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SHORT REPORT

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Vocabulary and automatic attention: The relation between novel words and gaze dynamics in noun generalization

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Abstract

Words direct visual attention in infants, children, and adults, presumably by activating representations of referents that then direct attention to matching stimuli in the visual scene. Novel, unknown, words have also been shown to direct attention, likely via the activation of more general representations of naming events. To examine the critical issue of how novel words and visual attention interact to support word learning we coded frame-by-frame the gaze of 17- to 31-month-old children ($n = 66$, 38 females) while generalizing novel nouns. We replicate prior findings of more attention to shape when generalizing novel nouns, and a relation to vocabulary development. However, we also find that following a naming event, children who produce fewer nouns take longer to look at the objects they eventually select and make more transitions between objects before making a generalization decision. Children who produce more nouns look to the objects they eventually select more quickly following the naming event and make fewer looking transitions. We discuss these findings in the context of prior proposals regarding children's few-shot category learning, and a developmental cascade of multiple perceptual, cognitive, and word-learning processes that may operate in cases of both typical development and language delay.

KEYWORDS
few-shot category learning, language delay, looking-while-listening, noun generalization, visual attention, vocabulary

Research Highlights

- Examined how novel words guide visual attention by coding frame-by-frame where children look when asked to generalize novel names.
- Gaze patterns differed with vocabulary size: children with smaller vocabularies attended to generalization targets more slowly and did more comparison than those with larger vocabularies.

- Demonstrates a relationship between vocabulary size and attention to object properties during naming.
- This work has implications for looking-based tests of early cognition, and our understanding of children's few-shot category learning.

1 | INTRODUCTION

Words direct attention. As infants, children, and adults hear words their gaze is directed to things in the world that match the words they hear (Dehan & Tanenhaus, 2005; Mani et al., 2013). This phenomenon is the target of increasing research elucidating the relationship between language and visual perception (Bobb et al., 2016; Carvalho et al., 2018) and the mechanisms that support early word learning (Vales & Smith, 2018). It is also the basis of preferential looking tests of early word and language learning including speed of processing tests using known words (Fernald & Marchman, 2012) and comprehension tests with likely-to-be-known words (Friend & Keplinger, 2003). In these, presentation of the word presumably activates a representation of the known or newly learned referent, that then directs attention to the corresponding visual realization. Looking at a visual stimulus then, provides evidence that children know a particular word (e.g., Friend & Keplinger, 2003).

Evidence also suggests that more abstract aspects of language, beyond known word-object mappings, can guide toddler attention such that the presence of language can cue attention to meaningful visual information, even in the case of novel, unknown words. Presenting a novel word when introducing a category increases the time infants spend looking at stimuli (Haaf et al., 2003). Novel words also influence specific gaze targets within stimuli—directing gaze to shared object features, for example (Althaus & Mareschal, 2014). In such studies, novel words are often presented in sentence frames (e.g., "Look at the blicket!"), suggesting that the ability of novel words to cue attention is based on acquired knowledge of similar naming events. One case in which this claim has been made directly is the shape bias.

The shape bias refers to a tendency to generalize novel names for novel solid objects according to similarity in shape. It is commonly measured in novel noun generalization (NNG) tasks with 3-dimensional objects that children can manually explore and are asked to hand to the experimenter when prompted with a novel name. For example, Samuelson and Smith (1999) gave 17- to 31-month-olds an exemplar and two test objects, a shape-only match, and a material-only match, to explore. The objects were then retrieved, the exemplar held up, and a novel name provided (e.g., "Look! This is my zup."). Children were then asked to generalize the novel name (e.g., "Can you get your zup?"). The common finding in this and other studies, is that from around 2 years of age, children select the shape-match test object (Kucker et al., 2019). The shape bias has received much interest in the 30 years since Landau et al.'s (1988) initial demonstration because it necessarily requires application of knowledge beyond that of the novel word presented and is an example of few-shot learning not yet rivalled by the best computer vision models (Ritter et al., 2017; Smith & Slone, 2017; Sung et al., 2018).

There have been multiple proposals regarding the nature of the bias and where it comes from (Samuelson & Bloom, 2008). One proposal is that the bias is based on knowledge of conceptual categories; children generalize by shape similarity because shape is often relevant to the kind of thing an object is (Booth & Waxman, 2008; Markson et al., 2008). Another proposal is that the bias results from learning associations between regularities in the early noun vocabulary and the perceptual properties of referents that train automatic attention to shape similarity when novel solid objects are named (Kucker et al., 2019; Samuelson, 2002; Smith et al., 2002). One issue with the suggestion that the presentation of a novel word directly cues attention to shape, however, is that evidence comes from children's final selections in the noun generalization task. However, while children's eventual selections of the shape-match test object could result from the name directly cuing their attention to shape, it is also possible that before selecting children have spent some amount of time comparing the possible referents or engaging other more deliberative processes. No prior work has looked directly at the visual exploration process that supports children's selections when generalizing novel nouns—critical for understanding how language and visual attention interact in word learning and communication more generally. Thus, we examine the timing of visual attention in the NNG task, asking whether naming drives attention to directly shape or whether more deliberative processes are involved.

