

**Looking for wugs in all the right places:
Children's use of prepositions in word learning**

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Author Note

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Abstract

To help infer the meanings of novel words, children frequently capitalize on their current linguistic knowledge to constrain the hypothesis space. Children's syntactic knowledge of function words has been shown to be especially useful in helping to infer the meanings of novel words, with most previous research focusing on how children use preceding determiners and pronouns/auxiliary to infer whether a novel word refers to an entity or an action, respectively. In the current visual world experiment, we examined whether 28- to 32-month-olds could exploit their lexical semantic knowledge of an additional class of function words—prepositions—to learn novel nouns. During the experiment, children were tested on their ability to use the prepositions *in*, *on*, *under*, and *next to* to identify novel creatures displayed on a screen (e.g., *The wug is on the table*), as well as their ability to later identify the creature without accompanying prepositions (e.g., *Look at the wug.*). Children overall demonstrated understanding of all the prepositions but *next to*, and were able to use their knowledge of prepositions to learn the associations between novel words and their intended referents, as shown by greater than chance looks to the target referent when no prepositional phrase was provided.

Keywords: syntactic bootstrapping, word learning, prepositions

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1. Introduction

Word learning is no easy feat for young children (e.g., Johnson & White, 2019). Setting aside the obvious challenge of identifying word forms in the first place, given that word boundaries are not neatly demarcated in continuous speech (e.g., Cole & Jakimik., 1980), researchers have long noted the added difficulty children face—even when they *have* successfully identified a word form—of deciding what that word actually refers to in the local context (Quine, 1960). Initially, children may rely primarily on extra-linguistic strategies to help assist them in the task of restricting the referential domain, including cognitive heuristics such as the whole-object assumption (Markman, 1990), knowledge of pragmatic cues (e.g., pointing and eye gaze; Baldwin, 1990), the principle of mutual exclusivity (Markman & Wachtel, 1988), and attention to contingencies between word forms and objects in context (Gleitman & Trueswell, 2020; Gograte, 2010; Jesse & Johnson, 2016; Smith & Yu, 2008). But once children accrue enough linguistic knowledge, they additionally begin to deduce the likely meanings of novel words through more linguistic means (e.g., Gleitman et al., 2005; Goodman et al., 1998; Jolly & Plunkett, 2008; Landau & Gleitman, 1985; Pinker, 1984), with neighboring words and morphemes providing valuable clues as to what a novel word might be referring to.

Given their high frequency and predictability, function words (e.g., determiners, pronouns, auxiliary verbs, etc.; Shi et al., 1998) are among the earliest linguistic units that children exploit to infer the meanings of novel words (Shi, 2014). Shortly after their first birthday, children are sensitive to dependencies between function words and neighboring content words (e.g., Babineau et al., 2020; Höhle et al., 2004; Kedar et al., 2017; Mintz, 2006; Shi & Melançon, 2010; Zhang et al., 2015), and by their second birthday, can infer semantic properties

of novel words based on neighboring function words (e.g., Booth & Waxman, 2009; Bernal et al., 2007; de Carvalho, He, et al., 2019; He & Lidz, 2017; Lidz et al., 2017). For example, a novel word preceded by a determiner indicates to children that the word likely refers to an entity rather than an action, while a preceding pronoun or auxiliary verb suggests the opposite (Waxman et al., 2009). Previous studies on word learning (via function words) have tended to focus on how children use *distributional* (i.e., syntactic) rather than lexical semantic knowledge of function words to guide word learning. For example, upon hearing *Regarde! Elle dase* ‘Look! She is dasing,’ children will direct their attention to a novel action (a female making circles with her arm) rather than a novel entity (a female holding a novel object), not because of the lexical meaning of the pronoun (there is after all one female in both scenes), but because of its syntactic properties (pronouns typically precede action words) (de Carvalho, Babineau, et al., 2019). In the current study, we instead focused on the converse, investigating whether children could use the lexical meanings of function words—in this case the spatial prepositions *in*, *on*, *under*, and *next to*—to learn novel words.

Prepositions, being among the most frequent function words in children’s language input (e.g., Quick et al., 2019) as well as some of the earliest produced words (e.g., Tomasello, 1987), represent a subclass of function words that children may recruit early in acquisition to facilitate word learning. Starting in the first months of life, children begin to show conceptual knowledge of spatial relationships (Antell & Caron, 1985; Casasola et al., 2003; Quinn, 1994), and during the second year of life, begin to understand (Bremner & Idowu, 1987; Choi et al., 1999; Clark, 1973; Meints et al., 2002) and subsequently produce (Tomasello, 1987; Valian, 1986) spatial prepositions, with *in*, *on*, and *under* being among the first to appear (Johnston & Slobin, 1979). Given this relatively rich conceptual understanding of spatial relationships and children’s

understanding/use of several common prepositions starting in the second year of life, and given that children also develop an ability to use function words (e.g., determiners) to learn novel words at around the same time, we predicted that by at least two- to three-years-old, children would be able to tap into this knowledge to learn novel words (i.e., the associations between the novel words and their intended referents).

In the current study, using the visual world paradigm, we tested 28- to 32-month-old's knowledge of the prepositions *in*, *on*, *under*, and *next to*, and, more importantly, their ability to use their knowledge of these prepositions to map novel words to novel objects. During the experiment, children listened to instructions to attend to one of two unfamiliar creatures displayed on a computer screen. In training trials, the instructions included a prepositional phrase uniquely identifying the target creature with respect to a familiar object also on screen (e.g., *The wug is on the table.*). In these trials—which served to teach children novel words as well as test their knowledge of prepositions—participants were expected to fixate more on the target creature compared to the distractor creature after hearing the prepositional phrase (e.g., *on the table*), assuming they could overall use information encoded in the preposition to locate the intended referent. In test trials, we tested children's word learning success, examining whether children could identify the novel words presented in the previous training trials in the absence of an accompanying prepositional phrase (e.g., *Look at the wug!*). If children had successfully associated the novel noun with its intended referent, we expected greater than chance looks to the target creature after hearing the target noun (e.g., *wug*). However, if children were only attending to the prepositional phrases in the training trials and not processing the novel words, then looks to the target creature were expected to be at chance in the test trials.

