us to test whether labeling affected children's fixation durations, and whether these initial differences led to lasting changes in either 1) children's retention of the label-object mappings or 2) their pattern of attention to the same objects when subsequently presented in silence.

Materials and Methods

Participants

Forty-eight participants from 24- to 30-months-old were included (24 female, 24 male; 10 multiracial, 4 Asian, 3 Black, 2 Hispanic or Latinx, 25 White, 4 unreported). Participants were assigned to either the Label condition ($n = 25$, $M_{age} = 26.8$ months, $SD = 1.64$) or No Label condition ($n = 23$, $M_{age} = 26.7$ months, $SD = 1.34$). Twenty-one additional participants were excluded for providing less than 25% attention to the screen across all trials (14); failing to complete the study (2); and technical malfunctions (5). All caregivers gave informed consent for their child's participation.

Procedure

Children sat on their caregiver's lap approximately 60 cm in front of a 57.3 × 45 cm screen equipped with a Tobii T60XL corneal-reflection eye-tracker (Tobii Technology, Sweden). Caregivers wore opaque glasses and did not interact with their child. Before the experiment, participants viewed a 5-point calibration, a brief unrelated categorization task (<2 min), and an attention-grabbing video (10 s). To introduce children to the new task, all children saw two "warm-up" trials with familiar objects and familiar labels ("ball" and "cookie"), introduced in a structure similar to the primary experiment. First, a target object was labeled (e.g., "Look at the ball!"), then children saw the same object alongside a new object and were prompted with the target object's label ("Where is the ball?").

The experimental phase included three kinds of trials: Exposure, Test, and Silent Re-exposure (see Figure 1). On Exposure trials, all children viewed the same four novel objects (each with a diameter of approximately 20° of the visual angle), presented sequentially for 6 s each. Children in the Label condition heard language that labeled each object (e.g., *"Look at the dax!"*) whereas children in the No Label condition heard language that directed their attention to each object without labeling it (e.g., *"Look at this!"*). Immediately following each Exposure trial, children saw a 5 s Test trial, in which the same target object was presented alongside a distracter object of a different shape and color. In the Label condition, children were prompted with the previously learned label (e.g., *"Where is the dax?"*) whereas in the No Label condition, children heard a non-labeling phrase (*"Where is it?"*). The location of the target and distracter images (right/left) alternated across trials. In all Test trials, the images appeared 1 s before the onset of the target word (either the label or the corresponding pronoun). Participants saw four pairs of exposure and test trials.

After all the Exposure and Test trials, children saw four consecutive Silent Re-exposure trials, one for each target object shown during exposure. These trials were identical for both conditions; on each trial, a brief sound drew participants' attention to the screen, then the target object was shown in silence for 5 s. The order of objects presented in Re-exposure trials matched the order of targets introduced during exposure trials. All participants viewed the same objects in the same order. This ensured any effects of specific items on visual attention would be matched across conditions. The target objects included two colorful objects and two objects with more neutral colors. All materials are available at https://osf.io/achxb/?view_only=f01e43177e0b4f8fbc08028c51c6b83e

Modeling approach

We constructed linear mixed effects models using the R package lme4 (Bates, Mächler, et al., 2015) and including random effects of participant and item, with sum-coded fixed effects. When these initial models were singular or failed to converge, item effects were dropped to accommodate model fitting, as they accounted for less variance. To evaluate the significance of fixed effects (e.g., condition) in these models, we used Satterthwaite approximations for degrees of freedom, implemented in the lmerTest package (Kuznetsova et al., 2017). This modeling approach enabled us to treat each fixation as an observation. Fixations were defined as lasting a minimum of 80 ms (Wass et al., 2013). Fixation durations were then log-transformed for analysis with linear models, as indicated by a Box-Cox test (see also, Csibra et al., 2016). All data and scripts may be accessed at: https://osf.io/achxb/?view_only=f01e43177e0b4f8fbc08028c51c6b83e.

Results

Preliminary analyses revealed no significant effects of age, sex, or trial number on looking behavior at Exposure, Test, or Silent Re-exposure, all *p*s > .10.

