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# Toddlers encode similarities among novel words from meaningful sentences

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## Abstract

Toddlers can learn about the meanings of individual words from the structure and semantics of the sentences in which they are embedded. However, it remains unknown whether toddlers encode similarities amongst novel words based on their positions within sentences. In three experiments, two-year-olds listened to novel words embedded in familiar sentence frames. Some novel words consistently occurred in the subject position across sentences, and others in the object position across sentences. An auditory semantic task was used to test whether toddlers encoded similarities based on sentential position, for (a) pairs of novel words that occurred within the same sentence, and (b) pairs of novel words that occurred in the same position across sentences. The results suggest that while toddlers readily encoded similarity based on within-sentence occurrences, only toddlers with more advanced grammatical knowledge encoded the positional similarities of novel words across sentences. Moreover, the encoding of these cross-sentential relationships only occurred if the exposure sentences included a familiar verb. These studies suggest that the types of lexical relationships that toddlers learn depend on the child's current level of language development, as well as the structure and meaning of the sentences surrounding the novel words.

Keywords: word learning; lexical development; syntactic bootstrapping; semantic networks

How do children build a lexicon? In addition to the connections between labels and their referents, mature lexical knowledge also contains the associations between words. This lexical-semantic structure includes information gleaned from what we see and experience in the world, such as the fact that "dog" and "cat" refer to similar animals.  However, there are also rich patterns in the linguistic input that young word learners could use to construct a lexicon. Words are not strung together randomly; languages are structured such that the positions of words in a sentence convey information about their meanings. Despite the fact that this structure is well documented, and that it provides potentially useful information about the semantics of words, we know very little about the types of lexical relationships that young children track in the speech stream when they hear new words.

Toddlers have an impressive ability to infer the meaning of an individual novel word from simply hearing it in a sentence. For example, toddlers can use word order and argument structure to infer the meaning of a novel verb (Naigles, 1990; Yuan & Fisher, 2009). In these studies, toddlers hear a sentence such as "*The duck is gorping the bunny,*" and use the syntax of the sentence to guide their interpretation of the novel verb (measured via looking behavior; Naigles, 1990). In addition to using syntax to map a novel verb to an action, toddlers can also use syntactic structure to glean information about other semantic properties of a novel verb, such as the subjects and objects it selects for (e.g., Gertner et al., 2006). Importantly, there is also evidence that this semantic information is encoded and can be used for later comprehension and learning (e.g., Yuan & Fisher, 2009). These findings demonstrate that young children readily exploit sentence structure to guide online comprehension of a novel word, and that they encode this semantic information into their lexical representations.

In addition to using sentence *structure* to learn about novel word meanings, toddlers also use the *semantics* of surrounding words to infer word meanings. For example, both adults and children use familiar verbs to predict the semantic properties of upcoming nouns (Altmann & Kamide, 1999; Fernald et al., 2008; Friedrich & Friederici, 2005; Valian, Prasada, & Scarpa, 2006). Moreover, children as young as 15 months of age use familiar verbs to predict semantic properties of adjacent *novel* nouns (Ferguson, Graf, & Waxman, 2014; Goodman, McDonough & Brown, 1996; Mani & Huettig, 2012; Yuan, Fisher, Kandhadai, & Fernald, 2011).

This literature on using sentential context to infer word meaning has focused on the information that young children can use and encode about individual words. However, adult word knowledge includes much more than just the meanings of isolated words; the structure of our lexical-semantic knowledge is better described as a web or network than as a dictionary (Rogers & McClelland, 2004; McNamara, 2005; Elman, 2009). As mature language users, we are exquisitely attuned to the similarities among the meanings and functions of words in our lexicon. Representing the relationships between words, or the presence of interconnectivity or structure within the lexicon, allows us to understand and produce language flexibly and efficiently.

**Gleaning Word Similarity From Sentences**

In addition to semantic information about individual words, sentential context provides information about lexical structure, or word relationships. For example, consider the following sentences: "The cat drank the milk" and "The dog drank the water." These two sentences reflect a general pattern found in English, namely that the subject of a verb phrase is often the agent of the action; "cat" and "dog" are both animate agents who are doing the drinking. Additionally, the verb *drink* selects for objects with certain semantic properties—inanimate, palatable, and liquid. Thus, if a child has sufficient knowledge of their language's grammatical structure and knows the verb *drink*, she could use this information to determine many semantic properties of the individual nouns (*cat, dog, milk,* and, *water*).

Crucially, though, a child who hears these sentences, and other sentences that use these four nouns in similar ways, could also learn about the relationships between the nouns. Over time, the child could encode that "cat" and "milk" regularly appear in the same sentence, as do "dog" and "water". This type of pattern, in which two words co-occur with an intervening item, is referred to as a non-adjacent dependency (e.g., Gómez, 2002; Newport & Aslin, 2004). Non-adjacent dependency learning is crucial to acquiring a language because many linguistic patterns follow this structure (Chomsky, 1957). Indeed, many theories purport that tracking this type of relationship is a crucial step in syntax acquisition (Gómez, 2002; Newport & Aslin, 2004).

It is possible that non-adjacent dependencies also contribute to the learning of semantic relationships. By tracking which words occur within the same sentence (albeit separated by intervening items), children could begin to learn which words occur within the same event structure. For example, "cat" and "milk" are semantically related because they participate in the same event. This type of thematic relationship between nouns is a component of mature lexical networks (e.g., Hare et al., 2009). Thus, young word learners could use this type of within-sentence regularity to begin to build their semantic network.