2. Method

2.1. Participants

We tested a total of 48 28- to 32-month-old children from the Greater Toronto Area ($M_{\text{age}} = 29.56$ months; 28 female), who—based on parental reports—were exposed to English at least 80% of the time and had no diagnosed hearing or language impairments. The majority of children came from mid- to high-SES families. Of the 46 families who provided information about parental education, 76% reported that both parents had received post-secondary degrees, 17% reported one parent completing a post-secondary degree, and the remaining 6% reported that no parents had obtained a post-secondary degree. Forty-two families also provided information of family income: 48% reported family incomes over \$140,000 a year, 40% reported a family income between \$90,000 and 140,000, and 12% reported family incomes of less than \$90,000.

An additional 11 children were tested but excluded from the final analysis because of fussiness (9) and trackloss (2).

2.2. Materials

Four pictures of unfamiliar creatures were used to construct displays, with each creature paired with a phonotactically legal English nonsense or infrequent word (*wug*, *geff*, *kip*, and *nat*) that did not vary between participants. Each display consisted of two creatures presented side-by-side on a white background, with the same two creatures always occurring together (*wug-geff*, *kip-nat*). Displays were accompanied by an audio instruction prompting children to look at one of the two depicted creatures. Each creature served as the target creature in 5 trials (4 training trials and 1 test trial; see Fig. 1 for examples of each trial type), for a total of 20 experimental trials. To counterbalance the location of the creatures for each trial (between participants), two

versions of each display were created, with the target creature occurring either on the left or right side of the screen, resulting in 40 displays total (20 trials per list).

In training trials, where prepositions were used to teach the novel words (*in*, *on*, *under*, and *next to*), displays additionally included two pictures of a common object (table, chair, bucket, or wagon). These served as landmarks for the creatures, who were each positioned relative to an object in order to depict particular spatial relationships. Configurations involving *on* and *under*, for example, showed one creature located on the surface of a chair or table and the other creature directly below an identical chair or table on the other side of the screen (see Fig. 1). *In* and *next to* spatial situations presented one creature partly occluded by a bucket or a wagon, with another creature presented laterally beside another bucket or wagon. Each landmark occurred in 4 trials each across the experiment, twice when the target creature was identified with one preposition, and twice when identified with the other.

Audio instructions were recorded in a sound-attenuated booth by a female speaker in a child-directed voice. Each instruction consisted of 4 components: an initial attention getter (e.g., *hey*), followed by 2 utterances directing children's attention to the target creature, and finally, a question to keep children engaged with the scene. Each component was separated by 750 ms of silence. In training trials, audio instructions took the form of *Look/Wow, the [CREATURE] is [PREPOSITION] the [LANDMARK]. See the [CREATURE] [PREPOSITION] the [LANDMARK]*, followed by *Isn't it cute?*, *Do you like it?*, or *Can you find it?*. In test trials, stimuli began with the greeting *hey*, followed by *Look at the [CREATURE]. See the [CREATURE]? Where is it?*. In training trials, the onset of the first instance of the preposition occurred approximately 2912 ms ($SD = 286$, Range = 2383 - 3295) after the start of the audio, with the second mention of the preposition occurring on average 3547 ms later ($SD = 348$); in test trials, the onset of the critical noun

occurred approximately 2644 ms ($SD = 183$) after audio onset, and the second mention occurred approximately 2263 ms thereafter ($SD = 82$). All recordings were scaled to the same RMS level (70dB SPL). The audio files, as well as the video files, are available on the OSF (<https://doi.org/10.17605/OSF.IO/R3VXS>).

2.3. Procedure

After filling out a language background questionnaire with parents to verify the language status of children as well as their knowledge of the four prepositions used in the experiment (understands, understands and says, or neither), participants were then seated on a parent's lap approximately 550 mm from a 1024 x 768 resolution computer screen while their eye gaze was recorded with an SR Research Eyelink 1000 LCD Arm Mount sampling at 500 Hz. Parents wore headphones with masking music in order to prevent them from influencing their child's behavior in response to the audio stimuli, which were presented through computer speakers positioned next to the display.

After calibration using a 5-point template, children first completed a short practice block consisting of 3 trials (2 training trials and 1 test trial using familiar animals) in order to get them oriented to the format of the experiment, followed by 4 randomly presented experimental blocks—one for each target creature—consisting of 5 trials each (4 randomly presented training trials followed by 1 test trial). Between blocks, children watched brief animations (~5 seconds long) to help keep them engaged with the experiment.

In the practice trials, children were presented with images of familiar animals (a dog and a duck) instead of novel creatures. In one experimental list, the dog's location was identified with the prepositions *in* and *next to*, and in another list with *on* and *under* during training trials.

The location of the dog and duck—whether they occurred on the left or right side of the screen—varied within each list, and were counterbalanced across lists.

Before each trial, one of 3 attention-getters, consisting of a 124 x 100 pixel video of a teetering cartoon image accompanied by a sound, appeared in the center of the screen. If children fixated on the attention-getter within 7 seconds of appearing, the upcoming trial was initiated (otherwise experimenters were prompted to display the attention-getter again or recalibrate). Throughout the duration of a trial, to better hold children's attention, each displayed image (320 x 280 pixels, corresponding to a creature in test trials or a creature + landmark in training trials) zoomed in to 1.25 times its size and back out several times. Rectangular interests areas for the target and competitor images were 400 x 350 pixels, equal to the size of each displayed image when zoomed in.

Within each experimental block (see Fig. 1), children saw 4 randomly presented training trials identifying one of the novel creatures, each using a different preposition (*in*, *on*, *under*, and *next to*). These training trials served to test children's knowledge of each preposition, as well as to teach children the novel word for that block, which was tested in an immediately following test trial. For each participant, the target creature appeared on the left side of the screen in half of the training trials and on the right side for the other half. In the immediately following test trial, children were asked to locate the novel creature identified in the previous training trials without the use of prepositions (*Hey, look at the wug. See the wug. Where is it?*). For each pair of creatures (*wug-geff*, *kip-nat*), the location of the target creature in test trials occurred once on the left side of the screen and once on the right side. Across two lists, the location of the target creature for each particular item was counterbalanced.