Exposure

We first conducted a mixed-effects analysis predicting how long children attended to the stimuli during Exposure trials, including random effects of participant and item and a fixed effect of condition (i.e., Total_Exposure_Looking ~ Condition + (1|Participant) + (1|Stimulus)). This analysis revealed no difference between conditions in the *quantity* of children's looking to the objects during Exposure trials, $\beta = 169$, $SE = 289$, $t(44) = .58$, $p = .56$. This suggests that children in the Label ($M = 2145$ ms, $SD = 552$) and No Label ($M = 1888$ ms, $SD = 701$) conditions were similarly engaged with the objects: thus, any differences between conditions, here or on other trials, are not attributable to differences in how long children engaged with the objects, but to differences in how they did so.

Next, we tested the hypothesis that labeling influenced children's individual fixation durations to the objects. A mixed effects model with a fixed effect of condition and random effects of item and participant (i.e., Exposure_Fixation_Duration ~ Condition + (1|Participant) + (1|Stimulus)) revealed that fixation durations were significantly longer for children in the Label condition (M = 363 ms, SD = 104) than the No Label condition (M = 312 ms, SD = 100), β = .17, SE = .08, $t(46)$ = 2.06, p = .045. See Figure 2. Because overall attention was similar between conditions, this also meant infants in the Label condition (M = 12.0, SD = 2.9) made numerically fewer fixations than infants in the No Label condition (M = 13.5, SD = 3.4); although this difference did not reach significance, $t(46)$ = 1.49, p = .11. Notably, fixations were longer in the Label condition even excluding the periods of time when a label was being uttered, β = .17, SE = .080, $t(46)$= 2.13, p =.038. This is consistent with the hypothesis that object labeling leads to more elaborate cognitive processing of the object, beyond the auditory processing of the label itself.

Test

On Test trials, we asked whether children in the Label condition successfully mapped the novel labels presented during Exposure to its corresponding novel object. Because Test trials presented a novel object alongside the familiar, previously labeled object, we expected all children to show an overall bias toward the novel object (e.g., Rose et al., 1982). To account for this, we calculated children's proportion looking to the target object during the 2000 ms before the label was uttered and subtracted this from their preference for the target during the "naming window," 300 to 1800ms after label onset (Fernald et al., 2008). All proportions were logit-transformed for analysis. We predicted that children in the Label, but not the No Label, condition would increase their looking to the target referent during the naming window.

With this measure as the dependent variable, we constructed a mixed-effects model, with random effects of participant and item and a fixed effect of condition (i.e., Target_Preference ~ Condition + (1|Participant) + (1|Stimulus)) . As predicted, children in the Label condition showed a significantly larger increase in looking to the target from pre- to post-label ($M_{difference}$ = .14, SD = .23) than children in the No Label condition ($M_{difference}$ = −.04, SD = .31), β = .16, SE = .047, t(42) = 2.15, p = .037. This is consistent with the prediction that children in the Label condition successfully learned object-word mappings during Exposure.

For the Label condition, we also asked whether children's fixation duration at Exposure predicted their performance at Test. A mixed-effects model with random effects of item, participant, and duration-by-participant slope found no significant relation between the average fixation duration on a trial and children's preference for that target object at Test in the Label condition, β = .015, SE = .17, $t(26)$ = .09, p = .93. Thus, while children in the Label condition showed longer fixations during Exposure and successfully retained the labels they heard, no association emerged between fixation duration at Exposure and retention of the label-object mapping.

Silent Re-exposure

Next, we asked whether children's increased attention to the target in the Label condition at exposure—the original naming event—persisted when that same object appeared later, this time in silence. As on Exposure trials, a mixed effects analysis (i.e., Re-exposure_Total_Looking ~ Condition + (1|Participant) + (1|Stimulus)) indicated that the total amount of time that children looked to the objects in Silent Re-exposure trials did not differ between the Label (M = 2518 ms, SD = 868) and No Label (M = 2662 ms, SD = 719) conditions, β = −120, SE = 221, t(43) = .54, p = .59. However, analyzing fixation durations revealed differences in children's fine-grained attention to the objects (Figure 2). A mixed effects model of children's fixation durations during Re-exposure with random effects of subject and item and a fixed effect of condition (Re-exposure_Fixation_Duration ~ Condition + (1|Participant) + (1|Stimulus)) yielded a significant effect of labeling, β = .18, SE = .09, t(45 = 2.03, p = .048. Children in the Label condition made significantly longer fixations (M = 386 ms, SD = 182) than those in the No Label condition (M = 322 ms, SD = 133). Children also made significantly fewer fixations in the Label condition (M = 6.80, SD = 1.98) than the No Label condition (M = 8.56, SD = 3.19) on Silent Re-exposure trials, β = −.51, SE = .21, t(45) = 2.51, p = .016. Thus, the change in children's visual object processing induced by hearing labels during Exposure persisted even when the objects were later viewed in silence.