To do this we embedded a looking-while-listening procedure (Fernald et al., 2008) within the standard NNG task via close-up video of the toddlers' face and eyes. We coded this video frame-by-frame to determine where toddlers were looking before and after the presentation of the novel noun. We considered three possible hypotheses for the relation between the naming event and children's attention. First, if the novel name cues attention to shape directly, children should look equally to the two test objects before the naming event and quickly to the shape-match test object after. If instead the name cues a more deliberative comparison process in service of the application of conceptual knowledge, the number of looking transitions may be expected to increase following name presentation (see, e.g., Folke et al., 2017; Leckey et al., 2020). A third possibility, based on demonstrated links between visual object perception, including abstract shape information, and word learning (Smith, 2003), is that children will have a more general bias to attend to the shape of solid objects even before the naming event.

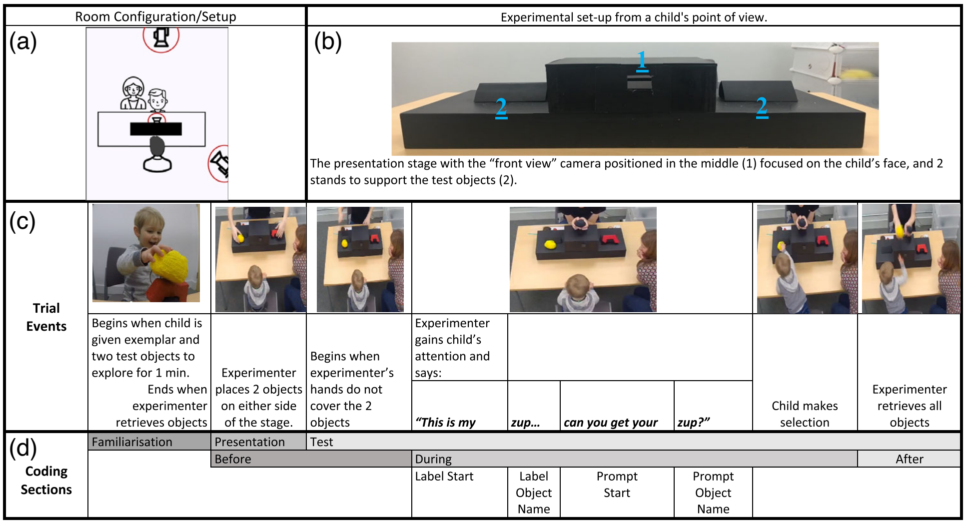

FIGURE 1 Experimental set-up including the room configuration (a) and the view from the child's point of view (b), as well as the sequence of events in a trial (c) and correspondence to coding sections (d).

2 | METHOD

2.1 | Participants

We recruited 66, 17-31-month-old children (38 females, 87.9% white, 6.1% mixed race, 6.1% not specified) from a medium-sized city in the East of the United Kingdom. Data from 26 additional children were excluded for failure to complete two warm-up trials ($n = 2$), becoming fussy ($n = 12$) or recording errors ($n = 12$). The study was approved by the local ethics committee. Informed consent was obtained from the parents prior to the experiment. All children received a small prize for participation.

2.2 | Stimuli and apparatus

The six familiar objects and four sets of novel objects had been used previously by Samuelson (2002). Each novel object set contained an exemplar, two test objects that matched the exemplar in shape but were different in color and made from a different material, and two test objects that matched the exemplar in material but were different in shape and color. Novel objects were made of clay, plaster, Styrofoam, yarn, and plastic mesh and ranged from 6 to 11 cm in length, 8–10 cm in width and 4–13 cm in height. The four novel words were Zup, Fum, Mip, and Kiv (Samuelson & Smith, 1999).

A wooden stage was built to house a GoPro camera that recorded a close-up of the child's face (Figure 1). The bottom was 80 cm × 33 cm × 12.5 cm and the camera box that sat on was top 23.5 cm × 16.5 cm × 29.7 cm. A support on each side of the camera box, each 10 cm × 10 cm × 9 cm, held the test objects upright during the naming and selection portion of the trial. Wall-mounted cameras recorded the experimenter and a side view of the table. A digital timer was mounted on the wall behind the child within view of the experimenter.

