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Toddlers Activate Lexical Semantic Knowledge in the Absence of Visual Referents: Evidence from Auditory Priming

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Language learners rapidly acquire extensive semantic knowledge, but the development of this knowledge is difficult to study, in part because it is difficult to assess young children's lexical semantic representations. In our studies, we solved this problem by investigating lexical semantic knowledge in 24-month-olds using the Head-turn Preference Procedure. In Experiment 1, looking times to a repeating spoken word stimulus (e.g., *kitty-kitty-kitty*) were shorter for trials preceded by a semantically related word (e.g., *dog-dog-dog*) than trials preceded by an unrelated word (e.g., *juice-juice-juice*). Experiment 2 yielded similar results using a method in which pairs of words were presented on the same trial. The studies provide evidence that young children activate of lexical semantic knowledge, and critically, that they do so in the absence of visual referents or sentence contexts. Auditory lexical priming is a promising technique for studying the development and structure of semantic knowledge in young children.

Understanding the structure and origins of semantic knowledge is one of the central problems in the study of cognition. Researchers have made considerable progress toward characterizing semantic knowledge structure

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and its brain bases (see, e.g., Bloom, 2000; Jackendoff, 2010; Mandler, 2000; Martin, 2007; Rogers & McClelland, 2004). However, the origins of this knowledge and how it develops remain controversial. Early investigations used methods that involved explicitly querying children about their knowledge of word meanings (e.g., Gelman & Wellman, 1991; Keil, 1983), and these methods have been useful in understanding young children's explicit semantic knowledge. Only recently, however, have researchers begun to use implicit methods to examine early lexical semantic knowledge in younger children (e.g., Meints, Plunkett, & Harris, 1999; Styles & Plunkett, 2009). In this article, we report two studies using an auditory paradigm adapted from adult lexical priming studies (e.g., Meyer & Schvaneveldt, 1971; Moss, Ostrin, Tyler, & Marslen-Wilson, 1995) to examine the semantic knowledge of very young children, in the absence of images of the named referents or useful sentence contexts. Together, these studies test whether early lexical knowledge includes an understanding of the relationship between the meanings of various words, and whether by 2 years of age, this knowledge is activated in the absence of visual referents and even when single words are uttered in isolation.

Our research built on a recent study using implicit measures to explore infants' sensitivity to lexical semantic information. Arias-Trejo and Plunkett (2009) used an intermodal preferential looking paradigm (IPL) to examine 18- and 21-month-olds' responses to related prime–target pairs such as *cat*-*dog*, compared with unrelated pairs such as *plate*-*dog*. Arias-Trejo and Plunkett chose their related pairs to be both strongly associated (according to adult associative norms) and highly imageable. Infants first heard a phrase such as "*I saw a cat,*" followed by a target word ("*dog*"). They then concurrently saw two images, one related (e.g., a dog) and one unrelated (e.g., a door). The dependent measure was looking time to the pictures. Their primary manipulation was whether the initial phrase contained a prime word related to the target word and picture (e.g., "*I saw a cat…dog*") or an unrelated word (e.g., "*I saw a plate…dog*"). Eighteen-month-olds looked significantly longer to the picture named by the target word (*dog*), regardless of whether it had followed a related or an unrelated prime phrase. In contrast, 21-month-olds looked significantly longer to the named picture in the related prime–target condition ("*I saw a cat…dog*") but not in the neutral prime–target condition ("*I saw a plate….dog*"). Styles and Plunkett (2009) used the same paradigm, again with word pairs that were highly associated based on adult norms, and found a priming effect in 24-month-olds, but not 18-month-olds. The older children's sensitivity to the semantic relatedness of the previous sentence provides evidence for lexical semantic organization in infants, and the age-related differences suggest that semantic relationships between words are learned between 18 and 21 months of age (see Mani & Plunkett, 2010, for related evidence concerning phonological priming). The studies by Arias-Trejo, Plunkett, and colleagues demonstrate that by 2 years of age, children are acquiring semantic knowledge that involves similarity structure and that this similarity structure leads to behavioral consequences, such as affecting eye movements to related visual images.

