The Ontogeny of Lexical Networks: Toddlers Encode the Relationships Among Referents When Learning Novel Words

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Abstract

Although the semantic relationships among 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 among novel words, we trained 2-year-olds on four novel words that referred to four novel objects, which were grouped into two visually similar pairs. Participants then listened to repetitions of word pairs (in the absence of visual referents) that referred to objects that were either similar or dissimilar to each other. Toddlers listened significantly longer to word pairs referring to similar objects, which suggests 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, which suggests that the results from Experiment 1 reflected the successful encoding of referents. Together, these results show that toddlers encode the similarities among referents from their earliest exposures to new words.

Ever 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. Although 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, he or she could also encode useful information about other nearby objects (such as a leash or a ball), the background context (e.g., a park vs. a kitchen), or the similarity between this new animal and his or her pet cat.

If the full complexity of the perceptual and semantic input available to young children is considered, word learning becomes a multidimensional problem that extends beyond label-referent associations. It has been shown 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 among 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 than if it is not. Adults show semantic priming effects for many types of lexical-semantic relationships, including feature overlap, thematic role similarity, and verb-noun relationships (e.g., McNamara, 2005; Neely, 1991).

Despite extensive research 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,

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1985) and into adulthood (Ameel, Malt, & Storms, 2008), so it is possible that representations of lexical relationships emerge later in the word-learning process. However, infants are sensitive to statistical relationships among newly learned words (e.g., Lany & Saffran, 2011), and adults can track multiple levels of statistical information in parallel (Romberg & Saffran, 2013; 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 among 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, it is not known whether young children encode the relationships among 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 nonlinguistic categorization (e.g., Behl-Chadha, 1996; Quinn, Eimas, & Rosenkrantz, 1993; Sloutsky, 2003). The fact that 2-year-olds attend to shapes 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'Arcais, & Glazenborg, 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 our first experiment, 2-year-olds learned four novel words that referred to four novel objects grouped into two visually similar pairs. Although participants were ostensibly taught object labels, the similarity structure of the referents provided them 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 among highly familiar words (Willits, Wojcik, Seidenberg, & Saffran, 2013). 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

Experiment 1 was designed to investigate whether toddlers encode the similarity structure among objects in a small artificial lexicon. Toddlers show sensitivity to semantic relationships among 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., 2013). 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 Fig. 1). We then investigated whether toddlers were sensitive to the similarities among 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 listening times for 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, 16 female) with a mean age of 27.0 months (range = 25.11–28.4). Eight additional toddlers were excluded from the analyses because of fussiness ($n = 7$) or an average looking time greater than 2 standard deviations from the mean ($n = 1$).

Stimuli. The training stimuli consisted of four novel labels (*tursey, coro, blicket, pif*), each paired with a single novel object image. Although the objects were all different, they were organized into two visually similar pairs: two were blue ovals, and two were red stars (see Fig. 1). Label-object pairings were counterbalanced across participants.
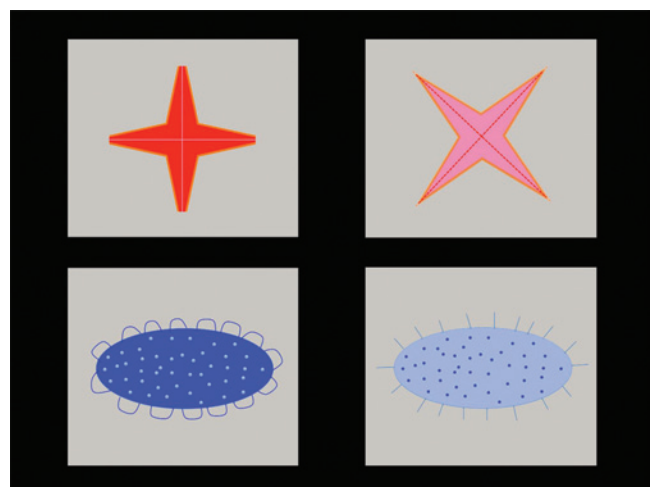
Fig. 1. The four novel objects that participants were trained on in the two experiments. Each object was visually similar to one other object and distinct from the other two. A novel label was paired with each object.