2.3 | Procedure

In a waiting room, the parent read an information document and completed the Oxford Communicative Development Inventory (Hamilton et al., 2000) while the experimenter played with the child. In the experimental room, the child sat across a table from the experimenter and the parent behind and to the right of the child (see Figure 1). Parents were instructed to interact only to encourage responding as necessary and then to only use the words used by the experimenter. If necessary, parents finished the OCDI during the study.

On warm-up trials children were given three familiar objects, two identical and one completely different (e.g., two sheep and a ladybug), to explore for one minute. The experimenter then retrieved all three, put one identical item to one side of the stage, the unique item on the other, held up the second identical item, and said: "This is my (label), can you get your (label)." If the child answered correctly, they were praised enthusiastically. If the child did not pick the identical item the experimenter said, "That's not your (label), this is your (label)," while pointing to the objects in turn. The child was then encouraged to pick up the correct object before the experimenter started the next trial. The right/left placement of the correct object was counterbalanced across trials. Two correct responses were required before continuing to the novel object trials.

Novel object trials proceeded identically: the experimenter gave the child an exemplar, a shape-match test object and a material-match test object to explore for a minute, touching all the objects to prompt attention to each as necessary. Following this familiarization, the experimenter placed the test objects on either side of the stage, held the exemplar up, and said, for example, "This is my zup; can you get your zup?" while looking directly into the child's eyes. When the child responded, the experimenter replied with neutral praise, and removed the objects. If no choice was made within 15 s, monitored via the digital timer, two re-prompts, each 15 s apart, were given before the experimenter removed the objects and started the next trial. The 16 total trials pitted each shape-match test object against each material-match in a set. Set and trial order and left/right position of objects were counterbalanced across children.

2.4 | Coding

Behavior was coded offline, frame-by-fame, by trained assistants using DataVyu (DataVyu Team, 2014). After the experimenter- and side-view videos were synchronized, a first coding pass marked the beginning and end of all trials and broke them into familiarization, presentation, and test sections (Figure 1). A second coding pass broke the test section of each novel object trial into sections relative to the prompt: before, during and after. "During" was further coded to specify the individual components of the naming event including "Label start," "Label object name," "Prompt start," and "Prompt object name."

A third coding pass used GoPro video to code children's looking as right, left, up, or off/not towards objects or camera. Because the exemplar was near the experimenter's face during naming, looks to the experimenter and exemplar could not be distinguished. A fourth coding pass used the side-view camera to determine the child's choice as either the shape-match test object, the material-match test object, or no response. A fifth pass used the experimenter-view and GoPro video to code children's touches during familiarization. When multiple objects were held at once, each object was marked as touched. Coding passes were done in order with different coders coding looking and children's selections. Twenty-five percent of sessions were double coded for reliability with high agreement for all passes: 100% for trial breakdown, 85% for language sections, 92% for looks, and 97% for children's choices. Disagreements were resolved by review of the coding manual and re-coding followed by joint review and discussion if disagreement persisted.

2.5 | Data processing

To calculate the proportion of shape and material choices during the NNG task, 48 "no response" trials were removed (5% of the data) from 23 different children with a max of seven trials from a single child. Data from eight of the 66 participants were excluded for failure to complete more than 8 of the 16 total trials, leaving data from 58 children. Additionally, data from three children whose vocabulary development was more than 1.5 standard deviations from the mean for their gender was removed, as children with slower vocabulary development have been shown to perform differently in NNG tasks (Colunga & Sims, 2016; Perry & Kucker, 2019). These data are examined separately, although additional analyses including these outliers revealed the same pattern of results reported below with the remaining 55 children (see Supplemental Materials). Frame-by-frame looking codes were processed using eyetrackingR (Forbes et al., 2021), which calculated the proportion of looks to the two test objects and "up" and "off" in each 100 ms bin. Regression analyses were conducted in R (R Core Team, 2020).

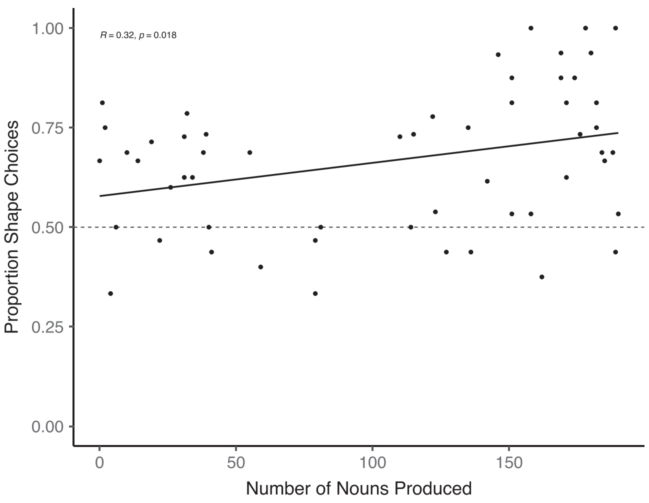

FIGURE 2 Proportion shape responding by productive noun vocabulary size. Solid line represents best fit linear regression. Dashed gray line represents chance level responding (.50).