However, these studies also leave open a number of interesting questions. How strong, rich, and accessible are children's semantic similarity representations, and how much context do children need to retrieve and use these representations? It is well established that the richer the cue, the easier it is to activate a representation (Craik & Lockhart, 1972; Fernald & Hurado, 2006). In Arias-Trejo and Plunkett's study, the words' retrieval cues were quite rich, including an enriching sentence context for the prime and a visual image of the target. How critical were the visual images to the activation of that target word? Because the IPL method involves hearing language, attending to a visual stimulus, and responding to the visual stimulus as a result of the linguistic input, the results from this paradigm do not mediate between a number of different theories that underlie semantic memory and semantic priming (see Hutchison, 2003; for a review). For example, the children could have been demonstrating word–word semantic priming; alternatively, children could also have been making a similarity judgment between the auditory prime and a combined cue of the auditory target and the visual image of the target. In a follow-up experiment, Arias-Trejo and Plunkett showed that there is no priming effect if there is no auditory presentation of the target word. For example, if children heard the sentence, "*I saw a cat… look*!", they did not show a difference in looking time between a subsequently presented related picture (a dog) and an unrelated picture (a plate). This suggests that hearing the target word was necessary for activating the semantic relationship between the prime word's concept and the visual target's concept. However, they did not test a condition where children heard the target word but did not see the picture (as this would be impossible in the IPL paradigm, which relies on children's looks to visual targets). Thus, it is unclear whether 21-month-olds only need to hear the target word to determine its similarity to the prime, or if they need a richer, audiovisual cue.

Equally of interest, how important was the prime's sentence context for activating a complete representation of the prime? Some of the verbs in Arias-Trejo and Plunkett's carrier phrases included a considerable amount of semantic information; some trials presented primes like "*I* <u>*ate*</u> *a biscuit*", followed by the targets "*cheese*" and "*chair*". Even the more neutral verbs from the study, like *buy* and *see*, are probably not truly neutral, as the affordances of those verbs to different nouns will vary. Some objects are more likely to be bought than others, a fact that children may know conceptually or linguistically (due to word cooccurrence statistics or more complex lexical semantic knowledge). We know that 2-year-olds activate semantically related nouns when processing verbs (Fernald, 2004). As a consequence, the exact locus of the semantic facilitation effects in Arias-Trejo and Plunkett's study is ambiguous. The effect could have been due to semantic relationships between the prime and target nouns that were easily accessible regardless of sentence context. But, the effects could also have been dependent on the infant having the full sentence and using it to activate a richer representation of the noun's semantics.

The goal of our studies was to ask whether children's knowledge of the meaningful relationships between words is accessible and usable in the absence of any additional context, including visual images and sentential contextual support. Specifically, we were interested developing a paradigm that more similar to adult semantic priming methodologies, to investigate whether this semantic knowledge can be activated in the absence of pictures of the named referents. In contrast to the previous IPL studies, the stimuli in our current experiments were decontextualized single words. Thus, with our auditory paradigm, we can directly ask whether toddler's lexical knowledge, in the absence of other contextual cues, includes the semantic relationships between words.

There is previous work that has examined the semantic relationships that young children activate when they hear auditory words in isolation. Torkildsen, Syversen, Simonsen, Moen and Lindgren (2007) used evoked potentials to examine the processing differences between semantically related and unrelated pairs of auditorily presented words to 24-month-olds (see also Friedrich & Friederici, 2005). They defined relatedness in terms of membership to the same superordinate category. Torkildsen et al. found a broadly distributed N400 effect for semantically unrelated word pairs, similar to effects in adults (see Kutas & Federmeier, 2011 for a review). Unfortunately, the basis of the effect is again somewhat unclear due to the nature of their experimental design. Semantic priming experiments with adults use counterbalanced designs in which the same stimulus words appear in both related and unrelated conditions, to control for other lexical factors that affect performance, such as word frequency, familiarity, and imageablity (McNamara, 2005). Torkildsen et al. did not follow this procedure and used different words for related and unrelated trials (e.g., they compared the results of trials like *dog*-*horse* to trials like *car*-*apple*, rather than comparing trials like *dog*-*horse* to trials like *car*-*horse*). Hence, the observed effects could be due to the relatedness manipulation, but they could also be due to other properties of the stimuli nested within condition (i.e., differences in the frequency or imageablity of the target words that happened to be in the two conditions). We chose our stimuli such that each word served as its own control, participating in both a related and unrelated pair, to address this methodological issue.

