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# The Ontogeny of Lexical Networks:

# Toddlers Encode the Relationships amongst Referents when Learning Novel Words

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Abstract

Although the semantic relationships between words have long been acknowledged as a crucial component of adult lexical knowledge, the ontogeny of lexical networks remains largely unstudied. To determine whether learners encode relationships amongst novel words, two-year-olds were trained on four novel words, comprising two pairs of visually similar referents. Participants then listened to repetitions of word pairs (in the absence of visual referents) that referred to either similar or dissimilar objects. Toddlers listened significantly longer to word pairs referring to similar objects, suggesting that their representations of the novel words included knowledge about the similarity of the referents. A second experiment confirmed that toddlers can learn all four distinct words from the training regime, providing evidence that the results from Experiment 1 reflected the successful encoding of referents. Together, these results show that toddlers encode the similarities amongst referents from their earliest exposures to new words.

*Keywords*: word learning, lexical development, semantic networks

Since Quine (1960) pointed out the complexity of mapping a new label to its proper referent, a large literature has emerged concerning how children learn words. Most of this research, however, assumes that the goal of word learning is to map a word to its correct referent or category of referents. While mapping is a crucial component of word learning, a tremendous amount of additional information comes along with hearing a new word. Imagine a child hearing a novel animal labeled for the first time: "That's a *dog*!" Obviously, the child needs to learn the label-referent mapping. However, she could also encode useful information about other nearby objects (such as a leash or a ball); the background context (i.e., a park versus a kitchen); or the similarity between this new animal and her pet cat.



If we consider the full complexity of the perceptual and semantic input available to young children, word learning becomes a multi-dimensional problem that extends beyond label-referent associations. We know that skilled language users exploit this rich structure; adult semantic knowledge is not organized like a dictionary of label-referent pairings. Instead, the lexicon is a complex semantic network that represents relationships amongst words (e.g., McClelland & Rogers, 2003; McNamara, 2005; Steyvers & Tenenbaum, 2005). This has been demonstrated most clearly with the semantic priming paradigm, in which participants are faster to respond to a target word if it is related to a prime word. Adults show semantic priming effects for many types of lexical/semantic relationships, including feature overlap, thematic role similarity, and verb-noun relationships (e.g., Neely, 1991; McNamara, 2005).

Despite extensive research focused on adult semantic knowledge, little is known about the ontogeny of lexical networks. In particular, how do lexical-semantic relationships emerge over the course of word learning? Lexical knowledge continues to develop throughout childhood

(Carey, 1985) and into adulthood (Ameel, Malt, & Storms, 2008), so it is possible that representations of lexical relationships emerge later in the word learning process. On the other hand, infants are sensitive to statistical relationships amongst newly learned words (e.g., Lany & Saffran, 2011), and adults can track multiple levels of statistical information in parallel (Romberg & Saffran, 2012; Yurovsky, Yu, & Smith, 2012). It is thus possible that from their earliest exposures to new words, young children encode not only label-referent associations, but also the relationships amongst the referents. Recent studies have demonstrated that by 21 months of age, infants show semantic priming effects for highly familiar words (Arias-Trejo & Plunkett, 2009). However, we do not know whether young children encode the relationships between the referents of novel words as they begin to learn those words, or alternatively, if individual word representations need to be robust before these connections are encoded. The current study was designed to address these issues.

There are many facets of semantic relatedness that might be encoded by young learners, such as functional or thematic similarity. In the current study, we focused on visual similarity because it is an early organizing feature in non-linguistic categorization (e.g., Behl-Chadha, 1996; Quinn, Eimas & Rosenkrantz, 1993; Sloutsky, 2003). The fact that two-year-olds attend to shape during word learning suggests that visual characteristics are prioritized (i.e., Samuelson & Smith, 2005). Semantic priming studies also suggest that visual similarity is a component of adults' lexical representations (Schreuder, Flores D'Archais, & Glazenburg, 1984; Yee, Ahmed, & Thompson-Schill, 2012). We thus chose to begin our investigation of the ontogeny of lexical relationships by manipulating the visual similarity of novel referents.

In the first study, two-year-olds learned four novel words that consisted of two visually-similar referent pairs. Although they were ostensibly taught object labels, the similarity structure of the referents provided the participants with another type of information that they could incorporate into their representations of the novel words. We then tested participants using an auditory task previously developed to examine toddlers' knowledge of the relationships between highly familiar words (Willits et al., 2012). The question of interest was whether listening preferences for pairs of novel words would be affected by the visual similarity of the referents of those words, in the absence of the referents themselves.