3 | RESULTS

We evaluate three hypothesized relations between the naming event in the NNG task and children's attention to shape: the name cues attention directly to shape, the name stimulates a more deliberative comparison process, or children have a bias to attend to the shape of solid objects that is independent of the naming event. To do so we examined three aspects of children's visual attention in the task: the time course of gaze dynamics to the exemplar and test objects before and after the naming event, children's looking transitions after the naming event, and differences in attention during the familiarization period of each trial. We also examined how these behaviors were influenced by productive noun vocabulary size, based on similar relations in prior studies (Samuelson & Smith, 1999).

We first ask if children demonstrated a shape bias in their noun generalizations and whether this was related to vocabulary development. The sample had a mean total productive noun vocabulary of 105.84 words, (sd = 67.64, median = 123). We ran a linear model predicting the proportion of shape choices by a full factorial of noun vocabulary (continuous, centered and scaled), gender, stimulus set, and set order as independent variables. Proportion shape choices was centered by subtracting 0.5 from all scores to enable comparison of the intercept to chance. Stimulus set and set order were not significant predictors and were removed. The intercept of the final model was significant, $t(51) = 7.41$, $p < .001$, suggesting an overall bias to attend to shape when generalizing novel names. There was also a significant main effect of vocabulary, $t(51) = 2.60$, $p = .011$ (see Figure 2) thus, as in prior studies, children's tendency to select the shape-match object was related to the number of nouns in their productive vocabularies. No effects involving gender were significant.