In addition to within-sentence relationships, there is another type of informative structure relating the nouns in the example sentences ("The cat drank the milk" and "The dog drank the water"). Words that are used in the same position across sentences (and particularly with the same verb, e.g., cat and dog; milk and water) share semantic properties. In the current example, the subjects are animate, and the objects are inanimate potable liquids. Thus, the tracking of word positions across sentences could help children detect meaningful similarities. Indeed, adults judge words that are used in the same position across sentences as more similar to each other than words that are used in different positions (Jones & Love, 2007). Moreover, corpus analyses of child-directed speech indicate that the sentence frames surrounding words are predictive of their grammatical category (Mintz, 2003). Thus, children could potentially use these similarities in how words are used across sentences to discover the semantic relationships between words.

Within the two example sentences alone, there is complex and useful information available not only about individual nouns, but also the relationships amongst the four nouns. However, we do not know whether young children encode these relationships during language acquisition. This type of learning could be particularly useful when children hear novel words for the first time. Encoding the similarities in usage amongst novel words, as well as between novel and familiar words, could aid in the integration of those words into the developing lexicon. The current set of studies was designed to ask whether toddlers track similarities among novel words based on how they are used in sentences. Specifically, we exposed toddlers to novel words within familiar English sentence frames that provided potentially useful information about how the words' referents are related to each other. The test items were designed to determine which types of lexical relationships the toddlers encoded from those sentences.

A second aim of the current studies was to examine the relationship between word-relationship encoding and language skill. There is evidence that children with larger vocabularies and increased grammatical knowledge are better able to use distributional cues and sentence context to learn new words (e.g., Fisher, Klinger, & Song, 2006; Lany & Saffran, 2011). We were particularly interested in the connection between *grammatical knowledge* and the ability to encode semantic relationships. While vocabulary size and grammatical development are correlated (see Bates & Goodman, 1997), some studies have found a particularly role for grammatical knowledge in some language learning tasks (see Hirsh-Pasek & Golinkoff, 1996). For example, Lany & Saffran (2011) found that while vocabulary size was related to the use of multiple types of cues in a word learning task, grammatical knowledge was specifically related to the use of distributional cues. Similarly, in the current set of studies, grammatical knowledge may be particularly useful for tracking the sentential cues to semantic relationships. As with the distributional cues in Lany & Saffran's (2011) study, tracking the sentential cues in the current study may require more advanced language processing skills or syntax knowledge, both of which a measure of grammatical knowledge reflects. Thus, while both vocabulary size and grammatical knowledge could correlate toddlers' learning in the current studies, our hypothesis was that grammatical knowledge in particular would interact with learning.

**Testing the Encoding of Novel Word Similarities From Sentences**

To test the learning of lexical relationships from speech, we used an auditory semantic task. This procedure was initially developed to assess the lexical encoding of visual similarity between novel word referents (Wojcik & Saffran, 2013). In our prior study, two-year-olds were taught four novel words whose referents were organized into two perceptually-similar pairs. The question of interest was whether toddlers would learn the similarity structure of the artificial lexicon. We addressed this question by testing toddlers using a variant of the Headturn Preference Procedure. The test items each consisted of repetitions of a single word pair. Crucially, the two words repeated on each trial had referred to either visually similar or visually dissimilar objects during the training phase of the experiment. Because the toddlers did not see the referents during testing, a difference in listening times to these two types of trials (similar referents vs. dissimilar referents) would indicate that toddlers encoded the similarity of the referents into their lexical representations. The results of this initial study suggest that toddlers encode visual similarity from their very first exposures to new words.

In the current study, we used this method to investigate a different aspect of similarity. Instead of exploring the visual similarity of referents, as in Wojcik & Saffran (2013), we asked whether toddlers treated novel words that occurred in particular sentential positions as similar versus dissimilar. That is, would the positions of novel words in familiar English sentential structures affect toddlers' encoding of the relationships among those novel words? We hypothesized that even in the absence of referents during training, sentential context would provide toddlers with cues about the potential similarity of novel words.

To provide information about lexical similarity structure, the training sentences included three English verbs that are well-known by the participating age group (26- to 28-month-olds), and that evoke distinct subject/agent and object/patient properties: *broke, opened, closed* (see Table 1.)

Table 1
*Example exposure sentences for Experiments 1 and 2 (novel word pairs were counterbalanced between participants)*

| | Word Pair 1 | Word Pair 2 |
|---|---|---|
| *Verb 1* | *the* ***tursey*** *broke the* ***pif*** | *the* ***coro*** *broke the* ***blicket*** |
| *Verb 2* | *the* ***tursey*** *opened the* ***pif*** | *the* ***coro*** *opened the* ***blicket*** |
| *Verb 3* | *the* ***tursey*** *closed the* ***pif*** | *the* ***coro*** *closed the* ***blicket*** |

These sentences provide two types of word similarities to investigate. First, toddlers could encode the within-sentence, or "**horizontal**" similarity, between pairs of novel words, (e.g., *tursey-pif* and *coro-blicket* in Table 1). Horizontal similarity refers to co-occurrence within the same sentence, separated by one or more words. Recall that this non-adjacent relationship is potentially semantically useful because it provides information about which nouns co-occur within the same event, and thus have a thematic relationship to each other (e.g., "The cat drank the milk").

Second, toddlers could encode the positional, or "**vertical**" similarity, between pairs of novel words. Vertical similarity refers to words that are used in the same position across sentences (e.g., *cat* and *dog* in the example sentences: "The cat drank the milk"; "The dog drank the water."). In Table 1, *tursey* and *coro* are always in subject position, and *pif* and *blicket* are always in object position. Thus, *tursey-coro* and *pif-blicket* are vertical pairs. As discussed previously, this relationship is also potentially highly informative. Words that are used in similar positions across sentences (or, those that have similar thematic roles in relation to verbs) often share semantic properties. The subjects in the sentences in Table 1 are all likely animate, while the objects are all likely inanimate. Thus, tracking vertical similarity could help toddlers to learn about the semantic relationships between novel words that occur in similar positions across sentences.