## Experiment 1

The current study was designed to investigate whether toddlers encode the similarity structure of a small artificial lexicon. Toddlers show sensitivity to semantic relationships amongst familiar words by 21 months of age (Arias-Trejo & Plunkett, 2009) and can activate this knowledge in the absence of visual referents by 24 months of age (Willits et al., 2012). Because our task required the activation of novel lexical representations, we tested a slightly older age group (26- to 28-month-olds).

Participants were first trained on four label-object pairs. Crucially, each object was visually similar to one other object and distinct from the other two (see Figure 1). We then asked whether toddlers were sensitive to the similarities amongst the referents of the words they had just learned. To do so, we compared participants' listening times for word pairs that referred to similar objects versus word pairs that referred to dissimilar objects. This method allowed us to examine toddlers' nascent lexical representations in the absence of visual referents, thus tapping into the encoded representations of the words they had just learned.

## Method

### Participants

Participants were 32 full-term monolingual English-learners (16 male) with a mean age of 27;0 months (25;11 - 28;4 months). Eight additional toddlers were excluded from the analyses due to fussiness (7) or an average looking time > 2 SDs from the mean (1).

**Stimuli**

**Training**. The stimuli consisted of 4 novel labels (*tursey, coro, blicket, pif*), each paired with a single novel object image. While the objects were all different, they were organized into two visually similar pairs: two were blue/rounded, and two were red/pointed (see Figure 1). Label-object pairings were counterbalanced across participants.

--Insert Figure 1 around here--

**Testing.** Each test trial consisted of repetitions of a word pair (e.g., *tursey, coro, tursey, coro…)*. Eight trials comprised word pairs that labeled visually similar objects, and eight comprised word pairs that labeled visually dissimilar objects. Counterbalancing ensured that word pairs referring to similar objects for half of the toddlers referred to dissimilar objects for the other half of the toddlers. Referents were not displayed during the test phase.

**Procedure**

Toddlers were seated on a caregiver's lap in a sound-attenuated booth; the caregiver wore blacked-out sunglasses and listened to music over headphones. The training trials were presented on a center monitor. The *training phase* (2.5 min) began with the 4 objects displayed in a grid for 10s. During each subsequent training trial (6s), a single object was displayed on either the left or the right side of the screen and was labeled twice: "*Look at the __! There's a __!*" or "*See the __! This is a __!*" The first two trials used familiar objects (*ball* and *shoe*) to introduce the format. The next 4 blocks each included 4 novel object trials, with each label-object pair presented once per block (randomized).

The *test phase* immediately followed training. Each of the 16 test trials began with a central attention-getter paired with music. Once the toddler looked to the center, the neutral visual stimulus (a spinning pinwheel) began to play on one of two side monitors 90° to the left and right. When the toddler looked to that side, a word pair was repeated from speakers mounted directly below the monitors until the infant looked away for more than 2s, or for a total of 20s. Half of the trials consisted of repetitions of word pairs with similar referents, and the other half consisted of repetitions of word pairs with dissimilar referents. Each block of 4 trials included two similar and two dissimilar trials. After the experiment, parents filled out the MacArthur-Bates Communicative Development Inventory (short form Level II; Fenson et al., 2000).



**Results and Discussion**

The question of interest was whether toddlers' listening times to word pairs were influenced by the visual similarity of their referents (in the absence of those referents). Thus, we compared listening times to word pairs that labeled similar or dissimilar objects. A paired sample t-test revealed a significant effect of trial type (similar vs. dissimilar): $t(31) = 3.91$, $p < 0.001$, $\eta^2 = 0.331$. Toddlers preferred to listen to label pairs referring to similar objects (7.99s; SE = 0.50) compared to labels referring to dissimilar objects (6.54s; SE = 0.38; see Figure 2). We also calculated a preference score for each toddler by subtracting their mean listening time on dissimilar trials from their mean listening time on similar trials. Of the 32 participants, 25 had a positive preference score, indicating that they listened longer on similar trials (see Figure 3).

--Insert Figures 2 & 3 around here--

The results of Experiment 1 suggest that when toddlers are learning new words, they do not just learn the associations between labels and their referents; they also encode relationships amongst the referents. The visual similarity of the objects affected which word-pairs toddlers preferred to listen to, *in the absence of the referents themselves*. Because the label-object pairings were counterbalanced across participants, the pattern of results cannot be due to idiosyncratic preferences for some labels or label pairings over others. The information toddlers encoded about the visual similarities amongst referents affected their behavior in an auditory test.