Finally, we tested the association between fixation durations at Exposure and Re-exposure. A mixed-effects model with trial-level data including condition, fixation duration at Exposure, the interaction with condition, and a random effect of participant (Reexposure_Fixation_Duration ~ Exposure_Fixation_Duration * Condition + (1+ Exposure_Fixation_Duration |Participant)) indicated that fixation duration at Exposure robustly predicted fixation duration during Re-exposure, β = .52, SE = .12, t(12) = 4.16, p = .0012. However, this held across both conditions, with a non-significant interaction between duration and condition, β = .44, SE = .25, t(13) = 1.75, p = .11. Thus, children in both conditions showed consistent looking patterns to the objects across exposures: children made longer fixations to labeled objects both during labeling and subsequently in silence.

Discussion

Building on previous research linking labels and attention, the current results demonstrate how labels affect children's attention, both during and after the moment of word learning. Two-year-olds' individual fixation durations—a prime component of their visual attention—increased in response to hearing novel objects labeled. This increase also persisted when children encountered the objects again in silence. Furthermore, children in the Label condition successfully retained the word-object mappings, as demonstrated by their performance in test trials, suggesting that they were successfully engaged in word-learning. This new evidence provides the first demonstration that object naming has both immediate and lasting effects not just on how *long* young children attend to an object but on *how* they do so, revealing key effects of labels on the fine-grained components of children's visual attention.

There are at least two plausible accounts of the observed relationship between labeling and visual attention: first, that labels facilitate learning in part by altering children's patterns of visual attention, and second, that labels alter children's cognitive processing, which is then reflected in their visual attention patterns.

On the first account, longer fixation durations are a key mechanism for the beneficial effect of object naming on learning. For example, the longer visual fixations induced in the Label condition may have a *functional* effect on learning, allowing children to take in more, or more relevant, information about the objects they are viewing. Children expect nouns to refer to object kinds (e.g., Markman & Hutchinson, 1984), and nouns increase looking to category-relevant features (Althaus & Mareschal, 2014). Labeling an object may invite children to learn more about its category and focus their attention on features, like shape, that often characterize noun meanings (Carvalho et al., 2018). Or perhaps object labels boost children's sustained attention to objects (McDuffie et al., 2006), which is often associated with both longer fixation durations (Lawson & Ruff, 2004; Papageorgiou et al., 2014) and more successful learning outcomes (e.g., West et al., 2021). The sustained attention generated by labeling might then persist on subsequent exposures.

Alternatively, longer fixation durations may be a reflection, rather than a cause, of increased cognitive processing. This account holds that labels enhance learning through some additional mechanism—one that is merely indexed, not driven, by this increase in the length of fixations. The current results are somewhat surprising under this account, as it unclear why an increase in fixation duration should *persist* when children encounter the object again in silence. Perhaps if children were attempting to recall the object's label, or surprised by the label's absence, this could result in increased cognitive load and longer fixations (cf. Twomey & Westermann, 2018), though one might still not expect that increased duration to correlate across exposures. Although the current study cannot tease apart these two accounts —and in theory, longer fixations could both contribute to learning and reflect additional, unrelated processing—the study does provide additional constraints on the two theories, fleshing out our understanding of both causal directions.

Finally, it is an open question whether increases in fixation duration accompany labeling in other learning contexts. Language impacts a variety of cognitive functions across many different ages (see Christie & Gentner, 2012; Novack & Waxman, 2020). Future work should consider the influence of labels on attention across development, in other learning contexts such as category learning, and using other measures, including the spatial distribution of fixations to an object and attention to label-relevant features.

In sum, by considering nuanced components of visual attention, we can sharpen our understanding of *how* object naming influences attention, permitting us to uncover the powerful influence of labels on early learning.