2.4. Data Analysis

In training trials, we wanted to confirm that children actually understood the prepositions, and were able to successfully locate the target object; in test trials, we were interested in whether children had successfully associated a novel word to an unfamiliar referent. Specifically, we were interested in whether children became more likely to look at the target creature after hearing each of the two tokens of a preposition in training trials (e.g., *The wug is **on** the table. See the wug **on** the table?*) or after hearing each of the two tokens of an unfamiliar noun in test trials (e.g., *Look at the **wug**. See the **wug**?*). Since the onset of the critical words varied between trials, we performed separate analyses for the first and second mention of each critical word, whereby trials were realigned for each mention so that time 0 corresponded to the onset of the critical word for all trials. For each mention, we limited our analysis to a 2000 ms ranges of time beginning 300 ms after the onset of each mention, primarily because we were only interested in any effects (if they existed) occurring within 2000 ms of hearing the critical word, but also because we wanted to ensure that the analysis of the first mentioned critical word did not overlap with that of the second. Observations were grouped into 50 ms bins, and trials with more than 75% track-loss (8.4%, or 81 trials), where the eye-tracker was unable to detect the child's gaze due to technical issues or looking off-screen, were excluded from the analysis (two participants with more than 75% track-loss in 50% or more trials were also removed). The proportion of looks to the target (out of the total looks to both the target and competitor creature) for each 50 ms bin was computed and then log-odds transformed, with one half of the smallest nonzero value added and subtracted from proportions of 0 and 1 (range = 0.022 to 0.026), respectively, before transformation, in order to prevent undefined values resulting from taking the log of 0.

With the resulting data, we compared the likelihood of fixating the target creature (e.g., the wug) to chance using bootstrapped cluster-based permutation analyses implemented in R, Version 3.6.0 (R Core Team, 2019) with the package `eyetrackingR` (Dink & Ferguson, 2015). While this method has been traditionally used to analyze EEG data, in recent years, it has been successfully extended to visual-world data, the advantage being that it allows for the identification of time ranges for which an effect is significant while at the same time also correcting for multiple comparisons (see Barr et al. 2014; Dautriche et al., 2015; Hahn et al., 2015 for other visual world eye-tracking studies using this method, and see Maris & Oostenveld, 2007 for a description of the method).

Cluster-based permutation analyses were conducted on each 2000 ms time range starting 300 ms after the critically mentioned words (prepositions in training trials and unfamiliar nouns in test trials). For the training trials, we conducted 10 analyses, two looking at each of the two time ranges across all prepositions, and an additional eight looking at each preposition in turn (four prepositions x two time ranges); for the test trials, we ran two more analyses, one for each of the two time ranges, resulting in 12 main analyses altogether. Each analysis consisted of 2 major steps: (1) selecting a time ‘cluster’ (if any) within the 2000 ms range of interest in which neighboring time bins exhibited significantly greater than chance looks to the target creature, and (2) testing the likelihood of observing the cluster identified in (1) from chance.

For step 1, in order to determine whether looks to the novel creatures differed significantly from chance for each time bin, we first created a chance data set to which our data could be compared by duplicating our data set and setting the probabilities for all time bins in all trials to .5 (0 on the log-odds scale). Then, for each time bin, we tested whether the log-odds of looking at the novel creature differed significantly from chance using a mixed-effect linear

regression model, with Chance (Chance/NotChance) included as a fixed effect, and by-subject and -item intercepts included as random effects. Any neighboring time bins with t -values greater than 1.68 (the critical t -value in a one-tailed test with $\alpha = .05$) were then grouped together to form ‘clusters’, with each cluster assigned a value equal to the sum of the t -values in each cluster.

For the next step, we selected the largest cluster identified in the previous step and tested the probability of finding the observed cluster by chance. To do this, we conducted 1000 simulations in which the trial conditions (Chance or NotChance) were randomly shuffled within subjects across the data set. For each simulation, a summed t -value score was computed for the time window of the cluster selected from step 1. The summed t -score from the cluster identified in the unshuffled data were then compared to the distribution of summed t -scores obtained from the 1000 reshuffled tests. If the summed score of the unshuffled data exceeded 95% of the simulated cluster values, then the difference observed in the data was considered to be significantly different from chance. The data and R script are available on the OSF (<https://doi.org/10.17605/OSF.IO/R3VXS>).

3. Results

3.1. Knowledge of prepositions

We first investigated whether children were overall able to recognize the target referents across all the training sessions using their knowledge of prepositions. Fig. 2 shows the proportion of looks to the target creature in training trials. For each time window, the permutation analyses identified significant clusters of time for which children were fixating on the target creature at above chance rates, suggesting that children were indeed able to use their knowledge of prepositions to identify the intended referent (see Table 1 for detailed information about time

course of the identified clusters). Notably, looks to the target creature appear to be numerically above chance even before the onset of the first mentioned preposition, likely because children across the training trials started mapping the novel word to the appropriate creature prior to the test trial. Indeed, an additional permutation analysis looking just at the first training trial in each block ($N_{in} = 59$, $N_{next\ to} = 40$, $N_{on} = 40$, $N_{under} = 37$)—before children had any evidence of which creature the novel label in that block would be associated with—revealed a marginally significant cluster from 1350 – 1950 ms after the onset of the first mentioned preposition (summed- $t = 29.09$, $p = .054$), far beyond the preposition onset, suggesting that the increased looks to the target at the preposition onset collapsed across training trials were due to word learning taking place in previous training trials.

Next, we examined which of the four prepositions actually directed children's attention to the intended referent during training trials, focusing just on the first training trial in each block, where children could not be aided by learning from previous training. With the exception of *next to*, the permutation analyses identified significant clusters of time after the onset of *in*, *on*, and *under* where children fixated the target creature at above chance rates. In the case of *on* and *under*, children began looking at the target above chance after ~1000 ms after the first mentioned preposition onset. Children's use of the preposition *in* appeared later than expected, perhaps due to the atypical nature of the containment scenarios (objects were not fully contained in the bucket/wagon, just partially occluded by them; Meints et al., 2002).¹

¹ Note that since the creatures occurred in yoked pairs (the wug creature always occurred with the geff creature, and the kip with the nat), it was theoretically possible for children to rely on mutual exclusivity rather than on their knowledge of prepositions when learning the second novel creature in each pair. Unfortunately, further subsetting the data by looking just at trials where the first creature in each pair was introduced would have resulted in too few trials for analysis (13 trials for *under*, 23 trials for *on*, 31 trials for *in*, and 22 for *next to*). Given that we do not find strong evidence for mutual exclusivity with the test trials (see analysis below), we do not think mutual exclusivity played a strong role (if any) in children's novel word learning in this experimental context..