The present studies used a simple auditory paradigm, inspired by semantic priming studies, to examine semantic knowledge in 24-month-olds in the absence of related visual stimuli. The two experiments employed a modified version of the Head-turn Preference Procedure (HPP; Kemler Nelson et al., 1995). In Experiment 1, each trial consisted of repetitions of a single word (e.g., *kitty-kitty-kitty*). The word presented on the preceding trial was either semantically related (e.g., *dog-dog-dog*) or unrelated (e.g., *shoe-shoe-shoe*). In Experiment 2, each trial consisted of repetitions of a pair of words that were either semantically related (*dog-kitty*) or unrelated (*shoe-kitty*). The principal question in both studies was whether responses to the words would be modulated by the semantic relatedness of other words, either across trials (Experiment 1) or within trials (Experiment 2). Together, the two studies allow us to perform two different tests of the important theoretical question of whether there is behavioral evidence that toddlers activate lexical semantic knowledge in the absence of visual referents or sentence contexts.

The studies also make an important methodological contribution by showing that the HPP can be used to adapt auditory semantic priming procedures for use with young children. Hundreds of studies have used HPP to test infants' and toddlers' ability to discriminate between stimuli based on both preexisting knowledge as well as what they can learn during an experimental session. While HPP is typically used with younger infants (between 6 months and 18 months), this is largely due to the fact that it has been employed most often to test hypotheses involving perceptual discrimination at those ages. Indeed, HPP has also been used with older children in the 20–36 month age range to investigate toddlers' knowledge of meaning, syntax, and the relationship between the two (Höhle, Schmitz, & Santelmann, 2006; Nazzi, Barrière, Goyet, Kresh, & Legendre, 2011; Santelmann & Jusczyk, 1998; Soderstrom & Morgan, 2007; Willits, J. A., Lany, J., & Saffran, J. R., 2012, in review). HPP, unlike the IPL procedure, allows us to present purely auditory stimuli without relying on toddlers' looks to specific images as a dependent measure. Moreover, HPP is considerably less expensive and easier to run with young children than EEG and other methodologies that rely on neurophysiological responses.

EXPERIMENT 1

In Experiment 1, we adapted a classic priming method used with adults for use with young children. In the simplest priming procedures (such as in Meyer & Schvaneveldt, 1971), participants are presented with a prime word followed by a target word and are asked to make a behavioral response to the target word, such as reading the word aloud or making a lexical (word/nonword) decision. Other research has employed a continuous variant of this task in which participants make a response to each stimulus, with semantic relatedness varied across trials (McRae & Boisvert, 1998; Moss et al., 1995; Nation & Snowling, 1999; Shelton & Martin, 1992). The semantic priming effect refers to faster responses when the prime and target are semantically related (e.g., *bread-cake*) compared with unrelated controls (e.g., *chair-cake*). Priming methods have been used to investigate questions about the structure and processes of semantic memory in adults (Ferretti, McRae, & Hatherell, 2001; McNamara, 1992; Moss et al., 1995; Neely, 1991) and older children (Nation & Snowling, 1999; Plaut & Booth, 2000).

Extending this approach to toddlers and infants has clear benefits for understanding the early development of semantic knowledge. Experiment 1 used the HPP, and on each trial, the child listened to repetitions of a highly familiar word. Starting with trial 2, the word the child heard on the preceding trial was either meaningfully related (e.g., "*kitty*") or unrelated (e.g., "*shoe*") to the word on the current trial (e.g., "*dog*"). If by 24 months, toddlers have begun to develop representations of word meaning that are sufficiently specific to encode relatedness, listening times should differ for trials on which a word was preceded by a related word, compared with trials on which the same word was preceded by an unrelated word.

One important issue surrounding any study testing for knowledge of semantic relationships is how one defines a semantic relationship. In the adult priming literature, there is considerable debate about the different ways in which words can be related and which types of relatedness lead to priming. The types of relationships explored have typically been broken down along two dimensions. The first is when words' referents are similar in some way (i.e., share semantic features or belong to the same taxonomic category). When words that are related in these ways prime each other, this is typically referred to as "semantic" priming (McRae & Boisvert, 1998; Neely, 1977).[1] Semantic relationships also encompass situations where words or their referents cooccur with high frequency, participate in the same thematic relations, or elicit each other in word association

[1]This label is perhaps unfortunate, given the more general and precedential usage of "semantic" to refer to meaningful relations more broadly, or to distinguish knowledge about words' meanings from knowledge about words' referential concepts (Bloomfield, 1933; Osgood, 1952).

norms. When words related in these ways prime each other, this is typically referred to as "associative" priming (for reviews of the differences between these types of priming in the adult literature, see Hutchison, 2003; Lucas, 2000; and McNamara, 2005). The infant study by Arias-Trejo & Plunkett (2009) chose their pairs based on adult word association norms, and thus can be thought of as a study of "associative" priming, whereas the study by Torkildsen et al. chose words from the same category, and thus would be considered an example of semantic priming.