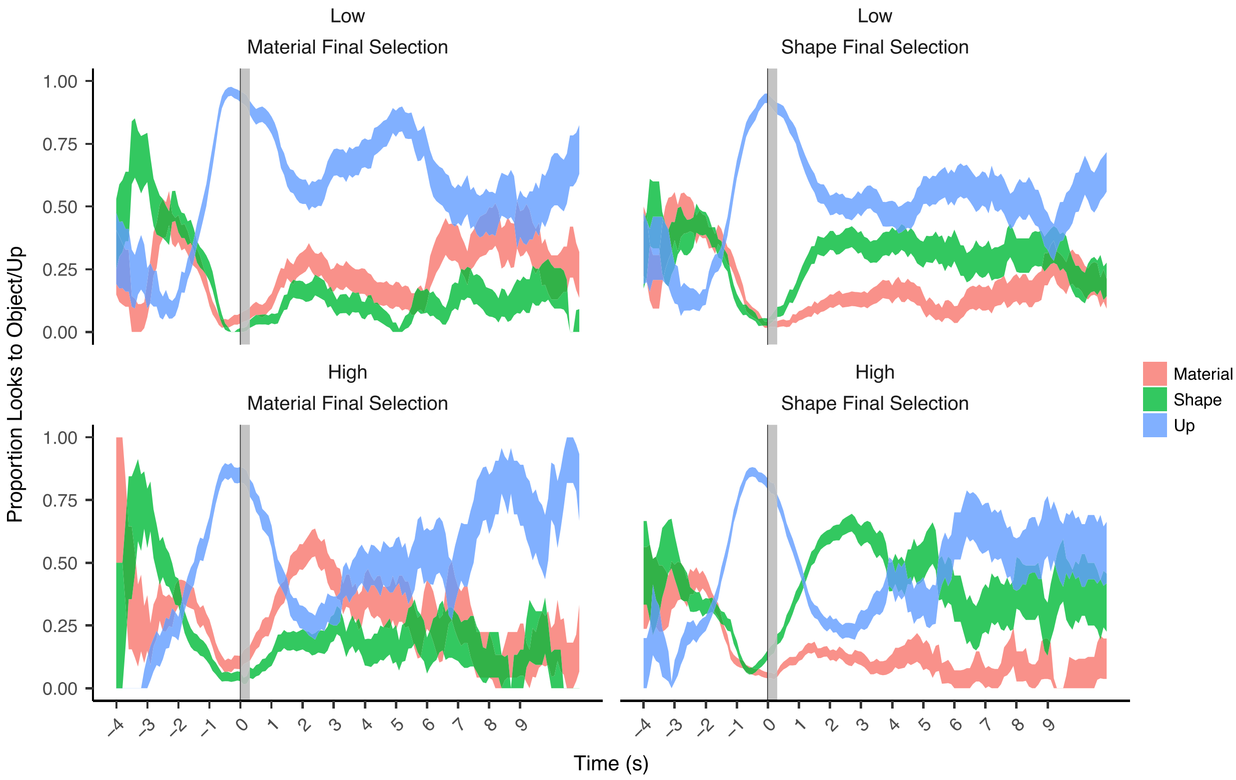

FIGURE 3 Average time course, across sets and trials, of looking to the shape- and material-match test objects and the exemplar for children with Low (<93) and High (>93) productive noun vocabulary groups (see Supplementary Materials for details). Data are grouped by trials ending in selection of the material-match (left) or shape-match (right) test object. Black line indicates the point in the naming event when the novel name was first said. Gray bar indicates beginning of the "after" analysis window. Note that grouping by vocabulary is for visualization only; vocabulary was a continuous variable in analyses. The figure captures 75% and 93% of trials by the Low and High groups, respectively.

3.1 | Looking time course

Figure 3 shows the time course of looking to the exemplar and test objects before and after the naming event grouped by children's final generalization selections and vocabulary level (for visualization purposes, see Supplementary Materials for details). The black line indicates word onset. The "after" analysis window was 300ms from name onset (c.f., Fernald et al., 2008; gray bar) until a generalization selection was coded. Because children were allowed to respond freely this window varied. It was negatively correlated with vocabulary, $R = -0.36$, $p < 0.001$, thus children with larger vocabularies took less time to generalize the novel noun.

All children looked equally to the shape- and material-match test objects before the naming event (see also Figure 4) and looked up to the exemplar and experimenter when cued. When the name was said, children with more nouns in their productive vocabularies looked to the shape-match test object and then up to the experimenter on the 72% of trials on which they selected the shape-match. These children looked to the material-matching test object before looking to the experimenter on the smaller number of trials ending in a material selection (28%). In contrast, children who said fewer nouns did not look to either test object more than the exemplar, although of the two test objects there appears to be some bias for the object that was eventually selected.

We were unable to run growth curve models on the time course data because trial lengths varied across children. Thus, we calculated the proportion looking to the shape-matching test object out of the total looking to the test objects (Figure 4) and ran separate generalized linear models with a beta-binomial link function on the before-naming and after-naming data predicting this proportion by the interaction of vocabulary (continuous) and final selection with random intercepts for participants. The model of the before-naming data revealed no significant main effects or interactions, all $|z\text{'s}| < .50$, $p > .01$. The intercept was also not significant, $z = 0.866$, $p = .39$, suggesting the proportions were not different from chance responding and thus looking to the two test objects was equal before the naming event.

The model of the after-naming data revealed significant main effects of final selection, $z = 12.02$, $p < .001$ and a significant interaction between vocabulary and final selection, $z = 2.47$, $p < .05$. Follow-up models predicting proportion shape responding by vocabulary with random intercepts for participants on the data from trials ending in shape and material selections separately, revealed a significant intercept, $z = 10.60$, $p < .001$, and effect of vocabulary, $z = 2.04$, $p < .05$ for trials ending in shape selections, but only a significant intercept, $z = -6.80$, $p < .001$, for trials ending in material selections. These models suggest that after the naming event children looked to the object they eventually selected and this was related to