In Experiment 1, we asked whether toddlers encode horizontal (within-sentence) relationships among novel nouns. We began by testing this relationship because research using non-adjacent dependency-learning paradigms suggests that toddlers are sensitive to within-sentence co-occurrences. However, it remains unknown whether toddlers perceive words that co-occur within sentences as more similar than words that do not.

## Experiment 1

To examine the effects of sentence structure on lexical encoding, toddlers were first exposed to four novel nouns in meaningful English sentence frames. The toddlers were then tested with the auditory semantic task used by Wojcik & Saffran (2013) to examine whether they encoded similarities among the novel nouns that had been heard in the same sentence (horizontal relationship). We hypothesized that toddlers would discriminate between word pairs previously heard in the same sentences versus word pairs previously heard in different sentences, based on prior studies suggesting sensitivity to non-adjacent dependencies. In addition, we hypothesized that native language skill, in terms of vocabulary and syntactic development, would not affect performance, given that infants significantly younger than the toddlers tested here are able to acquire within-sentence dependencies (Gómez, 2002; Gómez & Maye, 2005).

# Method

## Participants

Twenty-four full-term monolingual English-learners (14 male) with a mean age of 26.9 months (26.0 – 28.0 months) participated in Experiment 1. Parents reported that their toddlers had normal hearing and were currently free of ear infections. Three additional toddlers were excluded from the analyses due to fussiness.

## Stimuli and Design

**Exposure materials**. The stimuli consisted of 4 novel labels (*tursey, coro, blicket, pif*) in familiar sentence frames. Three familiar verbs (*broke, opened,* and *closed*) provided distinct subject-object semantic categories. These verbs were chosen because they are known by most toddlers in the participating age range: at 26 months of age, 71% of toddlers say “break”, 83% say “open”, and 60% say “close” (Dale & Fenson, 1996). Each novel noun occurred in the same position (either as the subject or the object of the verb) across all sentences; noun pairs were yoked across sentences (see Table 1). The positions of the novel nouns were counterbalanced between subjects, such that for some participants, *tursey* and *pif* were always heard in the same sentence, with *tursey* as the subject and *pif* as the object (as in Table 1), and for other participants, *tursey* and *coro* were always heard in the same sentence, with *tursey* as the subject and *coro* as the object (*blicket* and *pif* were counterbalanced in the same way.)

**Test materials.** Each test trial consisted of repetitions of a single word pair (e.g., *tursey, coro, tursey, coro…)*. Eight trials comprised horizontal word pairs (i.e. words that always occurred within the same sentence during exposure), and eight comprised crossed word pairs (i.e. words that never occurred within the same sentence during exposure, and always occurred in different positions: the subject from one sentence type and the object from the other). For example, given the items in Table 1, the horizontal pairs are *tursey-pif* and *coro-blicket*, and the crossed pairs are *tursey-blicket* and *coro-pif*. Counterbalancing ensured that horizontal word pairs for half of the toddlers were crossed word pairs for the other half of the toddlers.

**Procedure**

Toddlers were seated on a caregiver's lap in a sound-attenuated booth; the caregiver listened to music over headphones. The training audio was presented from front speakers with an attention-getting video presented on a front monitor. The *exposure phase* (~1.5 minutes) consisted of 4 blocks of the 6 sentence tokens described above, randomized within block. Each block was 20 seconds long. An attention-getting video (clouds) was presented with the audio to keep the participants' attention. Each block was separated by a 4-second video of colorful confetti paired with music.

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, a 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 horizontal word pairs (e.g., *tursey, pif, tursey, pif…*), and the other half were crossed pairs (e.g., *tursey, blicket, tursey, blicket…*; see Table 2). Each block of 4 trials included two horizontal and two crossed trials. After the experiment, parents filled out the MacArthur-Bates Communicative Development Inventory (MCDI, short form Level II; Fenson et al., 2000).

Table 2
*Example test pairs for the three experiments based on the example exposure sentences in Tables 1 and 3. Each test item was presented four times (randomized).*

| Horizontal Pairs (Experiments 1 & 3) | Vertical Pairs (Experiments 2 & 3) | Crossed Pairs (all Experiments) |
|---|---|---|
| tursey-pif | tursey-coro | tursey-blicket |
| coro-blicket | pif-blicket | coro-pif |

**Results and Discussion**

To examine whether toddlers' listening time to word pairs was influenced by whether the words in each pair had been heard in the same sentence during exposure, as well as the effect of toddlers' language development, we conducted a mixed-design ANOVA, with trial type (horizontal versus crossed word pairs) as a within-subjects variable and grammatical knowledge level and vocabulary size as between-subjects variables. Grammatical knowledge level was determined by the MCDI short form (Fenson et al., 2000), in which parents were asked if their child combined words, with possible answers of "not yet", "sometimes", or "often". Because no parents answered "not yet" (for all experiments reported in this paper), there were two levels for the grammatical knowledge variable: High (toddlers who combined words often) and Low (toddlers who combined words sometimes). Previous studies have used this type of split to examine the influence of grammatical development on the acquisition of patterns of novel words (e.g., Lany & Saffran, 2011). For vocabulary size, we used a median split of the distribution of vocabulary scores (parental report from MCDI, Fenson et al. 2000) to divide participants into two equal groups: high vocabulary and low vocabulary[1].

There was a significant main effect of trial type (horizontal vs. crossed) on listening time: $F(1,21) = 9.33$, $p < 0.01$, $\eta^2_p = 0.31$. Toddlers listened longer on horizontal trials (8.5s, SE = 0.7) than on crossed trials (6.7s, SE =0.6), 95% confidence interval of the difference: [0.05, 3.54], Cohen's d= 0.64. Eighteen of the 24 toddlers showed this pattern of response. There was no main effect of grammatical knowledge (F[1,21]=0.22, n.s.) and no interaction between trial type and grammatical knowledge level, $F(1,21) = 0.36$, n.s. (see Figure 1). We were particularly interested in the effect of grammatical knowledge because of the possibility that knowledge of language structure may motivate the attention to and encoding of word relationships from sentences (see Introduction). However, to tease out the role of grammatical knowledge from language skills more broadly, we also examined the effect of productive vocabulary. There was also no main effect of vocabulary size (F[1,21]=0.41, n.s.) and no interaction between trial type and vocabulary size (F[1,21]=0.66, n.s.).