However, there is an alternative hypothesis that could explain these results without recourse to the encoding of the similarity structure of the referents. It is possible that the toddlers failed to learn the 4 unique label/object pairs during training. Instead, they may have categorized the similar items together, treating their labels as synonyms; or, they simply may have not learned the words robustly enough to distinguish between the visually similar referents. For example, if *tursey* and *coro* referred to the two round blue objects, it could be that toddlers treated the labels as interchangeable or were confused about which word referred to which object. If the data reflect this alternative hypothesis, and toddlers under-learned the lexical structure provided in Experiment 1, the results do not address our original hypothesis concerning the encoding of similarity structure amongst the referents, but instead simply reflect category learning (blue round objects versus red pointy objects). To tease apart these two hypotheses, we conducted a second experiment, designed to determine whether or not the training procedure from Experiment 1 results in the specific learning of all four label/object pairs.



## Experiment 2

This study used the same training procedure as Experiment 1. However, instead of assessing lexical representations using an auditory task as in Experiment 1, we tested word-learning outcomes with a looking-while-listening task (see Fernald, Zangl, Portillo, & Marchman, 2008). We asked whether toddlers can learn all four label/object pairs as distinct lexical entries given the training regimen from Experiment 1. If so, this would support our original interpretation of the results of Experiment 1: namely, that toddlers' listening preferences reflect their newly acquired knowledge about the similarity structure of the referents.

## Method

### Participants

Participants consisted of a new sample of 24 full-term, monolingual English-learners (11 male) with a mean age of 27;8 months (26;11-28;12). Seven additional toddlers were excluded from the analysis due to inattentiveness (4) or experimenter error (3). These participants were comparable to the Experiment 1 participants in their expressive MacArthur-Bates CDI scores (64 versus 67.2 out of 100 possible, $t(54)=0.52$, $p= 0.61$).

### Stimuli and Design

The training stimuli were identical to Experiment 1. On each of the 16 test trials, two of the novel objects were displayed on the bottom left and right of the screen. Toddlers heard a pre-recorded sentence directing them to one of the objects. Half of the test trials contrasted similar novel objects (i.e., either the two blue, round objects or the two red, pointy objects). The other half contrasted dissimilar objects (i.e., one blue, round object and one red, pointy object). These two trial types allowed us to examine the robustness of the toddlers' representations of the novel words. In particular, successful word recognition on the similar object trials requires participants to have encoded the fine-grained details differentiating two perceptual neighbors, whereas successful word recognition on the dissimilar object trials does not.

### Procedure

The training procedure was identical to Experiment 1. The test phase began with two familiar-object trials (shoe and dog) intended to orient participants to the task. Next, participants viewed the novel-object trials in 4 blocks of 4. The test trials began with two objects presented in silence (1.5s). Participants then heard one of the objects labeled in a sentence frame (*"Where's the __?"* or *"Find the __."*). This was followed by an attention getting phrase such as "*Can you see it?"* or *"Do you like it*?" and 1 second of silence.

Each test block consisted of one trial for each label. The blocks were made up of two similar-object trials and two dissimilar-object trials. The target picture (i.e., the picture that was labeled) was presented equally on the left and right side within blocks, and each of the object pictures was displayed equally on the left and right throughout the test phase. Trial order was counterbalanced across participants. After the experiment, the parents filled out the MacArthur-Bates Communicative Development Inventory (short form Level II; Fenson et al., 2000).

**Results and Discussion**

The primary question was whether or not participants could learn four distinct word-referent pairs, given that each object was highly similar to one other object. Looking behavior was coded frame by frame (see Fernald et al., 2008). For each 33-ms frame, we calculated the proportion of trials on which toddlers were looking to the target picture.

To determine whether toddlers successfully learned the word-referent pairs, we compared looking behavior before and after the audio presentation of the target word. If participants learned the word, they should increase looking to the target object after hearing its label. A Baseline window (from 450 ms to 2450 ms) represented pre-labeling behavior. The Target window started at 2750 ms, beginning 300 ms after the noun onset to allow for the planning of eye movements (Fernald et al., 2008), and was 1500ms in duration. We calculated the mean proportion of looks to the target for each toddler across frames during the Baseline and Target windows. Trials were excluded if there were more than ten consecutive frames in which the participant was not attending to the stimuli (32 out of 386 total were excluded).