This pattern of results corresponded with parental reports of children's preposition knowledge, with *next to* being the preposition that children were reported to have the least familiarity with (see Fig. 3). In the parental reports, caregivers reported—for each preposition—whether their child both understood and said the word, only understood the word but did not produce it, or neither understood nor produced it. Statistical analysis (Fisher's exact test) confirmed that children did not have equal knowledge of the four prepositions, as reported by parents ($p < .001$). Post hoc analyses (Bonferroni-corrected pairwise Fisher's exact tests) conducted with the *pairwiseNominalIndependence()* function in the *rcompanion* package (Mangiafico, 2020) revealed that the distribution of responses for *next to* differed significantly from each of the other prepositions (all adjusted $ps < .001$), while responses for the other prepositions did not differ from one another (all adjusted $ps > .59$). Specifically, parents were more likely to indicate that their children only understood or did not know at all the preposition *next to* compared to the other prepositions, which most children were reported to be able to both understand *and* say. Interestingly, a sizeable proportion of parents reported that their child could understand *next to*, despite the fact that the eye-tracking data revealed that children were not successful in using that preposition to successfully identify the target creature in training trials, suggesting either that parents had over-estimated their children's understanding of the preposition, or that children—while they may have understood *next to* in a more contextually rich environment—were unable to apply that knowledge in the experimental setting. Relatively speaking, however, parental reports accurately identified *next to* as children's weakest preposition, making this one of the first studies to link parental reports of closed class word knowledge to behavioral data (see Supplementary materials for analyses directly correlating

parental reports of children's preposition knowledge, as well as their productive vocabulary more generally, to eye-tracking data).

3.2. Mapping of meaning to novel words

We next examined our main question, whether children—having used their knowledge of prepositions to successfully identify unfamiliar creatures—were able to remember the labels of the novel creatures, and correctly identify the target creature in trials that did not include accompanying prepositional phrases (e.g., *Look at the wug. See the wug?*). Fig. 4 shows the proportion of looks to the target creature after each of the two mentions of the target word in test trials. Approximately 500 ms after the onset of the first mention, the proportion of looks to the target creature begin to diverge from chance, increasing until approximately 1300 ms after the target word onset. The permutation analysis confirmed that the log-odds of looking at the target creature were statistically above chance throughout the duration of a time cluster stretching from 1050 to 2000 ms after noun onset (summed $t = 55.98$, $p < .01$). Similarly, after the second mention of the target noun, a second permutation analysis identified a marginally significant cluster in which looks to the target creature differed from chance, this time stretching from 1200 to 2000 ms after target noun onset (summed $t = 34.54$, $p = .057$). Children thus appeared to have associated the novel creature name (e.g., *wug*) with its correct referent, being able to successfully identify it in test trials without the aid of neighboring prepositions.

Since the novel words and their referents were in yoked pairs (e.g., the brown creature, *wug*, always co-occurred with the green creature, *geff*), it was possible that children's above chance looks to the target were due either to children learning both words in each pair, or learning the first novel word in each pair, and then relying on mutual exclusivity (i.e., the other creature was called X, so this other one must be called Y; Markman, 1989) to learn the second.

While this does not undermine our conclusion that children *did* use prepositions to learn novel words, we nevertheless conducted additional permutation analyses examining just the 1st learned novel word in each yoked pair, thereby excluding the possible influences of mutual exclusivity. Similar to the previous analysis, we observed a cluster of time between 850 and 2000 ms after the novel noun was first mentioned, in which the log-odds of looking at the target creature were significantly above chance, thus demonstrating children's novel word learning without the possible influence of mutual exclusivity (see Fig. 5).

4. Discussion

This is the first study we are aware of to investigate children's use of spatial prepositions to learn novel words, which, in contrast to the function words previously studied, provide spatial (i.e., an object's location) in addition to ontological (i.e., it refers to an entity) information about the intended referent. First, this study showed that 28-month-old children understand the prepositions *in*, *on*, and *under* (but not *next to*), as reflected in greater than chance looks to the target objects after hearing the three prepositions during training trials. This finding is consistent with previous research demonstrating that those three prepositions are among the first prepositions to be learned by children, with other spatial prepositions like *between*, *in front/back of*, and *beside/next to* being acquired later (e.g., Clark, 1973; Corrigan et al., 1981; Johnston & Slobin, 1979). Interestingly, we further showed that parents, while they may have overestimated their children's knowledge of the prepositions, were nevertheless fairly accurate in assessing their children's *relative* mastery of the four prepositions, providing some of the first evidence linking parental reports of closed class word knowledge to behavioral (eye-tracking) data (see e.g., Styles & Plunkett, 2009 for similar work linking children's knowledge of nouns to parental reports).

More importantly, this study showed that young children are able to use their lexical knowledge of spatial prepositions to learn the labels of novel objects. In test trials, without the presence of prepositional phrases (e.g., *Look at the wug.*), children were able to correctly identify the target creature, suggesting that they had successfully associated the novel creature labels in training trials with their respective referents. Given that some prepositions (e.g., *in* and *on*) appear quite frequently in infant-directed speech (e.g., Quick et al., 2019) and become part of toddler-aged children's core vocabulary (Banajee et al., 2003), they may play a more important role in children's word learning than previously considered. In fact, our results showing that children can learn nouns from prepositions, interpreted alongside other studies showing that children can learn new prepositions from neighboring noun arguments (Casasola et al., 2004; Fisher et al., 2006; Landau & Stecker, 1990), suggest that children might have a rather sophisticated understanding of the relationships expressed between prepositions and their arguments, which could be useful in learning other types of relational terms (e.g., verbs).

While this study provides evidence that children can use prepositions to help form associations between novel objects and words, it is less clear exactly how this process works. Certainly hearing a familiar preposition directs children's attention to a spatial configuration consistent with that preposition. However, once children have identified the target referent using their knowledge of prepositions, it is not obvious how they then succeed in mapping the novel word to the intended referent. In the current study, children heard the novel words *before* the prepositions that would allow children to disambiguate what the target referent was (e.g., *The wug is on the table. See the wug on the table.*). It could be that children were able to hold a novel word in working memory, and successfully map it onto the intended referent directly after they heard the upcoming preposition shortly thereafter. Another possibility is that the subsequent

mention of the target creature in the second clause was necessary to help children make the association, once their attention had already been directed to the target creature. Future research will need to examine in greater precision the conditions that are necessary for children to actually map a novel word to a referent once they have used the surrounding context to identify a novel referent.