[1] For this sample, there were only 4 participants in the low grammatical knowledge group, but of those participants, two were in the low vocabulary size group, and two were in the high vocabulary size group, suggesting that grammatical knowledge and vocabulary size are relatively independent measures.

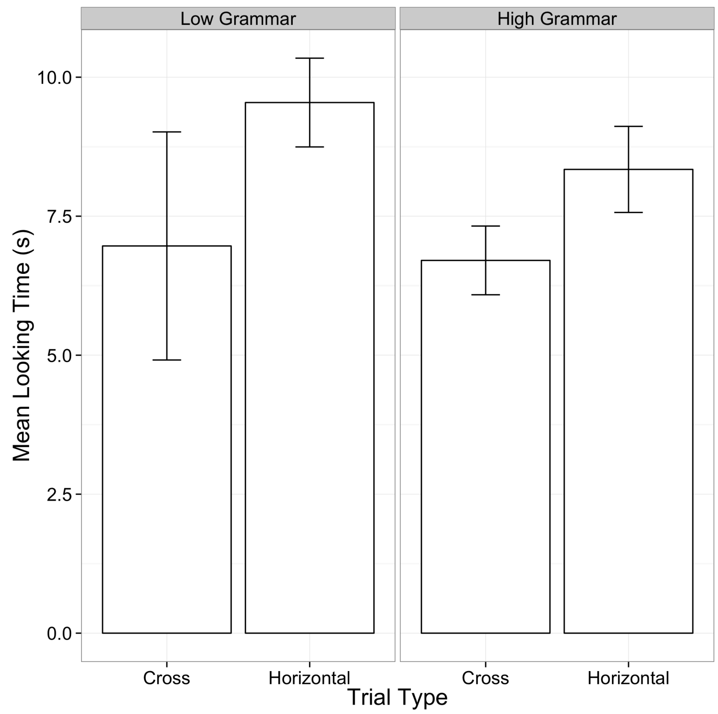


*Figure 1.* Experiment 1 results: mean looking time to crossed and horizontal trials for participants with high and low grammatical knowledge level. Error bars represent standard error of the mean.

These results indicate that the toddlers encoded horizontal (within-sentence) relationships between novel words embedded in meaningful sentences, regardless of their native-language grammatical knowledge or productive vocabulary size. Participants discriminated word pairs that had occurred in the same sentences from word pairs that had not, suggesting that toddlers readily encode which novel words co-occur within the same English sentence frames. This experiment is similar to studies examining the learning of non-adjacent dependencies mentioned previously (such as Gómez, 2002) in that we investigated in the encoding of word relationships with an intervening item (in this case, the verb and the determiner “the”). Interestingly, previous studies suggest that infants have difficulty tracking non-adjacent dependencies unless there are many types of intervening items (Gómez, 2002). Toddlers in the current study were able to track the within-sentence relationships with only three intervening item types (verbs + *the*) — half of the number of types needed for tracking non-adjacent dependencies in Gómez's studies. Implications of this aspect of the results are discussed further in the General Discussion.

## Experiment 2

The results of Experiment 1 suggest that toddlers are sensitive to horizontal relationships: the co-occurrence of novel words within sentences. However, toddlers could have also encoded the vertical relationships among the novel words: the similarity between words based on the positions in which they occur across sentences. Cross-sentential positional similarity is of particular interest because encoding this information could help children learn semantic similarities; as noted above, words that are used in similar sentence positions often have similar semantic roles (see also Boland & Tanenhaus, 1991; Resnik, 1996). In our exposure sentences (see Table 1), for example, the English verbs typically select for animate subjects.

While the horizontal relationship investigated in Experiment 1 can be thought of as a non-adjacent dependency, the vertical relationship represents a different type of regularity; toddlers must track similarities in word distributions across sentences. Thus, although we found no effect of grammatical knowledge in Experiment 1, it is possible that tracking vertical relationships requires some knowledge of language structure, particularly the argument structure of verbs. If, for example, children do not know that the agent of an action is in the subject position in their language, or even which words are verbs in the sentences that they are hearing, they may not track which words occur in the subject position of the sentences.

In Experiment 2, we investigated whether toddlers encode this potentially useful vertical relationship between words. A new sample of toddlers was exposed to the same sentences used in Experiment 1, but with a new test contrast: vertical pairs versus crossed pairs (see Table 2). We predicted that only toddlers with high grammatical knowledge would track the relationship.

## Method

### Participants

Twenty-four full-term monolingual English-learners (13 male) with a mean age of 27.1 months (26.0 – 28.2 months) participated in Experiment 2. Parents reported that their toddlers had normal hearing and were currently free of ear infections. Thirteen additional toddlers were excluded from the analyses due to fussiness (10) or an average looking time > 2 SD from the mean (3).

### Stimuli and Design

**Exposure**. The exposure stimuli were identical to Experiment 1.

**Testing.** As in Experiment 1, each test trial consisted of repetitions of a word pair (e.g., *tursey, coro, tursey, coro…)*. However, the experimental manipulation in Experiment 2 was whether the tested word pairs comprised words that occurred in the same or different positions *across* sentences. Eight trials presented these vertical word pairs, and eight trials presented crossed word pairs (the same comparison trials as in Experiment 1; See Table 2). Counterbalancing ensured that vertical word pairs for half of the toddlers were crossed word pairs for the other half of the toddlers.

### Procedure

The procedure was the same as Experiment 1.