Each test trial consisted of repetitions of a word pair (e.g., *tursey, coro, tursey, coro . . .*). Eight trials contained word pairs that labeled visually similar objects, and eight contained word pairs that labeled visually dissimilar objects. Counterbalancing ensured that word pairs referred to similar objects for half of the toddlers and 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 glasses and listened to music over headphones. Three monitors were used: The training trials were presented on a center monitor, and two side monitors were positioned 90° to the left and to the right, respectively. The training phase (2.5 min) began with the four objects displayed in a grid for 10 s. During each subsequent training trial (6 s), 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 four blocks each included four 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 monitor, the neutral visual stimulus (a spinning pinwheel) began to play on one of the two side monitors. 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 2 s or for a total of 20 s. 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 four trials included two similar-object and two dissimilar-object trials. After the experiment, parents filled out the MacArthur-Bates Communicative Development Inventories (CDI; 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 referred to similar or dissimilar objects. A paired-samples t test revealed a significant effect of trial type (similar object vs. dissimilar object), $t(31) = 3.91$, $p < .001$, $\eta^2 = .331$. Toddlers preferred to listen to labels referring to similar objects (7.99 s, $SE = 0.50$) compared with labels referring to dissimilar objects (6.54 s, $SE = 0.38$; see Fig. 2). We also calculated a preference score for each toddler by subtracting his or her mean listening time on
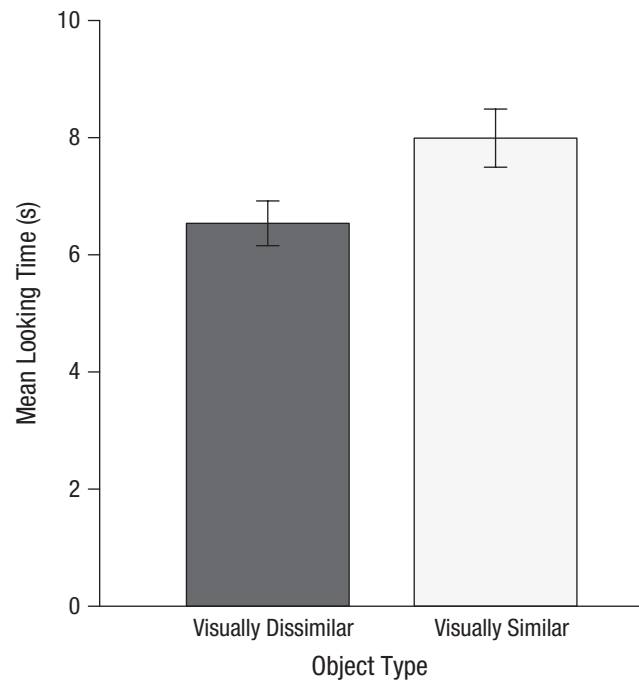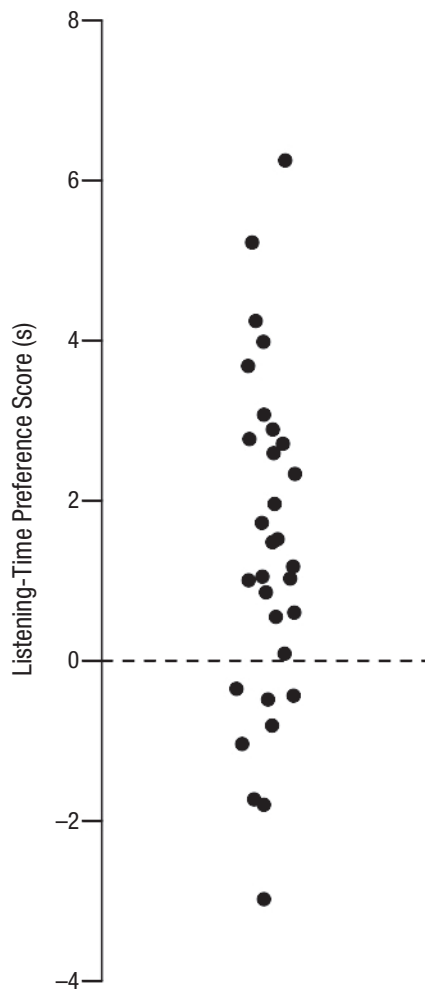

Fig. 2. Results from Experiment 1: mean looking time as a function of whether spoken words referred to visually dissimilar or visually similar objects. Error bars show standard errors.

dissimilar-object trials from his or her mean listening time on similar-object trials. Of the 32 participants, 25 had a positive preference score, which indicates that they listened longer on similar-object trials than on dissimilar-object trials (see Fig. 3).