In sum, this study is the first to show that by 2.5 years of age, children are able to use prepositions to help associate novel words with their intended referents. It adds to a growing literature demonstrating children's resourcefulness when it comes to word-learning, and their ability to exploit a variety of morpho-syntactic features to make inferences about the properties of novel words such as plural marking (Jolly & Plunkett, 2008; Paquette-Smith & Johnson, 2016), grammatical gender (Arias-Trejo & Alva, 2012), the number of semantic arguments in an utterance (Fisher et al., 2006; Naigles, 1990; Yuan et al., 2012), word order (Gertner et al., 2006), and as this study shows, prepositions. Future work will investigate whether even younger children can use prepositions to learn novel words, and whether parental reports of children's preposition knowledge at these younger ages also aligns with children's eye movement behavior.

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Figure Captions

Figure 1. An example experimental block. In training trials (left), unfamiliar creatures were positioned in relation to a third object type (chair, bucket, wagon, or table). In test trials (right), creatures were presented by themselves. In each block, children completed four, randomly presented training trials identifying the same novel creature (e.g., wug) using each of the four prepositions (*in*, *on*, *under*, and *next to*), followed by a trial testing their memory of the novel creature.

Figure 2. Proportion of looks to the target creature in training trials starting from the preposition onset. (a) Displays the proportion of looks across all prepositions, and (b) for each preposition, looking only at the first training trial in each block. The area between the red dashed lines (a 2000 ms time range starting 300 ms after preposition onset) represents the time range in which the analysis searched for clusters. Shaded boxes represent clusters identified by the permutation analysis for which looks to the target creature were significantly above chance.

Figure 3. Parental reports of their child's knowledge of prepositions. Parents reported—for each preposition—whether their child produced it, comprehended it only, or neither

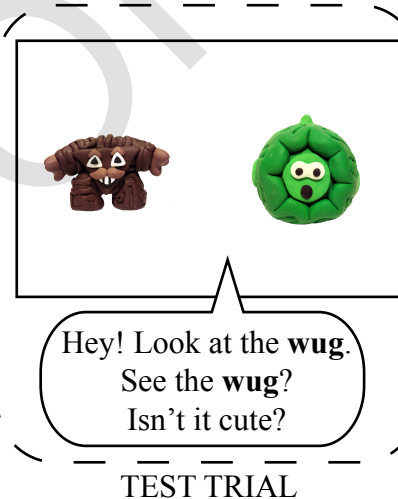
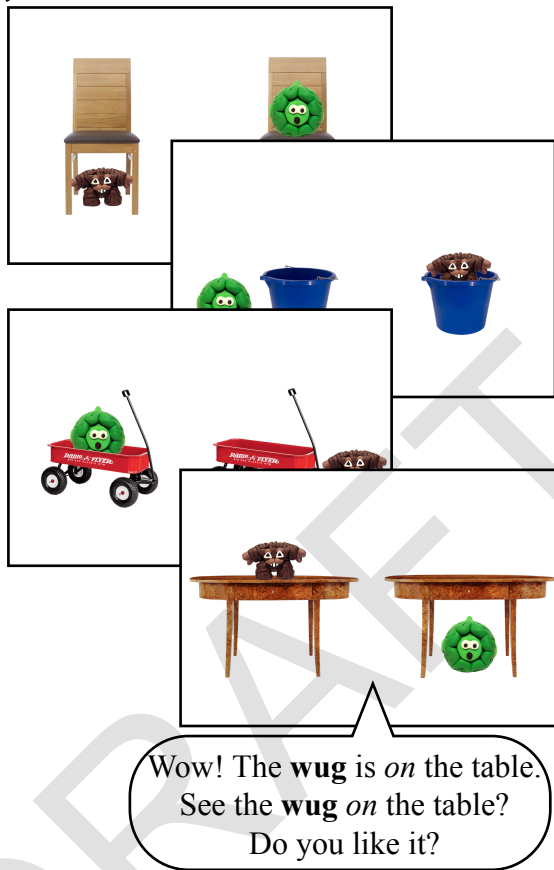
Figure 4. Proportion of looks to the target creature in test trials starting from the creature noun onset. The area between the red dashed lines (a 2000 ms time range starting 300 ms after noun onset) represents the range in which the analysis searched for potential clusters. Shaded boxes represent clusters identified by the permutation analysis for which looks to the target creature were significantly above chance.

Figure 5. Proportion of looks to the target creature in test trials, looking only at children's knowledge of the first learned novel word in each pair. The area between the red dashed lines (a 2000 ms time range starting 300 ms after noun onset) represents the range in which the analysis searched for potential clusters. Shaded boxes represent clusters identified by the permutation analysis for which looks to the target creature were significantly above chance.