## Results and Discussion

The question of interest for Experiment 2 was whether toddlers' listening times to word pairs would be influenced by whether the words had occurred in a vertical (same position across sentence tokens) or crossed (different positions across sentence tokens) relationship during exposure. Additionally, we were interested in the potential effects of grammatical knowledge. Thus, as in Experiment 1, a mixed-design 2 (trial type) x 2 (grammatical knowledge level) x2 (vocabulary size) ANOVA was conducted[2].

There was no significant main effect of trial type ($F[1, 21] = 0.54$, n.s.), grammatical knowledge ($F[1,21]=0.26$ n.s.), or vocabulary size ($F[1,21]=0.24$ n.s.). There was also no significant interaction between vocabulary size and trial type ($F[1,21]=0.003$, n.s.). However, the interaction between trial type and grammatical knowledge level was significant: $F(1,21) = 15.93$ $p< 0.001$, $\eta_p^2= 0.43$ (see Figure 2). Follow-up tests revealed that toddlers with high grammatical knowledge listened significantly longer to the vertical pairs than to the crossed pairs. A paired-sample t-test including only the participants who combined words "often" revealed a significant effect of trial type ($t[15]=2.87$, $p < 0.05$), with longer listening to the vertical pairs (9.2 sec, SE=0.8) than to the crossed pairs (7.3 sec, SE=0.6; see Figure 2); 95% confidence interval of the difference: [0.00, 3.79], Cohen's $d = 0.71$. Thirteen of the 16 participants showed this direction of effect. There was a marginal effect of trial type for the participants who did not combine words often ($t[7] = 2.06$, $p < 0.1$). However, this effect was in the opposite direction, with participants listening longer to the crossed pairs (9.0 sec, SE=1.0) than to the vertical pairs (6.4

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[2] Of the eight participants in the low grammatical knowledge group within this sample, three were in the low vocabulary size group. Thus, as in Experiment 2, there was little overlap between the two measures.

sec, SE=0.7); due to the small sample size of this group, and thus lower power, it is difficult to draw conclusions.

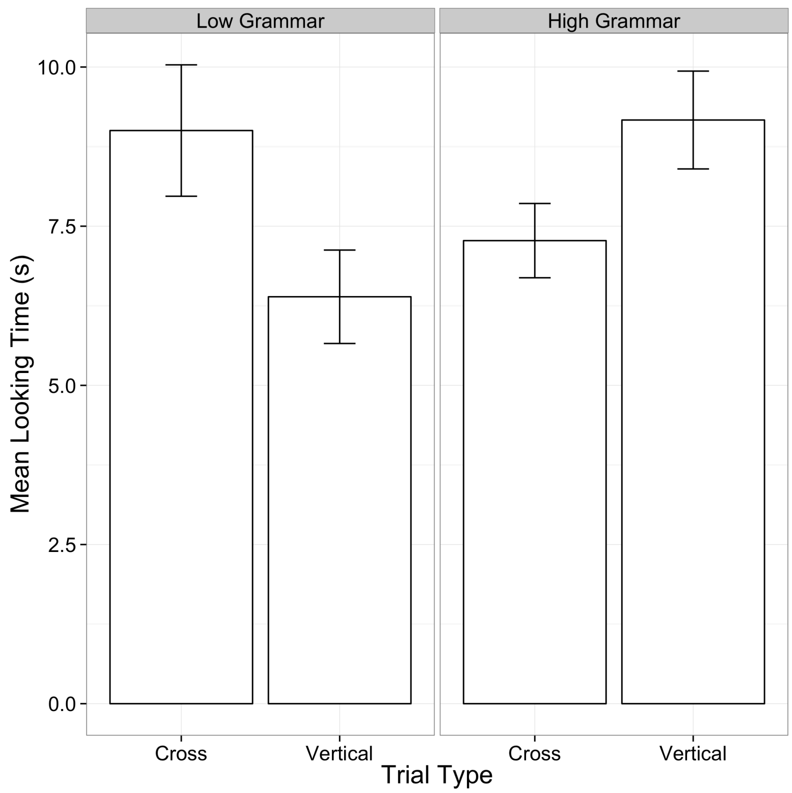


*Figure 2.* Experiment 2 results: mean looking time to crossed and vertical trials for participants with high and low grammatical knowledge level. Error bars represent standard error of the mean.

The results of Experiment 2 suggest that as toddlers' grammatical knowledge increases, as indexed by the level of grammatical complexity of their utterances, they are able to track more abstract relationships in spoken language. Only the toddlers who came into the lab with more advanced grammatical abilities (based on parental report) encoded the association between words used in the same sentential position across utterances. Interestingly, there was no effect of productive vocabulary size on word-relationship encoding, suggesting that the effect of grammatical level is not due to higher verbal skills in general, but specifically to syntactic knowledge. This pattern of results suggests that knowledge of sentence structure facilitates the discovery of vertical relationships. An alternative third-variable explanation is that children with higher grammatical proficiency have better verbal working memory, which supports both more advanced grammar and the ability to track lexical similarity across sentences. Indeed, it has been argued the working memory capacity is related to language acquisition and processing (Just & Carpenter, 1992; Federenko, Gibson & Rohde, 2006; however, see MacDonald & Christiansen, 2002, for an alternative theory). Thus, the current results motivate future explorations of the mechanisms behind the interaction between language skill and language learning.

Combined with Experiment 1, the results from Experiment 2 demonstrate that toddlers have an impressive ability to encode relationships among novel words from their sentential positions. Even before toddlers learn about the referents of novel words, they may begin to use the surrounding sentential context to learn about semantic similarities, forming word categories that could be useful for more efficient sentence processing and word-referent mapping (e.g., Frisch, Hahne, & Friederici, 2004).