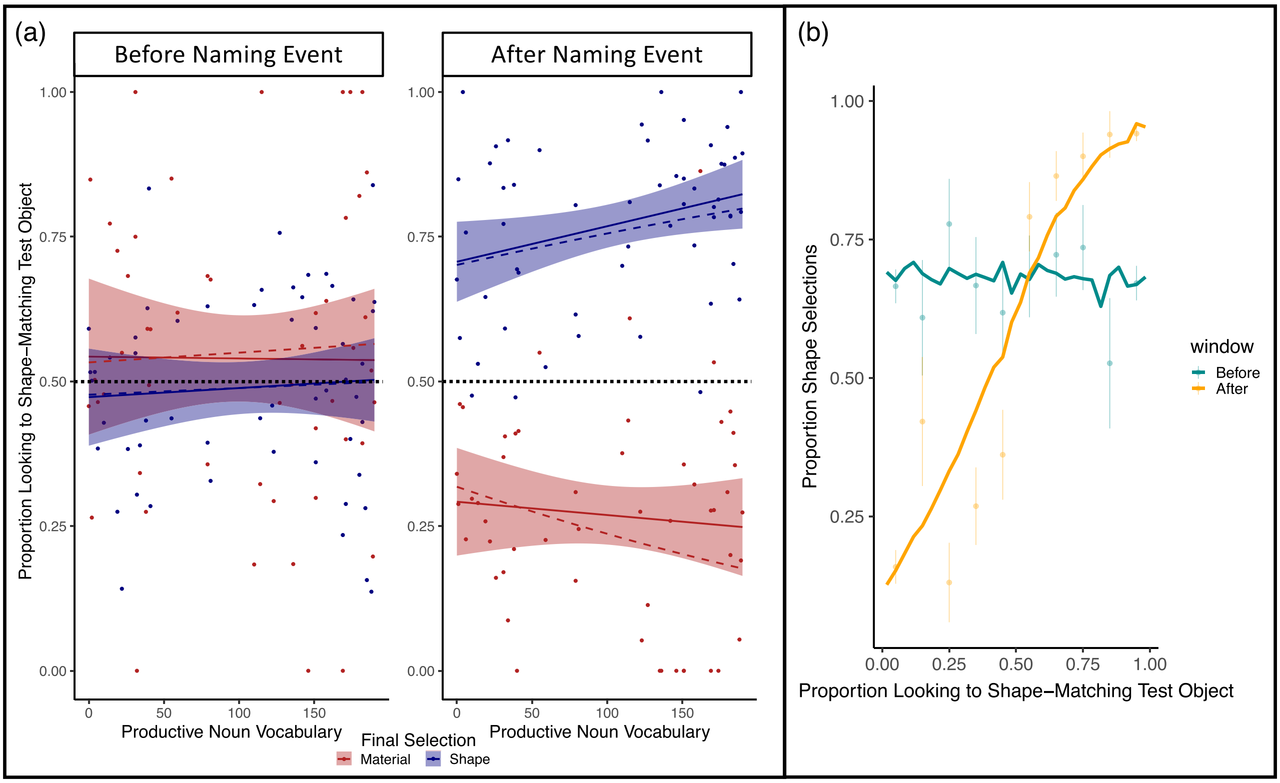

FIGURE 4 (a) Proportion looking to the shape-match test object by productive noun vocabulary size, before and after the naming event. Dashed colored lines are model predicted data. Dashed black line indicates equal looking to the shape- and material-match test objects (0.50). (b) Relation between looking to the shape-match test object before and after the naming event and selections of the shape-matching test object.

vocabulary, but only when the name was generalized by shape similarity. Finally, we examined whether looking predicted children's choices (Figure 4b). Mixed-effect models with a binomial link predicting children's final selection by proportion looking to the shape-match test object revealed that looking after the naming event, but not before, strongly predicted generalization, z = 14.50, $p < .001$. Together then, the looking time course suggests that the naming event cued attention to the selected object, especially when this was the shape-match test object and when children had more nouns in their productive vocabularies.

3.2 | Looking transitions

To examine whether the naming event cued a deliberative comparison process we ran a series of linear models with a gamma link function predicting the number of transitions after the naming event by productive noun vocabulary, where children were looking when the name occurred (at the exemplar or off), and final selection. Model comparison resulted in a final model predicting transitions by productive vocabulary (continuous) only, z = -3.098, p = 0.002, with random intercepts for participants. As can be seen in Figure 5a, the number of transitions decreased as vocabulary increased. This suggests the naming event stimulated more comparison of the objects in children with smaller vocabularies.

We also examined "reaction time"—how long it took children to switch looking from the exemplar to the shape-or material-match test object on trials that started with looking to the exemplar (83% of trials). Model comparison eliminated final selection and test object as predictors, resulting in a final model predicting reaction time by productive noun vocabulary (continuous) only, $t(52.03) = -3.225$, $p = 0.002$ with random intercepts for participants. As can be seen in Figure 5b, reaction time decreased as vocabulary increased. Thus, children who produced more nouns looked to the selected object more quickly and did less comparison of the test objects, while those who produce fewer nouns compared the stimuli more.