Our goal in these initial studies with 2-year-olds is not to address the differences between types of semantic relationships. Instead, we were interested in determining whether young children show priming effects *at all*, in purely auditory single-word contexts. As such, we chose our related pairs so that they were highly related along multiple dimensions (e.g., taxonomic overlap, thematic relatedness, shared semantic features, high associativity) to maximize the potential for observing priming effects in this age range. The primary goal of these studies was to test for semantic effects in the absence of visual imagery or sentence contexts and to establish the viability of the Head-turn methodology for testing these questions.

We chose to study 24-month-olds in light of previous studies examining knowledge of relations between word meanings in young children. In their studies using the IPL method, Styles and Plunkett (2009) found a priming effect in 24-month-olds but not 18-month-olds, and Arias-Trejo and Plunkett (2009) found a priming effect in 21-month-olds but not in 18-month-olds. Other research has found that 24-month-olds activate properties (such as color) or a word's meaning when they hear that word (Johnson, McQueen, & Huettig, 2011; Swingley & Fernald, 2002). Because of the novelty of our method, and especially due to the removal of all contextual cues to a word's meaning, we studied 24-month-olds in order to ensure that participants had the requisite knowledge for the task.

Using the HPP methodology offers one further potential advantage. The extensive body of work using the procedure may allow us to make directional hypotheses about toddlers' looking behavior. Infants could show a familiarity bias (longer looking to familiar or related stimuli) or a novelty bias (longer looking to unfamiliar or unrelated stimuli). Hunter and Ames (1988, see also Houston-Price & Nakai, 2004) have argued that infants' novelty and familiarity biases in HPP will follow a predictable trajectory as a function of their familiarity with the stimuli. If infants are extremely familiar with the stimulus (either due to long exposure times or strong preexisting knowledge of the stimuli) they tend to show a novelty bias in the experiment. In contrast, if infants have low familiarity, they tend to show a familiarity bias. In our experiments, as we used high frequency words that children of this age were likely to know very well

TABLE 1
Stimulus characteristics for individual words in Experiments 1 and 2

Word	*MCDI percentile*	*Childes percentile*	*Freq. per million words*	*Intensity (dB)*	*Duration (msec)*	*Ave. pitch (Hz)*
Dog	91.6	98.0	477.9	70.99	620	248.5
Kitty	81.3	99.0	1325.2	66.89	500	281.2
Shoe	82.2	96.7	279.1	67.76	800	200.9
Sock	90.7	94.1	122.6	71.06	802	264.5
Juice	87.9	98.3	617.0	66.59	720	310.9
Milk	81.3	97.6	383.5	66.46	667	251.9
Mouth	77.6	98.5	659.3	69.70	705	217.3
Nose	85.0	98.4	708.1	69.02	790	242.1

(see Table 1), then under Hunter and Ames hypothesis we would predict to find novelty effects; if infants are sensitive to the semantic relationships between the words, they ought to listen longer to unexpected stimuli (e.g., have longer listening times on unrelated trials).

METHOD

Participants

Participants were 32 monolingual English-learning toddlers (16 male) with a mean age of 24 months (M = 24.3, range = 22.5–25.4). All participants were full-term, were reported to have normal vision and hearing, and were from households with a minimum amount of exposure to non-English languages (<4 h/week of exposure to another language). One additional toddler was unable to sit through the task and was excluded from the analyses.

Stimuli and design

While adult priming studies benefit from the use of word association norms in choosing appropriate stimuli, there is no equivalent database for young children. Thus, we relied on Dale and Fenson's (1996) MCDI lexical development norms to choose words that at least 75% of 24-month-olds are reported to understand. We further constrained our choice of stimuli such that the words could be arranged into highly related word pairs. Within each pair, the words were related along a number of different dimensions, including shared taxonomic category membership; similar thematic relations; high semantic feature overlap in normative evaluations of semantic features (McRae, de Sa, & Seidenberg, 1997); and often high associativity in normative measures of word association in adults (Nelson, McEvoy, & Schreiber, 1999).