An alternative explanation of the results of Experiments 1 and 2, however, is that toddlers are not using their knowledge of verb semantics and syntax to encode the similarities between the nouns. It is possible that the data reflect the tracking of general co-occurrence statistics and word order, without any use of the familiar verbs' semantics or argument structure. In Experiment 1, toddlers could have tracked which words were heard close together in time; in Experiment 2, toddlers could have tracked which novel words were used first or last in sentences (ordinal positions). The fact that the results of Experiment 2 were related to toddlers' English grammatical attainment does suggest that the vertical relationship reflects linguistic knowledge. However, as stated previously, the findings could also reflect greater working memory capacity rather than increased grammatical attainment, which would not support our hypothesis that toddlers recruited linguistic knowledge to encode similarities between the nouns. We designed Experiment 3 to begin to tease apart these potential explanations.

**Experiment 3**

To investigate whether toddlers indeed use semantic and syntactic information to track lexical relationships within and across sentences, we exposed two new samples of toddlers to sentences that included the same four novel words. Crucially, in these sentences, the familiar verbs were replaced with conjunctions (e.g., "*The tursey and/or/then the coro*"; see Table 3). Conjunctions provide weaker semantic information than verbs, allowing us to tease out the roles of argument structure and word order (e.g., Yuan et al., 2011). For example, in Experiment 1, the sentence *"The tursey broke the coro"* links the two nouns both by their syntactic relationship and by their co-occurrence within a sentence. When the verb is replaced by a conjunction, as in "*The tursey and the coro*", the only link between the two nouns is their co-occurrence; the conjunction does not provide the argument structure that the verb does. Thus, by testing whether toddlers encode the same word relationships when they are exposed to sentences with conjunctions instead of verbs, we will be able to better understand whether toddlers are using the structure provided by the familiar verb to encode lexical connections, or if they are simply encoding lexical co-occurrences.

Tracking lexical co-occurrence can be semantically informative (see Burgess & Lund 1997; Resnik, 1996), and thus it is possible that toddlers would track word similarity even without the verbs present. Additionally, infants' ability to track non-adjacent dependencies suggests that syntactic and semantic support may not be necessary to encode word relationships (Gómez, 2002; Gómez and Maye, 2005). However, it is also possible that toddlers need information provided by syntactic and semantic structures to encode novel word relationships. Experiment 3 tested these viable, competing hypotheses for both horizontal and vertical relationship encoding.

Table 3
*Example exposure sentences for Experiment 3 (novel word pairs were counterbalanced between participants).*

| | Word Pair 1 | Word Pair 2 |
|---|---|---|
| *Conjunction 1* | *the **tursey** and the **pif*** | *the **coro** and the **blicket*** |
| *Conjunction 2* | *the **tursey** or the **pif*** | *the **coro** or the **blicket*** |
| *Conjunction 3* | *the **tursey** then the **pif*** | *the **coro** then the **blicket*** |

## Method

### Participants

Forty-eight full-term monolingual English-learners (20 male) with a mean age of 27.0 months (26.0 – 27.9 months) participated in Experiment 3. Ten additional toddlers were excluded from the analyses due to fussiness (8) or experimenter error (2). For half of the participants (randomly assigned), the test stimuli were identical to Experiment 1 (horizontal versus crossed word pairs; see Table 2). For the other half of the participants, the test stimuli were identical to Experiment 2 (vertical versus crossed word pairs; see Table 2).

### Stimuli

The exposure stimuli were identical to Experiments 1 & 2, except that the three different verbs were replaced by three different conjunctions (*and, or,* and *then;* see Table 3). Thus, the participants heard the novel labels an equal number of times, with the same number of intervening word types, as the participants in the first two experiments.

### Procedure

The procedure was the same as Experiments 1 and 2.

## Results and Discussion

As in Experiments 1 & 2, we analyzed in the effect of trial type on looking time. Additionally, we also examined the effect of grammatical knowledge because of the significant interaction found in Experiment 2[3]. For the participants tested on the horizontal relationships with intervening conjunctions, there was a significant main effect of trial type on looking time ($F[1,22] = 7.00$, $p < 0.05$, $\eta_p^2 = 0.24$) and no significant main effect of grammatical knowledge ($F[1,22]=0.69$, n.s.) or interaction ($F[1,22] = 0.0855$, n.s.). Participants looked significantly longer to the crossed pairs, regardless of grammatical knowledge level (M= 7.2s, SE=0.6s for horizontal pairs, M= 8.3s, SE=0.6s for crossed pairs; 95% confidence interval of the difference [0.24, 1.94]; Cohen's d = 0.54; see Figure 3). Sixteen of the 24 participants showed this looking pattern. Note that the direction of preference is the opposite of Experiment 1, which tested the same relationship, but with verbs in the exposure sentences instead of conjunctions.

The difference in direction of preference across the two studies could be due to the fact that the conjunctions were shorter and less salient than the verbs, leading to greater perceptual similarity between the exposure sentences and the test trials in Experiment 3 than Experiment 1. Exposure-test similarity may have simplified the test for toddlers in the conjunction condition, rendering a flip from a familiarity preference to a novelty preference (see Houston-Price & Nakai, 2004). Alternatively, the toddlers could have employed a different, more surface-level strategy to encode the horizontal relationship in the conjunction condition. When there is a familiar verb in a sentence (as in Experiment 1), toddlers encode and remember the thematic relationship between the subject and object. However, when there is a conjunction that does not provide information about argument structure, toddlers only encode word co-occurrences. This would make the encoding task in Experiment 3 easier because of the shallower level of

[3] In Experiment 3, there were 9 participants in the low grammatical level group.

processing, leading to a novelty preference at test. Regardless of the explanation for the switch in direction of preference, the important finding is that participants did show a difference in looking times between the horizontal and crossed pairs, which suggests that they encoded the horizontal relationship in both Experiments 1 and 3.