3.3 | Attention during familiarization

Finally, we asked whether children had a more general bias to attend to the shape-match test object by examining the proportion of time during the familiarization period children spent freely exploring the exemplar and test objects before the trial began. The mean length of familiarization was between 12.16 – 75.35s, M = 29.21s and was not correlated with vocabulary ($p = .57$) or age ($p = .26$). Initial linear mixed-effects models included final selection and vocabulary (continuous), but model comparison suggested a model with a significant effect of object, χ^2 (2) = 39.93, $p < .001$, and random intercepts for participants was best. Children explored the two test objects equally and more than

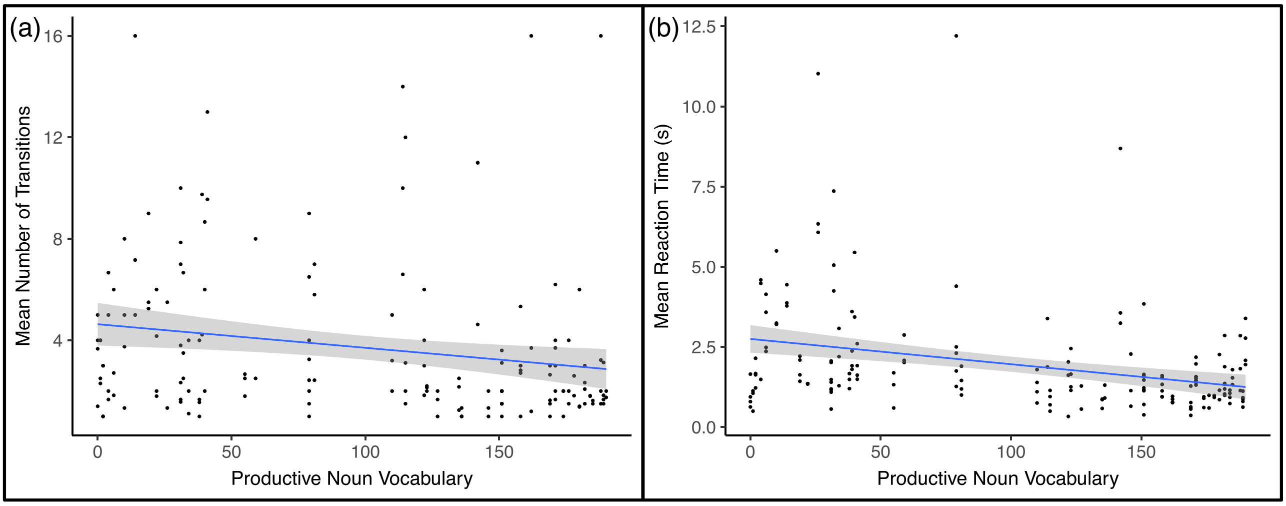

FIGURE 5 (a) Relation between the number of looking transitions after the naming event and productive noun vocabulary. (b) Relation between reaction time to look at the shape or material test object and vocabulary on the 76% of trials (614 of 808) with a first look to the exemplar following the naming event.

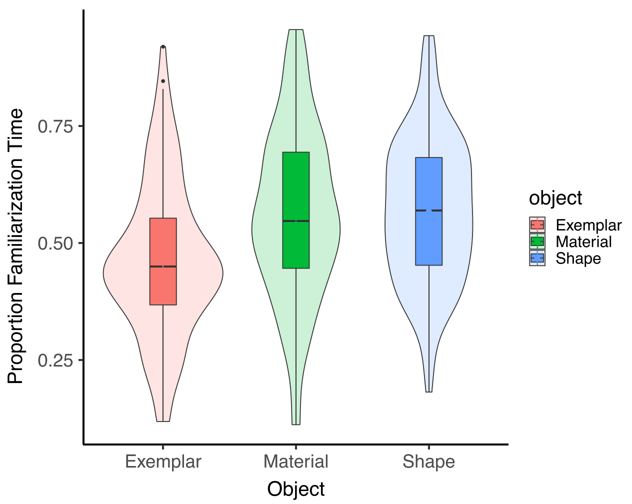

FIGURE 6 Proportion of familiarization time spent exploring each object. Note that because children often touched or handled more than one object at once these proportions do not sum to 1.

the exemplar (Figure 6). Thus, there is no evidence of a bias to attend to the shape-match test object prior to the naming event.

4 | DISCUSSION

Words and attention are inexorably linked. As we listen to the language around us our gaze moves to fixate the available people, places and things being mentioned—a fact used as the basis of many tests of infant, child, and adult cognition. Studies of infant and toddler categorization have shown that *novel*, unknown, nouns can also influence patterns of visual exploration, suggesting that more abstract aspects of children's linguistic knowledge influence attention. Indeed, the 17- to 31-month-old children in our study demonstrated a bias to attended to shape similarity when generalizing *novel* nouns.

We replicated prior findings that attention to shape increased with the number of nouns in children's productive vocabularies but add to this work by showing that while children look at the shape- and material-match test objects equally before the name, those who produce more nouns quickly looked to the shape-match test object after. Interestingly, these children also looked to the material-match test object more quickly after the naming event on the smaller number of trials ending in generalization by material similarity. These data support the hypothesis that the novel name cues attention to the generalization target, most often the shape-match, rather than cueing a deliberative comparison process, at least for children who produce many nouns. Further, the fact that children attended equally to the shape- and material-match test objects during the object familiarization period before the naming sequence suggests that their attentional bias was cued by the naming event.