The stimuli, spoken by an adult female in an infant-directed register, consisted of eight words: *dog*, *kitty*, *shoe*, *sock*, *juice*, *milk*, *mouth*, and *nose*. We limited our study to these eight words to reduce the amount of interitem variance. The stimuli were also equated for volume, pitch, and the length of trials such that these factors were not confounded with relatedness condition. In addition, we also calculated the frequency of the words in a corpus of child-directed speech, created by combining all samples of child-directed speech from the CHILDES database (MacWhinney, 2000) for children up to 24 months of age. We converted these frequencies to percentiles, finding that all of our words were in at least the 94th percentile (e.g., of all the words in the CHILDES corpus database, our words were in the top 6% in terms of word frequency). The eight items and their stimulus properties are shown in Table 1.

The words were then organized into lists consisting of 16 trials. On each trial, one word was repeated with a 750 ms pause between repetitions. Half the trials were preceded by a trial containing repetitions of the related word (e.g., *dog* on trial n, *kitty* on trial $n - 1$), and half were preceded by repetitions of an unrelated word (e.g., *dog* on trial n, *shoe* on trial $n - 1$). As described above, we chose the related pairs in order to maximize relatedness among many dimensions, maximizing the chance of finding an effect, resulting in the related pairs "*dog*-*kitty*," "*shoe*-*sock*," "*mouth*-*nose*," and "*milk*-*juice*." The pairings and their word association strengths from adult behavioral norms (in both directions, e.g. *dog*-*kitty* and *kitty*-*dog*) are shown in Table 2.

The unrelated pairs were created by pseudorandomly repairing the items for each participant, with the constraint that pairings that would have resulted in thematic relationships (such as *mouth*-*juice* or *kitty*-*nose*) were not allowed as unrelated items. In addition, the word association strength in adult norms for unrelated pairings was always zero. Thus, for some participants, the unrelated trial that preceded the *shoe* trial may have been *dog*, and for others, it may have been *juice*. Importantly, within each participant's stimulus list, they heard each word exactly twice, once as a related trial and once as an unrelated trial. This technique of randomly repairing unrelated items across different participants is common in the adult semantic priming literature (McNamara, 2005), as it leads to a better estimate of the actual unrelated average response time, rather than reflecting idiosyncratic relationships that may exist for particular unrelated pairings if the same unrelated pairing is used for every participant in the experiment. The set of related stimulus pairings, as well as their word

TABLE 2
Association strength of related pairings in Experiments 1 and 2

Related pair	*Association strength*
Dog-kitty[a]	0.667
Shoe-sock	0.212
Juice-milk	0
Mouth-nose	0.011
Kitty-dog	0.513
Sock-shoe	0.617
Milk-juice	0
Nose-mouth	0.149

Note. [a]The association strength is the proportion of adult participants who, when given the first word as a cue, generated the second word as an association (Nelson et al., 1999). The table shows the association strength for the related pairings used in the experiment. The association strength of all unrelated pairings used in both experiments (e.g. dog-juice) was always zero. The listed association strengths for *dog* and *kitty* are actually those for *dog* and *cat* (*dog and kitty* were not normed in the Nelson et al. study).

association strengths in the related and unrelated conditions, are shown in Table 2.

We created different pseudorandomized experimental lists for the 32 participants, counterbalancing three factors: (1) each participant heard each word in both a related and unrelated context, with the order of which condition they heard first counterbalanced across participants; (2) to control for asymmetric association effects (e.g., *shoe* given *sock* has a higher association strength than *sock* given *shoe*), half the participants heard the pairs in one order (e.g., *sock*-*shoe*) and the other half heard the reverse order (*shoe*-*sock*); (3) all pairs' side of presentation was counterbalanced; for example, one participant's *shoe* and *sock* trials were both presented from the left side, a second heard both from the right, a third participant heard *shoe* from the left and *sock* from the right, and a fourth heard *shoe* from the right and *sock* from the left. An example stimulus list for the experiment is shown in the Appendix, but it is important to note that this is a single example stimulus list, and many others lists were used to pseudorandomize the presentation order of the items.

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 neutral visual stimuli were presented on three computer monitors positioned at the infant's head-level approximately three feet away. One monitor was placed directly in front of the infant, and the other two were placed 90º to the infant's left and right. The auditory stimuli were presented on wall-mounted speakers directly below the three monitors. Presentation of stimuli and collection of the experimenter's button presses were controlled by HABIT software (Cohen, Atkinson, & Chaput, 2000).