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 among the referents. The visual similarity of the referents 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 that toddlers encoded about the visual similarities among 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 four unique label-object pairs during training. Instead, they may have categorized the similar objects together, treating their labels as synonyms, or they simply may not have learned the words robustly enough to distinguish among the visually similar referents. For example, if *tursey* and *coro* referred to the two blue ovals, it could be that toddlers treated the labels as interchangeable or were confused about which word

Fig. 3. Results from Experiment 1: scatter plot showing mean listening-time preference scores. Preference scores were calculated by subtracting each participant's mean listening time on dissimilar-object trials from his or her mean listening time on similar-object trials.

referred to which object. If the data reflect this alternative hypothesis, and toddlers underlearned the lexical structure provided in Experiment 1, the results do not address our original hypothesis concerning the encoding of similarity structure among the referents but instead simply reflect category learning (blue ovals vs. red stars). To tease apart these two hypotheses, we conducted a second experiment designed to determine whether the training procedure from Experiment 1 resulted in the specific learning of all four label-object pairs.

Experiment 2

In this experiment, we used the same training procedure as in 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 investigated whether toddlers could 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, 13 female) with a mean age of 27.8 months (range = 26.11–28.12). Seven additional toddlers were excluded from the analysis because of inattentiveness ($n = 4$) or experimenter error ($n = 3$). The remaining participants were comparable with the Experiment 1 participants in their expressive MacArthur-Bates CDI scores (64 vs. 67.2, respectively, out of a possible score of 100), $t(54) = 0.52$, $p = .61$.

Stimuli and design. The training stimuli were identical to those used in Experiment 1. On each of the 16 test trials, two of the novel objects were displayed, one on the bottom left and one on the bottom right of the screen. Toddlers heard a prerecorded sentence directing them to one of the objects. Half of the test trials contrasted similar novel objects (i.e., either the two blue ovals or the two red stars). The other half contrasted dissimilar objects (i.e., one blue oval and one red star). 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 required participants to have encoded the fine-grained details differentiating two perceptual neighbors, whereas successful word recognition on the dissimilar-object trials did not.

Procedure. The training procedure was identical to that in Experiment 1. The test phase began with two trials using familiar objects (shoe and dog); these trials were intended to orient participants to the task. Next, participants viewed the novel-object trials in four blocks of four trials each. The test trials began with two objects presented in silence (1.5 s). 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 s of silence.

Each test block consisted of one trial for each label. The blocks consisted 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 an equal number of times 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 CDI (Short Form Level II; Fenson et al., 2000).

Results and discussion

The primary question was whether 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, the proportion of looking time to the target object after hearing its label should increase. A baseline window (from 450 ms to 2,450 ms) represented prelabeling behavior. The target window started at 2,750 ms, beginning 300 ms after the noun onset to allow for the planning of eye movements (Fernald et al., 2008), and was 1,500 ms 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 10 consecutive frames in which the participant was not attending to the stimuli (32 out of 386 total were excluded).

A paired-samples *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* < .001 (see Table 1). This suggests that the toddlers learned the novel words. However, as noted previously, there were two types of test trials: dissimilar-object trials, in which toddlers had to locate the target given one of the blue objects and one of the red objects, and similar-object 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-object trials.