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Data statement:

The data and processing scripts that support the findings of this study are openly available in OSF and can be found at https://osf.io/achxb/?view_only=f01e43177e0b4f8fbc08028c51c6b83e

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Research Highlights

- Labeling objects induces changes in children's online visual processing of these objects
- Two-year-olds' visual fixations became longer if they heard a label for an object
- Visual fixations to objects were also longer if the objects had been labeled previously

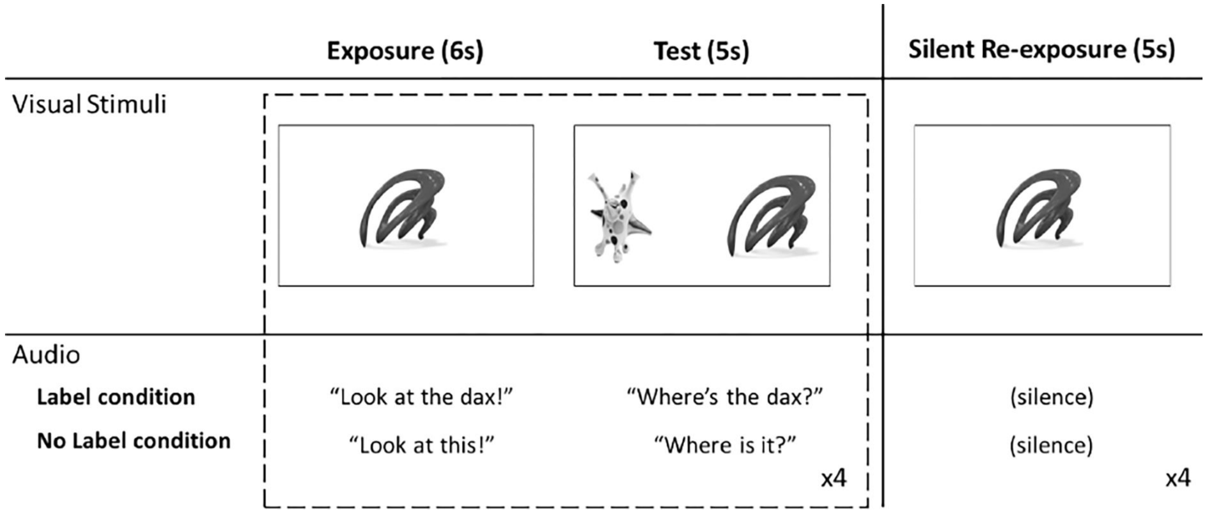

Figure 1.
Study design. During Exposure, 2-year-olds viewed a series of four novel target objects, presented in either the Label condition (each paired with a label) or No Label condition (each paired with non-labeling speech). Immediately after each Exposure trial, children saw a Test trial presenting the previous object alongside a new object. After completing all four rounds of Exposure and Test trials, children saw four Silent Re-exposure trials, featuring each object from Exposure presented in silence.

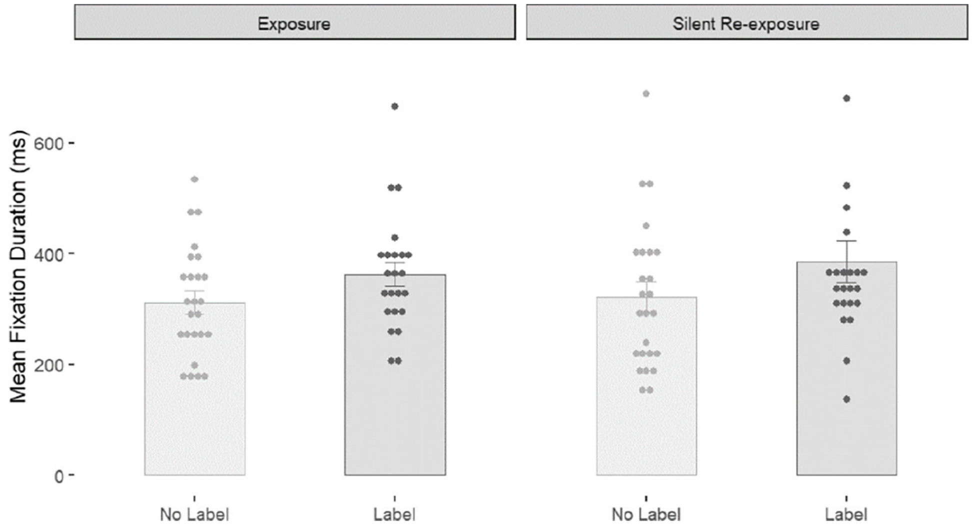

Figure 2.

Children's average fixation durations during Exposure and Silent Re-exposure trials in the No Label and Label conditions. Dots represent individual participant averages, shaded bars represent condition means, and error bars indicate +/− 1 SEM.