A paired sample t-test was used to compare looking during the Baseline and Target windows. Participants looked significantly more to the target object during the Target window than during the Baseline window: $t(23) = 4.78$, $p < 0.001$ (see Table 1). This provides evidence that the toddlers learned the novel words. However, as noted previously, there were two types of test trials: dissimilar trials, in which toddlers had to locate the target given one of the blue objects and one of the red objects; and similar trials, which required a decision between either two blue or two red objects. It is possible that the overall learning effect was driven by the easier dissimilar trials.

Follow-up analyses were conducted to examine the dissimilar and similar trials separately. A paired sample t-test comparing the Baseline and Target windows for the dissimilar trials revealed that the participants looked significantly more to the target object during the Target window than during the Baseline window: $t(23) = 3.28$, $p <0.005$ . We found the same pattern for the more challenging similar trials: $t(23) = 3.06$, $p < 0.01$ (see Figure 4 and Table 1). To compare performance on the two trial types, we calculated difference scores for each subject by subtracting baseline window accuracy from target window accuracy for both similar and dissimilar trials. A paired sample t-test comparing those difference scores revealed no significant difference between trial types, $t(23) = 0.41$, $p = 0.69$. These results suggest that our participants' representations of the novel words were robust and included sufficient detail to permit learners to distinguish between the visually similar referents.

--Insert Figure 4 and Table 1 around here--

The results from Experiment 1 left open the possibility that toddlers did not learn distinct label-referent associations for the visually similar objects; they could have encoded only the broad visual features and treated the similar object labels as synonymous at test. A separate word comprehension task was needed to ensure that toddlers could learn the four distinct words from our testing regime. The results from Experiment 2 demonstrate that the toddlers formed a strong enough representation of each word to be able to distinguish it from a visually similar neighbor. This finding supports the hypothesis that the participants in Experiment 1 learned the novel words as distinct lexical items and encoded the relationships between them. The results from Experiment 1, therefore, are likely due to successful encoding of the relationships between similar referents during the word learning process.



## General Discussion

When we think about word learning, we tend to focus on how children acquire the mapping between sounds (or signs) and their referents. However, we know that the links amongst meanings underpin our conceptual knowledge (see McClelland & Rogers, 2003). The current study was designed to take a first step towards understanding the ontogenesis of the associations comprising a semantic network by looking at what toddlers learn about semantic relationships during their *initial* exposure to new words.

In Experiment 1, we asked whether toddlers encode the relationships between word referents when learning novel words. Participants were taught four novel words structured as two visually similar pairs. Toddlers listened significantly longer to word pairs consisting of the labels for visually *similar* referents compared to pairs of labels for visually *dissimilar* referents in the absence of the referents themselves. Because the only difference between the pairs of words was the similarity of their referents, these results suggest that early lexical representations include information about the similarity structure of the words' referents, even for words toddlers have just learned.

To examine the possibility that the results did not reflect the encoding of word relationships, but instead the conflating of labels for visually similar items, we exposed the participants in Experiment 2 to the same training regimen. We found that the toddlers successfully learned the 4 novel word/referent pairings as distinct lexical entries. Together, our two experiments provide evidence that while toddlers are learning novel word-referent associations, they are also encoding the relationships amongst these words.

Our findings are particularly striking because the training procedure is similar to what is used in most traditional word learning studies; it was not designed to highlight the relationships amongst the referents. The training provided ostensive labels for four novel objects, but toddlers learned more than just this one type of association. They are also taking into account other relationships, such as those amongst the referents.

The demonstration that early lexical representations include information about visual similarity amongst the referents can be construed as the referential analog to the neighborhood density effects observed for the sounds of words (e.g., Hollich, Jusczyk, & Luce, 2002). On this view, young learners encode the visual overlap amongst the referents of different words much as they encode the auditory overlap of their labels. If this is the case, then what we know about early lexical representations can inform the study of early semantic representations. For example, Hollich, Jusczyk & Luce (2002) found that 17-month-olds acquired words forms from dense neighborhoods (i.e., words that sound similar to many other known words) more readily than words from sparse neighborhoods. Because our results show that toddlers encode information about visual relationships amongst referents, it is possible that novel objects with many similar neighbors are more easily learned than those in a sparse visual neighborhood. In fact, results from a connectionist model looking at semantic growth suggest that novel words that are semantically associated with many known words are acquired more quickly (Hills, Maouene, Riordan, & Smith, 2010). With the results from the current studies in hand, research can use findings from the auditory domain to advance our understanding of how semantic relationships interact with word learning.