Figure 1

BLOCK

x4



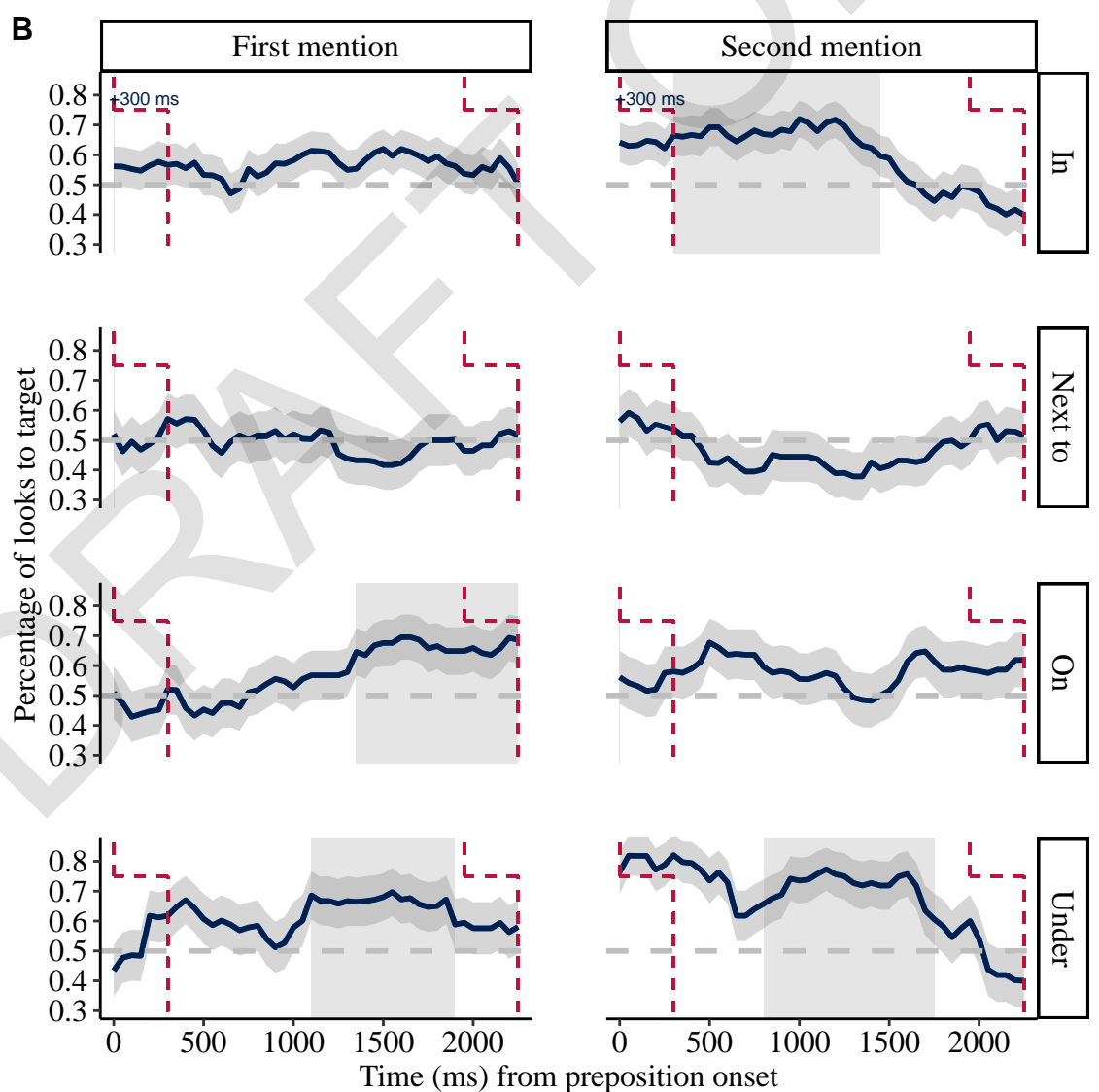
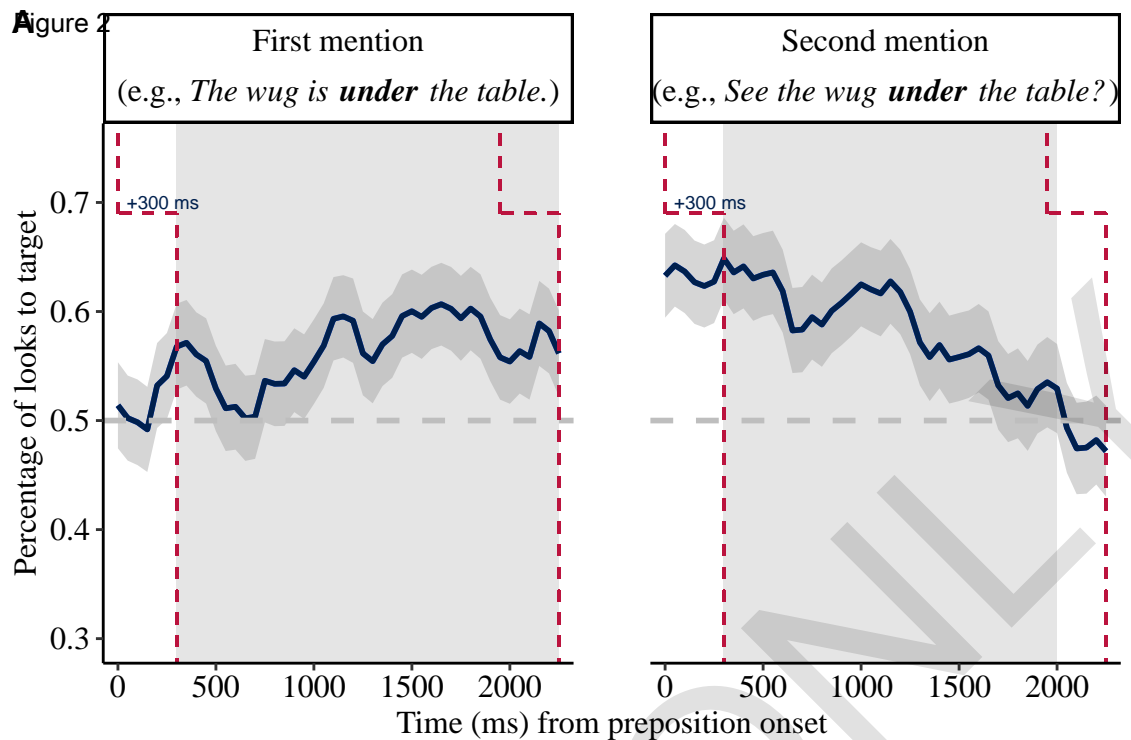
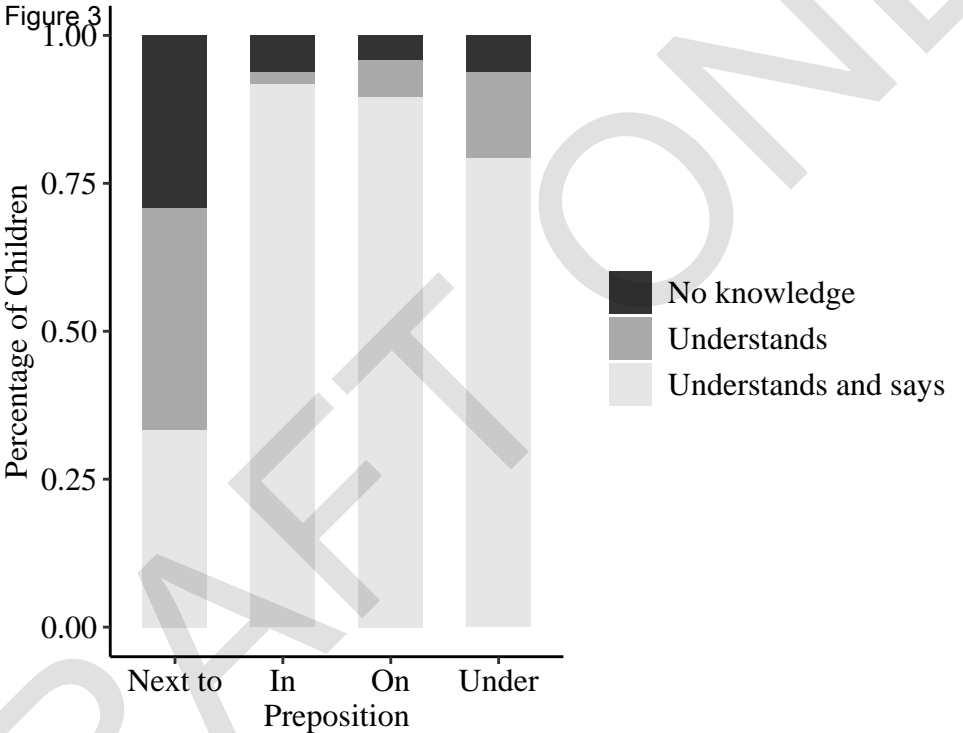