Follow-up analyses were conducted to examine the dissimilar-object and similar-object trials separately. A paired-samples *t* test comparing the baseline and target windows for the dissimilar-object 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* < .005. We found the same pattern for the more challenging similar-object trials, *t*(23) = 3.06, *p* < .01 (see Fig. 4 and Table 1). To compare performance on the two trial types, we calculated difference scores for each subject by subtracting baseline-window accuracy
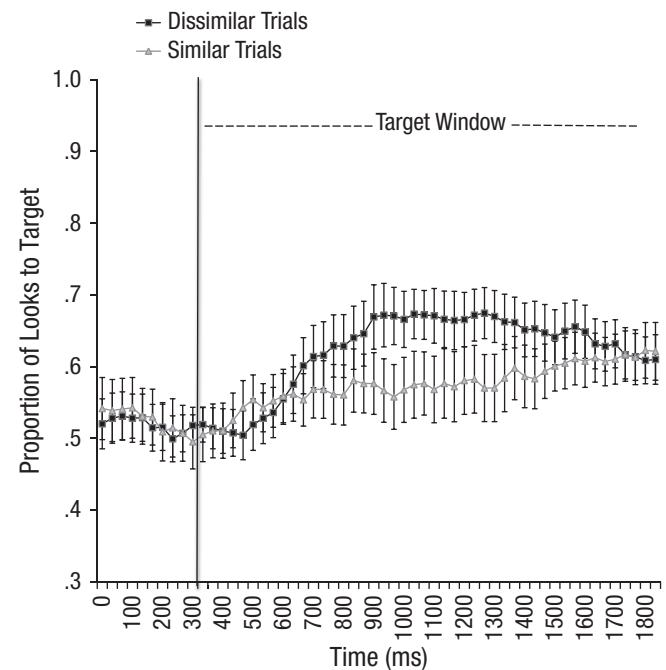
Table 1. Results From Experiment 2: Mean Proportion of Looks Infants Made to the Target Object in the Baseline and Target Windows

Trial type	Baseline window	Target window
All	.50 (.009)	.60 (.022)
Dissimilar object	.51 (.018)	.62 (.031)
Similar object	.49 (.013)	.59 (.025)
Red star	.47 (.028)	.61 (.041)
Blue oval	.50 (.025)	.61 (.032)

Note: Standard errors are given in parentheses.

from target-window accuracy for both similar- and dissimilar-object trials. A paired-samples *t* test comparing those difference scores revealed no significant difference between trial types, *t*(23) = 0.41, *p* = .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.

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

Fig. 4. Results from Experiment 2: mean proportion of looks infants made to the target object as a function of time and trial type. The vertical line marks the beginning of the target window (300 ms after the onset of the spoken word, to take into account eye movement planning; Fernald, Zangl, Portillo, & Marchman, 2008). Error bars show standard errors.

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 the visual object associated with 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 among similar referents during the word-learning process.

General Discussion

When people think about word learning, they tend to focus on how children acquire the mapping between sounds (or signs) and their referents. However, it has been shown that the links among meanings underpin people's conceptual knowledge (see McClelland & Rogers, 2003). The current study was designed to take a first step toward understanding the ontogenesis of the associations composing a semantic network by looking at what toddlers learn about semantic relationships during their initial exposure to new words.

In Experiment 1, we investigated whether toddlers encode the relationships among word referents when learning novel words. Participants were taught four novel words that referred to four novel objects consisting of two visually similar pairs. Toddlers listened significantly longer to word pairs labeling visually similar referents than 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 four novel word-referent pairings as distinct lexical entries. Together, our two experiments suggest that although toddlers learn novel word-referent associations, they also encode the relationships among 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 among the referents. The training provided ostensive labels for four novel objects,

but toddlers learned more than just this one type of association. They also took into account other relationships, such as those among the referents.

The demonstration that early lexical representations include information about visual similarity among 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). According to this view, young learners encode the visual overlap among the referents of different words much as they encode the auditory overlap of their labels. If this is the case, then what is known about early lexical representations can inform the study of early semantic representations. For example, Hollich et al. (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 among 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 than novel words without many semantic associations (Hills, Maouene, Riordan, & Smith, 2010). With the results from the current studies in hand, researchers can use findings from the auditory domain to advance the understanding of how semantic relationships interact with word learning.

The current results can also help to expand how people 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 two-dimensional screen. Because of this stripped-down artificial situation, it is unclear whether participants' resulting knowledge is wordlike. In these lab settings, infants may just be forming an association between a sound and a picture. Although this type of association is an important component of word learning and knowledge (e.g., Smith & Yu, 2008; Vouloumanous & 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 among words. Our findings thus provide evidence that when researchers employ traditional word-learning paradigms that teach new words in

short training sessions, they 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 is known about adult lexical representations to investigate when and how toddlers acquire that knowledge. For example, it is known 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, & 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, in which relationships among words might be somewhat more abstract. By manipulating the structure of the artificial lexicon, research can 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 (IPP) 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 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. Adults know many important relationships among words, and this connectedness is a crucial component of people's semantic and linguistic systems. Investigating the emergence of these relationships will help researchers 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 an 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.

Author Contributions

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

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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