The current results can also help to expand how we think about the word learning literature. The majority of word learning tasks used with infants and young toddlers involve brief training sessions designed to expose participants to novel words, often on a 2D screen. Because of this stripped-down artificial situation, it is unclear whether participants' resulting knowledge is word-like or not. In these lab settings, infants may just be forming an association between a sound and a picture. While this type of association is an important component of word learning and knowledge (e.g., Smith & Yu, 2008; Voloumanous & Werker, 2009), lexical representations are much richer than just associations between labels and objects. Thus it is important to determine the character of novel word representations acquired in experimental paradigms. The current study demonstrates that during toddlers' first encounters with novel words, they are encoding more than just the label-object associations. In fact, even in the stripped-down environment of a computerized word learning experimental paradigm, novel word representations include information concerning the relationships amongst words. Our findings thus provide evidence that when we employ traditional word learning paradigms that teach new words in short training sessions, we are indeed investigating novel lexical entries, not just label-object associations.

More broadly, the results from this study show the importance of expanding the study of word learning beyond just the study of how young children learn which labels go with which referents. Researchers can draw from what we know about adult lexical representations to investigate when and how toddlers acquire that knowledge. For example, we know that skilled language users are sensitive to many other types of relationships beyond the visual similarity of referents. Adults' semantic knowledge includes the functional relationships between words (such as "broom" and "floor"; Moss, Ostrin, Tyler, and Marslen-Wilson, 1995). It would be interesting to teach toddlers different kinds of novel words, such as those with overlapping functional or conceptual representations, to determine which types of relationships are encoded in early lexical entries. Similar questions emerge for words across multiple syntactic categories, where relationships between words might be somewhat more abstract. By manipulating the structure of the artificial lexicon, we will begin to further tease out the type of information encoded by young word learners – along with the dimensions of similarity that toddlers fail to encode. Indeed, given the richness of early linguistic, conceptual, and social environments, it is just as important to discover which types of information learners ignore as to discover which types of information they encode.

Researchers have just begun to explore early semantic networks in young children. Notably, the auditory task used in the current study is quite different from other behavioral methodologies that have been used previously, such as the Intermodal Preference Procedure priming task (e.g., Arias-Trejo & Plunkett, 2009). One benefit of our auditory task is that it allows researchers to test word knowledge in the absence of visual referents; this was necessary for the present research question because presenting the toddlers with the referents would have provided them with the exact information that we were trying to assess. Because the auditory task is novel, we hope to further explore this methodology, in conjunction with other techniques such as the IPP priming task, to uncover both the mechanisms behind our effect and the characteristics of young children's semantic networks.

Word learning is not just about mapping a label to its referent and making the appropriate extensions to other similar referents. Children must also learn how different words are semantically related to each other. As adults, we know many important relationships between words, and this connectedness is a crucial component of our semantic and linguistic systems. Investigating the emergence of these relationships will help us more fully understand the early word learning process. By demonstrating that young children encode the visual similarity of referents during word learning, this study contributes to our understanding of word learning and presents a paradigm that can be used to further investigate early encoding of semantic relationships and how this knowledge interacts with early word learning.

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## Author Contributions

Both authors developed the study concept and design. Testing, data collection, data analyses, and interpretation were performed by E.H.W. under the supervision of J.R.S. Both authors drafted and revised the manuscript.

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Table 1

*Mean Proportion of Looks to Correct Object in Baseline and Target Windows*

| Trial type | Baseline Mean (SE) | Target Mean (SE) |
|---|---|---|
| All | 0.50 (0.009) | 0.60 (0.022) |
| Dissimilar | 0.51 (0.018) | 0.62 (0.031) |
| Similar | 0.49 (0.013) | 0.59 (0.025) |
| Similar - Red | 0.47 (0.028) | 0.61 (0.041) |
| Similar – Blue | 0.50 (0.025) | 0.61 (0.032) |