Figure 3



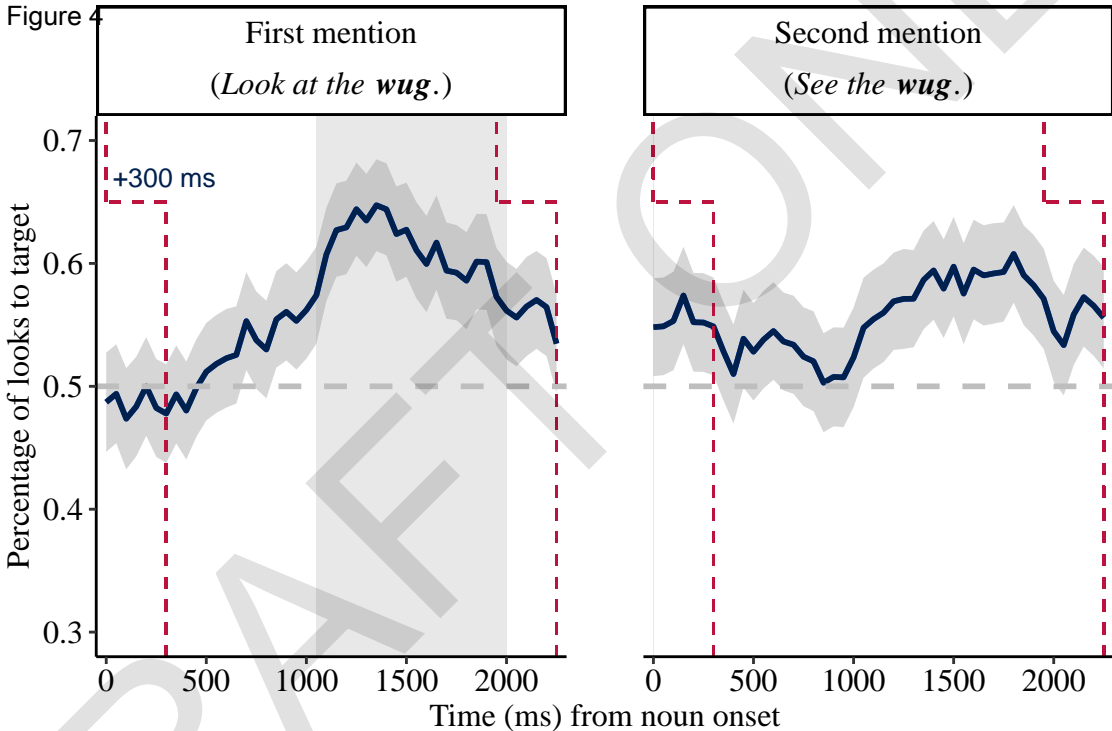


Figure 5

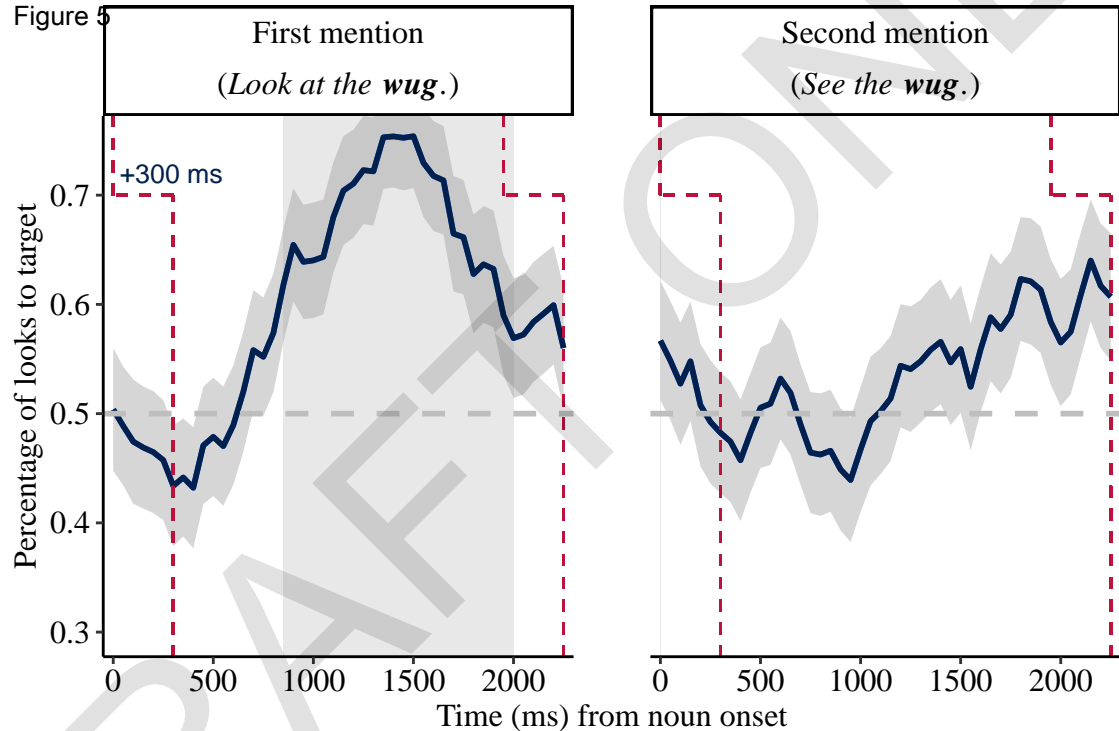


Table 1

Identified clusters and their probability of differing from chance

	1 st mention			2 nd mention		
	identified cluster	summed- <i>t</i>	<i>p</i>	identified cluster	summed- <i>t</i>	<i>p</i>
Prepositions						
all	300 – 2300	190.39	< .001	300-2000	149.44	< .001
<i>in</i>	1600 – 1700	3.58	.49	300 – 1450	63.70	<.01
<i>on</i>	1350 – 2300	40.46	.025	500 – 600	4.36	.45
<i>under</i>	1100 – 1900	33.64	.035	800 – 1750	56.00	.01
<i>next to</i>	No clusters identified			No clusters identified		
Nouns						
creature	1050 – 2000	55.98	< .01	1200 – 2000	34.54	.057

Supplementary materials

1. Correlating parental reports of preposition knowledge with eye-tracking data

For this analysis, we examined only a subset of the training trials (the first training trial in each block), where looks to the target creature could not be attributed to learning in previous training trials. This left us with 176 trials ($N_{\text{on}} = 40$, $N_{\text{in}} = 59$, $N_{\text{under}} = 37$, $N_{\text{next to}} = 40$). For every trial, we coded the level of knowledge that parents reported their child having for the particular preposition encountered in the trial, with values ranging from 0 to 2 (0 = no knowledge of the preposition, 1 = understands the preposition, and 2 = understands and produces the preposition).

We then conducted a permutation analysis (see main text for an explanation of the analysis procedure), but instead of searching for clusters where looks to the target creature significantly differed from chance, we instead looked for clusters in which the effect of Preposition Knowledge was significant. This analysis observed a significant cluster after the first mentioned preposition, stretching from 1300 ms to 2200 ms after preposition onset (summed- $t = 42.19$, $p = .01$), in which looks to the target creature increased as a function of preposition knowledge (i.e., the more knowledgeable children were of the prepositions, the greater the looks to the target creature; see Figure 1). The largest cluster identified after the second mention, stretching from 900 to 1400 ms after preposition onset, was not found to be statistically significant according to the permutation analysis (summed- $t = 19.32$, $p = .097$).