That increased attention to generalization targets and fewer looking transitions following the naming event were both related to the number of nouns in children's productive vocabularies can be seen to support the proposal that the attentional cuing of novel names is learned during vocabulary development. Smith et al. (2002) proposed that because many of the first words that young English-learners acquire are names for categories of solid objects whose members share similar shapes (e.g., "spoon," "chair") their attention is biased to shape in the context of a naming event with a solid object. However, the data presented here also point to a developmental progression in the influence of novel words in directing attention. Although children who knew fewer nouns often generalized novel nouns by shape similarity, they took longer to make selections, were slower to look to the shape-match test object and transitioned more between the objects following the naming event. These children were also slower to look to the material-match test object on trials ending with a selection of that object. These findings all suggest that for these children the name may cue a more deliberative process of comparing stimuli to apply conceptual knowledge to the generalization decision.

The nature of this deliberative process will be an important target of future work to understand how words guide attention and children's few-shot generalization abilities. While the data are consistent with the proposal that children compare stimuli to determine the kind of thing they are, it is also possible the greater number of looking transitions shown by these children is indicative of a need to refresh the working memory representation that supports directed visual exploration. This latter possibility fits with Vales and Smith's (2015) proposal that the influence of names on preschoolers' visual search (Vales & Smith, 2015), visual sampling (Carvalho et al., 2018), and object identification (Vales & Smith, 2018), stems from improved working memory representations of visual stimuli created when names are provided. However, while the contribution of working memory to vocabulary development is well established, the more specific contribution of *visual* working memory requires more investigation (Pickering et al., 2021).

It is also possible that rather than vocabulary size differences creating differences in attention, a visual attention system that prioritizes attention to shape has contributed to the development of a larger vocabulary. Indeed, prior work suggests that training children to attend to shape accelerates vocabulary development (e.g., Samuelson, 2002; Smith et al., 2002). In this way then, the children in our sample with smaller vocabularies may know fewer nouns because not being quickly cued to the generalization target makes noun learning more difficult. This suggestion fits with recent data examining the vocabulary structure of "late talker" toddlers, those below the 15th vocabulary percentile for their age and gender. Perry, Kucker, et al. (2022) found that late talkers who have a smaller proportion of nouns naming categories of objects organized by shape similarity in their vocabulary are more likely to continue to be slow to learn nouns. Additionally, children with a diagnosis of Developmental Language Disorder are more likely to have had a smaller proportion of names for categories organized by similarity in shape in their vocabulary as toddlers.

These possibilities are not easily separated and the relationship between vocabulary and attention is likely not unidirectional. Rather, both may be part of a cascade of processes that are co-evolving and mutually reinforcing. The fact that concrete objects are easier to pick up and manipulate means both that children have increased experience with them, experience that helps to train the young visual and attentional system, and also that parents and children talk about solid things more so their labels more frequent in the input (e.g., Perry, Custode, et al., 2022). This then influences what words enter the vocabulary first and biases what things are easier to learn next (e.g., Hills et al., 2010). And with each step in this cascade there is the possibility of interactions between word learning mechanisms and perceptual mechanisms such that one feeds the other creating a snowballing process that supports future learning. In such a cascade, however, there is also the chance for differences between children to emerge with some differences leading to less future learning and potential developmental delay. This cascade would also likely involve the action and development of multiple additional cognitive processes such as memory, response inhibition, and speed of processing (see, e.g., Samuelson, 2021). Indeed, current work in multiple laboratories, including our own, is investigating the relations between such processes and vocabulary development.

Beyond word learning, the centrality of visual exploration processes to many studies of early cognitive development, including studies that examine how words modulate attention, makes it clear we also need detailed understanding of the processes that determine children's gaze dynamics. Formal models may be particularly useful here, especially those that make explicit proposals of how memory and attention processes create visual exploration and how words change the operation of such systems. For example, Bhat et al. (2021) presented a model of autonomous visual exploration in preferential-looking tasks, and captured performance in multiple studies of infant (and adult) word learning. Generalizing such a model to the NNG task would enable concrete tests of how even novel, recently encountered, words become able to cue attention to specific object properties as vocabulary grows.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data, coding manual, and full analysis scripts are publicly available on OSF (https://osf.io/45m2p/?view_only=b5d75008430d4f9eadd3b5f04d55bb42) and GitHub: https://github.com/developmentaldynamicslab/Bakopoulou_etal_LWL_NNG.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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