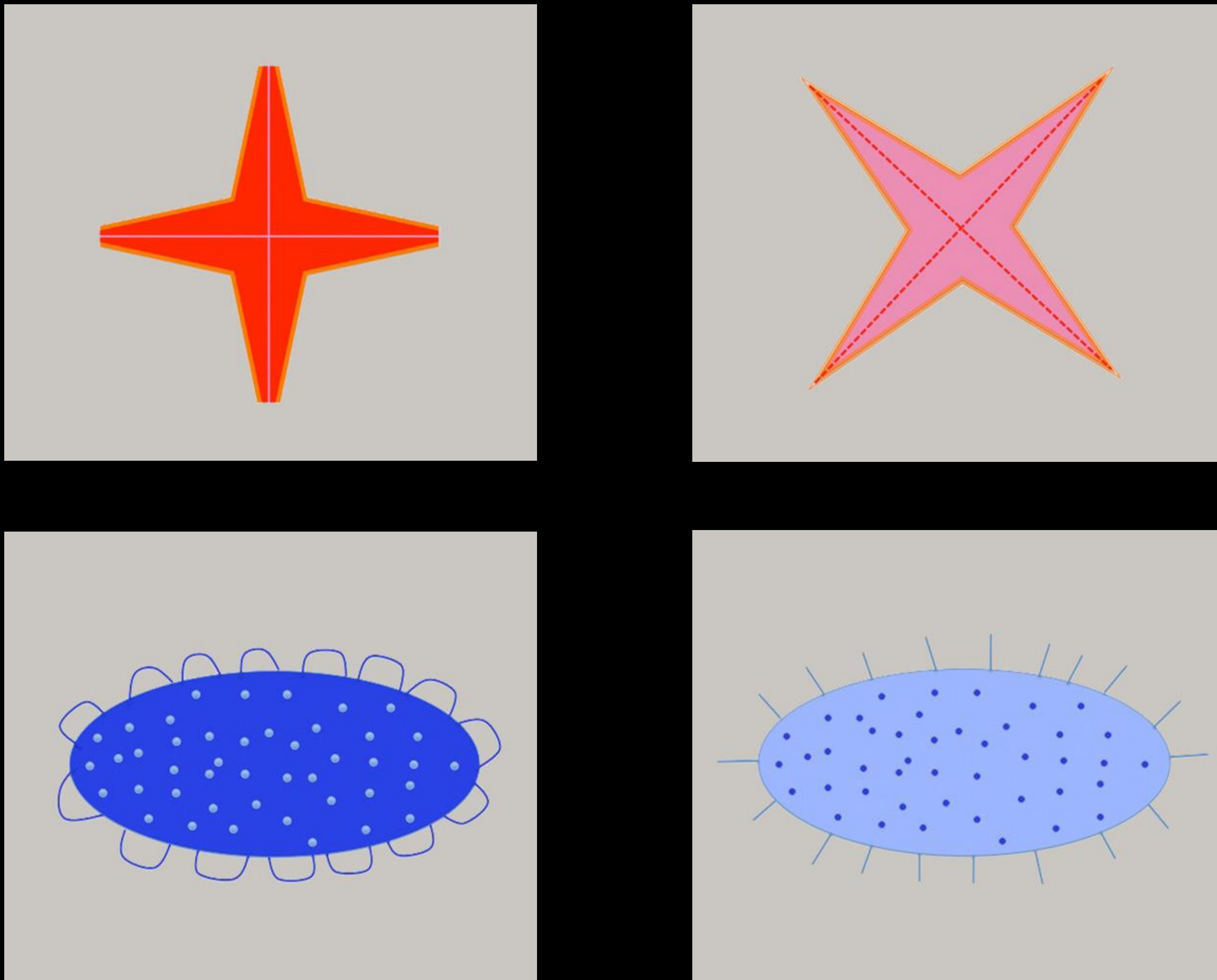
Figure Captions

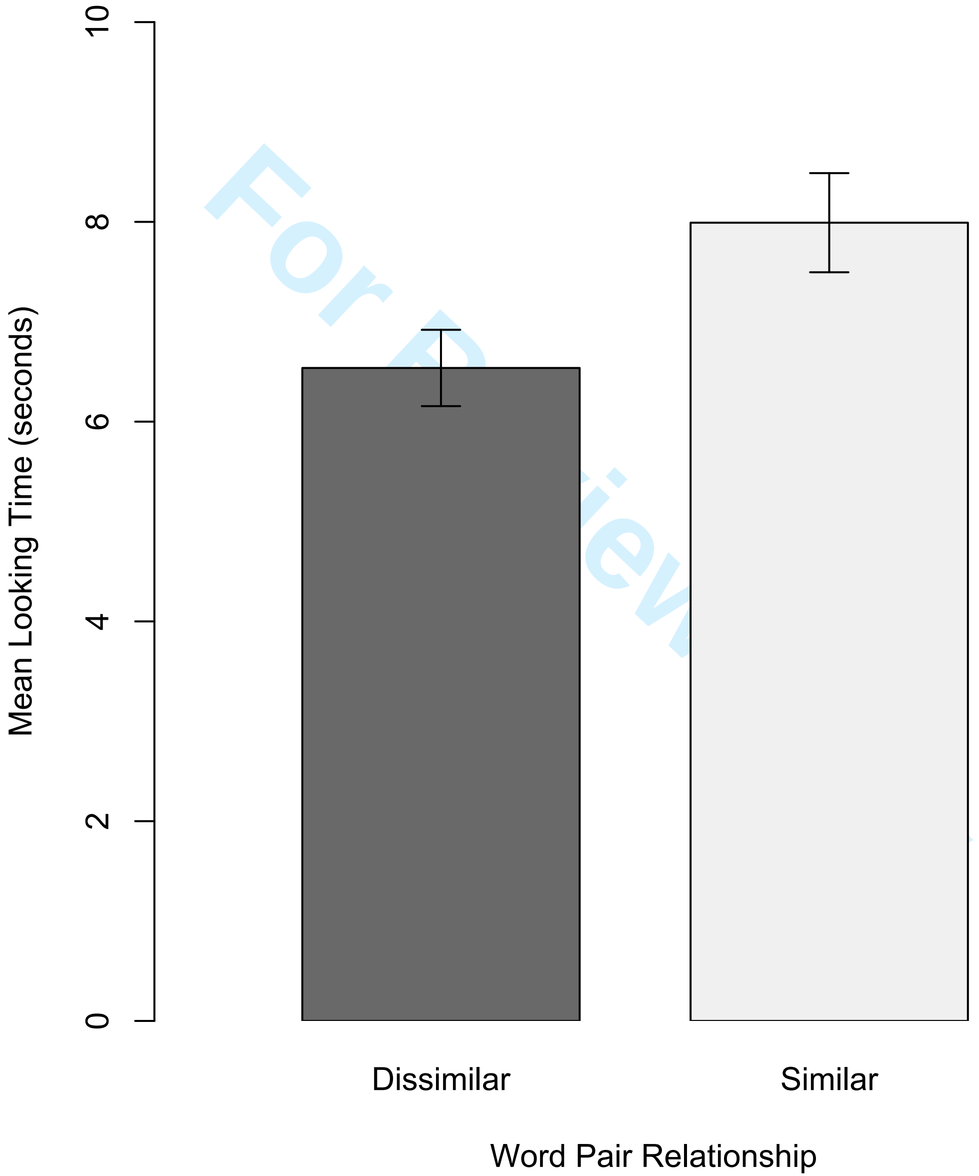
*Figure 1.* The participants were trained on the four novel objects presented above. Note that the objects comprise two visually similar pairs.