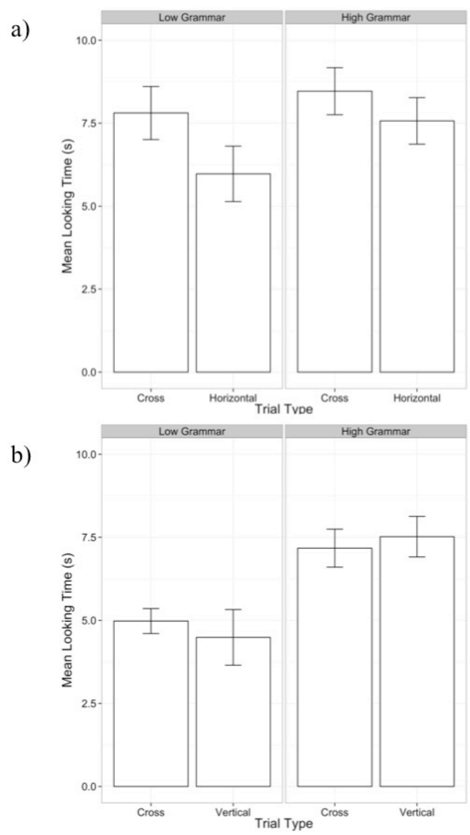


*Figure 3.* Experiment 3 results. a) Mean looking time to crossed and horizontal trials for participants with high and low grammatical knowledge level. b) Mean looking time to crossed and vertical trials for participants with high and low grammatical knowledge level. Error bars represent standard error of the mean.

Turning to participants who were tested on the vertical relationship in Experiment 3, we found no significant effect of trial type ($F[1,22] = 0.14$, n.s.). There was a main effect of grammatical knowledge on looking time ($F[1,22]=5.20$, $p<0.05$, $\eta_p^2 = 0.19$; see Figure 2), with the high grammar group listening longer to test trials (regardless of trial type; M=7.3, SE=0.53), than the low grammar group (M=4.7, SE=0.25); 95% confidence interval of the difference: [2.4, 3.2]; Cohen's D=1.5). However, there was no significant interaction between trial type and grammatical level ($F[1,22] = 0.31$, n.s.; see Figure 2). This contrasts with Experiment 2, where toddlers with higher levels of grammatical knowledge did appear to track cross-sentential positional regularities. Without a familiar verb structuring the exposure sentences, toddlers did not form an association between words used in the same position across sentences.

This finding supports our hypothesis that toddlers use knowledge of language structure and semantics to track the vertical similarity between novel nouns. The results of Experiment 3 suggest that increased knowledge of language structure, rather than increased working memory capacity, accounts for the results of Experiment 2. If tracking the vertical relationship requires the ability to hold more items in memory during sentence processing (e.g. Just & Carpenter, 1992), and if the grammatical complexity measure simply reflects this ability, then those participants with higher grammatical complexity should have succeeded in encoding the vertical relationship in Experiment 3, without the verbs present. This is not the pattern of results that we observed. Because the syntactic and semantic information provided by a verb appears crucial to the tracking of the vertical relationship, it is likely that knowledge of the interaction between semantic and syntactic information is necessary to be able to encode this type of word similarity.

## General Discussion

The current set of studies investigated whether toddlers are able to encode similarities among novel words based on their positions in sentences. Because sentential context conveys potentially useful information about the relationships between words, noticing the positions of words within and across sentences could help children begin to form the associations that make up their lexical network. We found that 2-year-olds readily tracked the relationships between novel words that occurred within the same sentence. However, only toddlers with more advanced language abilities (as indexed by increased grammatical complexity in their productions) encoded lexical similarities across sentences—in particular, the association between words that occurred in the same positions across sentences. Additionally, toddlers only encoded those across-sentence similarities if there were familiar verbs in the sentences (Exp. 2: e.g., "*The tursey broke the coro*"), failing to encode this type of association if the sentences involved conjunctions (Exp. 3: e.g., "*The tursey and the coro*"). Together, these results indicate that toddlers track lexical similarities from sentences, and that the types of relationships that are encoded depend on language experience as well as the semantics and structure of the sentences.

The finding that toddlers encode horizontal similarity regardless of grammatical knowledge, but only encode the vertical relationship given more advanced grammatical knowledge, is in line with decades of research on toddlers' early conceptual categories. Younger children tend to categorize objects based on thematic relationships (those implied by horizontal similarity in the current studies), while older children tend to categorize objects based on taxonomic relationships (those implied by vertical similarity; see e.g., Markman & Hutchinson, 1984). Our finding that toddlers track horizontal relationships from sentences before vertical relationships could be one potential mechanism behind the early preference for thematic similarity. Performance on categorization tasks may be influenced by not only conceptual, but also linguistic experiences. If toddlers do not begin to track across-sentence (vertical) similarities as readily as co-occurrences, this may contribute to the saliency of thematic over taxonomic categorization early in development. Future work on the mechanisms underlying these results will help tease apart potential relationships between linguistic and conceptual development.

What learning mechanisms could explain the current pattern of results? One potential explanation is that infants are simply tracking lexical co-occurrence patterns from the structure of the sentences. It could be that the looking times in our studies do not reflect any semantic or higher-order structural processing, and that they instead reflect toddlers' encoding of which words occurred close together in time (Exp 1 and 3); before or after the verb or conjunction (Exp. 2 & 3); or before or after the pause at the end of a sentence (Exp. 2 & 3). Indeed, even much younger infants are highly skilled at learning co-occurrences from meaningless streams of syllables (e.g., Saffran & Wilson, 2003; see Gomez & Gerken, 2000, for a review). The pattern of results for the within-sentence (horizontal) relationships supports a co-occurrence-based explanation. Toddlers tracked the horizontal relationship *regardless* of language experience or sentence semantics and structure, indicating that they are most likely encoding the fact that the words occur close together in time. While tracking this information may seem trivial, previous work has found that learning the association between novel words that are separated by a variable item (non-adjacent dependencies) is difficult for infants and even adults, unless there is high variability in the intervening item or the presence of other correlated cues to the dependencies (Gómez, 2002; Newport & Aslin, 2004). However, those studies used artificial grammars made up of completely novel words. The current set of studies used English sentences that included only a few novel words, which may facilitate sentence parsing, as well as tracking of the sentence-internal associations (see Amato & MacDonald, 2010; Willits, Lany & Saffran, 2014). Thus, as children gain more experience with their native language, they may be able to use this knowledge to more efficiently track non-adjacent dependencies from speech. Further work is needed to tease out the role of meaning in the tracking of non-adjacent dependencies.