Note that in most of the trials (130/176 trials = 74%), children could reportedly both understand and say the preposition in question. Of the 46 trials in which children had reportedly less mastery of the preposition (either no knowledge or only understanding), the vast majority were with the preposition *next to* (33/46 = 72%). Thus, the analysis essentially captures the fact that children looked less to the target creature when hearing *next to* compared to the other

creatures. Future work should explore this question with younger populations, who would exhibit greater variability in the level of knowledge they have across multiple prepositions.

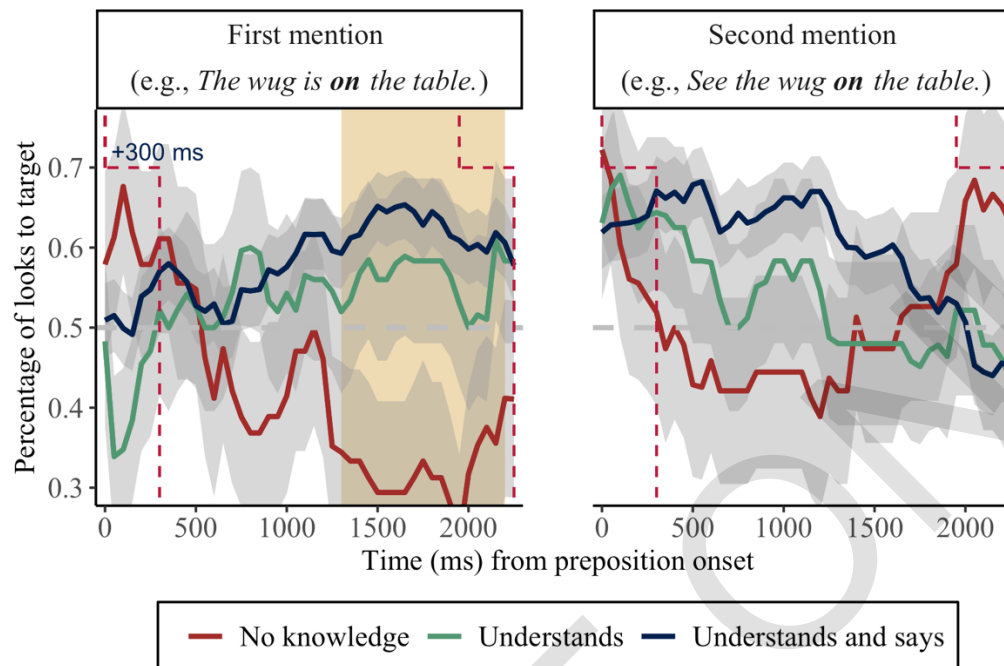


Figure 1. Proportion of looks to the target object as a function of children's reported knowledge of prepositions.

2. Correlating children's vocabulary size with eye gaze behavior

Children's productive vocabulary was measured using the short-form version of MacArthur Communicative Development Inventory (Words and Sentences; Fenson et al., 2000). We summed the number of words (out of 100) that parents reported their children producing, and then conducted permutation analyses to determine whether larger productive vocabulary sizes led to increased looks to the target objects (see Table 1). We did not obtain vocabulary size data from eight participants, so our analyses are restricted to 40 participants.

Table 1*Identified clusters and their probability of differing from chance*

	1 st mention			2 nd mention		
	identified cluster	summed- <i>t</i>	<i>p</i>	identified cluster	summed- <i>t</i>	<i>p</i>
Training trials	1400 – 1800	16.17	.15	300 – 1700	113.84	<.001
Test trials	1050 – 1100	1.74	.59	No positive clusters identified		

3. References

Fenson, L., Pethick, S., Renda, C., & Cox, J. L., Dale, P. S., & Reznick, J. S. (2000). Short-form versions of the MacArthur communicative development inventories. *Applied Psycholinguistics*, 21, 95-116. <https://doi.org/10.1017/S0142716400001053>