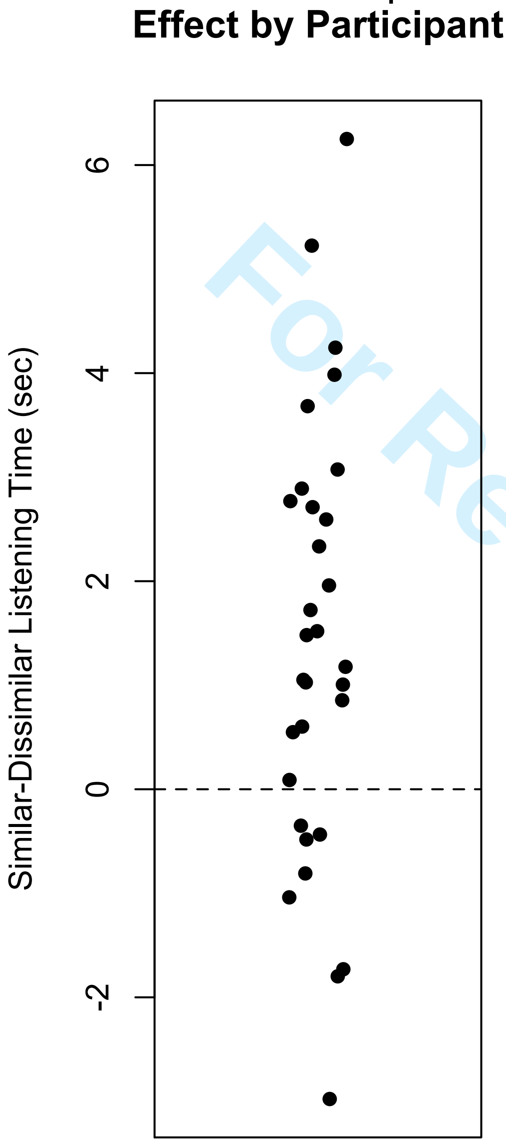
*Figure 2.* Toddlers listened significantly longer to word pairs that referred to visually similar objects than to word pairs that referred to visually dissimilar objects.