The findings from Experiment 2, which tested the encoding of the vertical (cross-sentence) similarity when novel words occurred in sentences structured by a familiar verb, also do not rule out a co-occurrence-based mechanism. Recall that in this experiment, only toddlers with more advanced English grammatical abilities were able to track the vertical similarity relationship (Experiment 2). Because grammatical knowledge, but not productive vocabulary size, predicted which toddlers encoded the vertical relationship, these results imply that with more knowledge of language structure, toddlers learn which relationships are important to track. The results, therefore, do not depend on participants using or encoding semantics; learning might reflect increased attention to ordinal positions of words in the input, or simply more efficient sentence processing.

The findings from Experiment 3, however, provide evidence against a purely co-occurrence-based account for the results of Experiment 2, and instead imply that toddlers were using the structural and semantic information in the exposure sentences. Toddlers in Experiment 3 failed to track the vertical (across-sentence) relationships when there was no verb present. The three verbs presented during exposure in Experiments 1 and 2 (typically) select for animate beings in the subject position and inanimate objects in the object position, and thus the verbs indicate semantic and syntactic similarity between the vertically related words. In the conjunction materials (Experiment 3), there was no implied semantic category or thematic role based on whether the novel word came before or after the conjunction. Therefore, associating words that are used in the same position across those sentences would not provide the toddlers with useful information. The fact that toddlers only tracked *meaningful* relationships implies that they were sensitive to the semantics and structure that were provided by the verb.

While further work will tease out the roles of structural and semantic information in toddlers' tracking of word relationships, the current studies hint that toddlers can learn about semantic relationships between new words simply from linguistic input. Indeed, there is evidence that young children do use and learn about semantics from speech. Seminal work by Landau and Gleitman (1985) demonstrated that blind children have just as complex semantic knowledge as sighted children, despite the fact that they do not see the referents of the speech that they hear. One finding was that blind children show the typical pattern of development in their use of thematic relations (relationships between verbs and their predicates). This work suggests that semantic relationships can indeed be learned quite well from speech. Secondly, research on the learning of color terms demonstrates that a great deal of color semantics can be learned from how these words are used in sentences (Au, 1990; Au & Laframbroise, 1990; Sandhofer & Smith, 1999). For example, before being able to map a color label to the correct color referent, toddlers learn which words fit in the class of color terms (Sandhofer & Smith, 1999). It has been argued that the word-word associations that make up the class of color words are learned from how frequently those words are heard together in speech, and that these associations can bootstrap into the more specific word-color mapping that emerge later on (Sandhofer & Smith, 1999). Lastly, in an EEG study, 3-year-olds showed signatures of semantic processing when they heard sentences comprising novel content words and familiar function words (Silva-Pereya, Conboy, Klarman & Kuhl, 2007). This finding supports the interpretation that toddlers in the current experiment are extracting meaning from the training sentences, despite the presence of novel words.

Overall, while some of the current results can be explained by a purely co-occurrence-based mechanism, the package of findings taken together adds to the body of literature demonstrating that toddlers activate and learn about syntactic and semantic knowledge from sentences, even in the absence of visual referent. Our results provide a new piece of the puzzle by demonstrating that toddlers learn about structural and semantic relationships between completely novel words from sentences; from their first exposures to new words, toddlers are using the input to build up a lexical network.

Tracking novel word relationships from the speech stream may indeed be a very useful word learning strategy. Analyses of transcriptions from parent-child interactions indicate that there are indeed patterns in the input that indicate lexical-semantic structure. Sentence frames surrounding a word can be highly predictive of that word's grammatical category (Mintz, 2003). While Mintz's analysis did not examine the precise type of semantic categories that were provided by the exposure in the current study, the findings indicate that there is consistent structure in the input that children can use to learn about word categories and semantic relationships. It is possible that syntactic regularities in child-directed speech also provide cues to other aspects of lexical structure. In fact, computational modeling of a combination of adult- and child-directed speech indicates that the semantic features for which a particular verb selects (for example, "drink" selects for objects that are potable liquids) can be learned from co-occurrence statistics alone (Resnik, 1996; see also Burgess & Lund, 1997). This work suggests that tracking co-occurrences could help children learn about noun similarities. Further support for this learning mechanism comes from corpus analyses demonstrating that speech to younger infants contains even more consistent statistical regularities that speech to older children (Hills, 2012); tracking regularities in speech may be crucial to getting word-relationship learning off the ground.

While the use of co-occurrence statistics to extract meaning could explain the current data, it is possible that non-statistical mechanisms are behind our results. Toddlers could simply be extracting the meaning of the sentences, and using this meaning to infer relationships between the nouns. They could infer over the course of hearing the sentences that *turseys* and *coros*, for example, are both animate, and thus belong to the same semantic class. Further work will manipulate the content of the training sentences to teach out the role of co-occurrence statistics, syntactic structure, and meaning in toddlers' encoding of the novel word relationships.

In conclusion, this set of experiments demonstrates that toddlers use meanings conveyed by the syntactic structure of sentences to form potentially useful associations between novel nouns. Further work is needed to tease out the quality of the lexical associations that toddlers encode from sentences, and how these associations are used to comprehend language more efficiently and map novel words to referents. Nevertheless, the results from this study provide evidence that toddlers do encode novel word similarities from speech, revealing a new avenue for building up a mature lexical-semantic network.

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