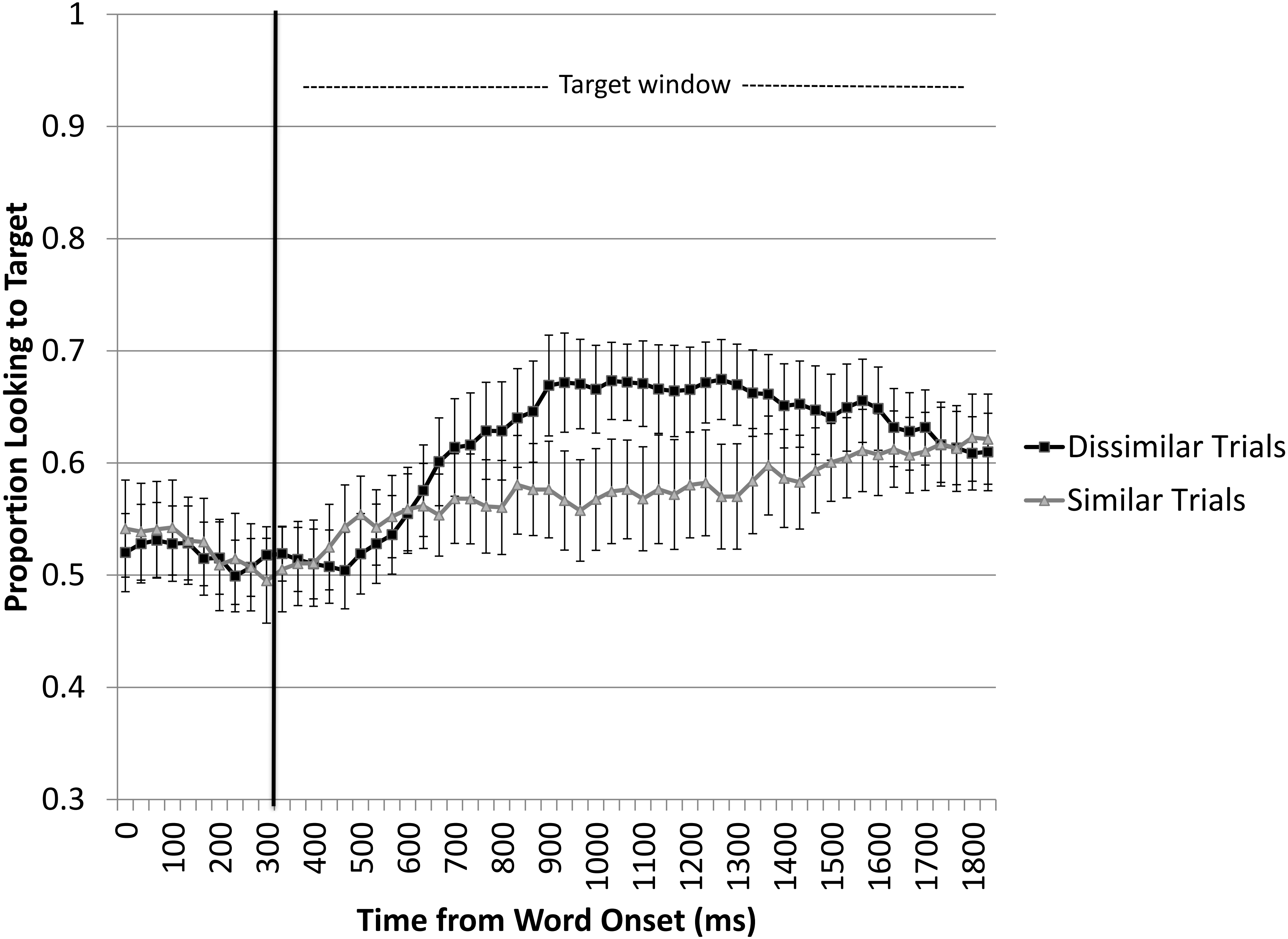
*Figure 3.* A preference score was calculated for each participant by subtracting their mean dissimilar trial listening time from their mean similar trial listening time. Twenty-five out of the 32 infants showed a positive preference score, indicating a preference for the similar trials.

*Figure 4*. Infants looked significantly more to the target picture compared to the distractor after they heard the target label. This effect held for both the dissimilar and similar trials.




Mean Looking Time (seconds)
0
2
4
6
8
10
Dissimilar
Similar
Word Pair Relationship


Effect by Participant
Similar-Dissimilar Listening Time (sec)
6
4
2
0
-2


Target window
Proportion Looking to Target
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Time from Word Onset (ms)
Dissimilar Trials
Similar Trials