Each trial began with a central attention-getting stimulus (a scene of a balloon and clouds) paired with music playing from the center speaker. Once the infant oriented to the center, the experimental stimulus began to play on either the left or right side. This stimulus consisted of a neutral visual stimulus (a spinning pinwheel, used on every trial) and one of the eight spoken target words repeated with 750 ms of silence between repetitions. The word was repeated until the infant looked away for more than 2-sec, or for a total of 15 sec, whichever came first. The experimenter outside the booth, who was blind to the stimulus presented on each trial, used button presses to keep track of the infant's looking behavior. The dependent measure on each trial was the total time the infant spent looking at the monitor on the side from which the experimental auditory stimulus was presented.

After the experiment, the child's caregiver was debriefed and given a questionnaire containing the eight target words and four filler words that were not used in the study. They were instructed to provide a 1–7 confidence rating for whether their child did (rating 7) or did not (rating 1) know the meaning of the words. All but two infants were at ceiling (7) for all 16 words. Nearly identical results were obtained in analyses (not reported here) that excluded data from the trials for the words that the two infants were reported not to know.

RESULTS AND DISCUSSION

The principal data consist of mean looking times for each participant on related and unrelated trials, collapsing across items. We also computed mean looking times for each item for related and unrelated trials, collapsing across participants. The first trial for each participant was discarded because it was not preceded by another stimulus. Ten additional trials (across seven participants) out of a total of 480 trials (15 trials $\times$ 32 participants) were excluded due to participant inattention (e.g., crying, or never looking to the stimulus side during the trial). The results for all of the included trials are presented in Figure 1. In line with our directional hypothesis, infants looked longer on unrelated

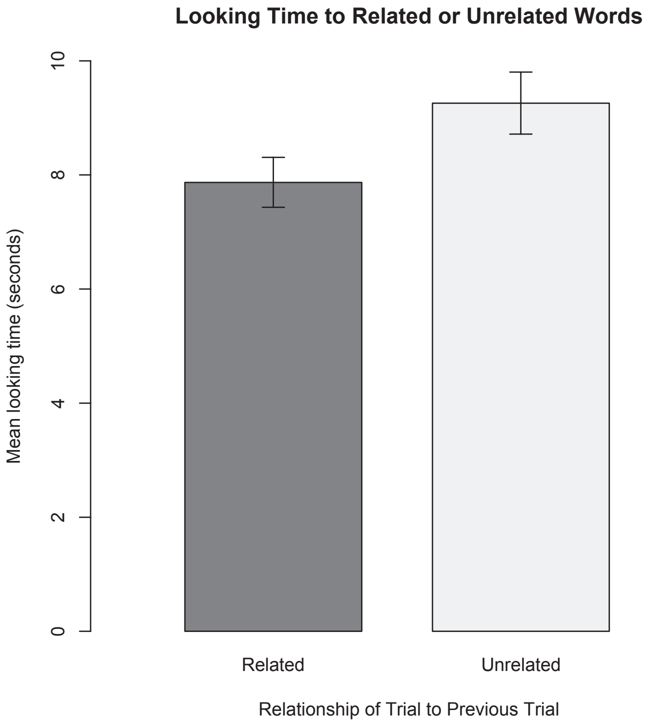

Figure 1 Mean looking times for trials that followed a related word and trials that followed an unrelated word.

trials (M = 9.18 sec, SE = 0.54 sec) than on related trials (M = 8.04 sec, SE = 0.44 sec.). This effect was significant both by participants [$F_1(1, 31) = 9.69$, $p < 0.01$, $\eta^2 = 0.24$] and by items [$F_2(1, 7) = 6.56$, $p < 0.05$, $\eta^2 = 0.48$]. The size of this effect, both in terms of the difference score between conditions (approximately 1.5 sec) as well as the statistical effect size (0.24/0.48) are in line with typical effect sizes using HPP to test for infants' abilities to discriminate familiar from novel stimuli (Houston-Price & Nakai, 2004).

To completely rule out the possibility that the differences were due to acoustic factors or other factors unrelated to meaningful differences between the words, a mixed-effects model was used to analyze the data (Baayen, Davidson, & Bates, 2008). In this model, we used participant and target as random factors; the fixed factors were relatedness, duration of the current target (in milliseconds), difference between duration of the current and previous trials, side of presentation, and whether the previous trial was on the same side. In this analysis, only relatedness was a significant predictor of looking time ($t = 2.11$, $p < 0.05$).[2]

To summarize, in Experiment 1, we show that 24-month-olds exhibit a relatedness effect, similar to the priming effects found in adults for spoken words: looking times were shorter on trials for which the preceding trial contained a semantically related word, just as reaction times for adults are faster after a semantic prime in lexical decision tasks. Our results are also consistent with those of Arias-Trejo and Plunkett (2009) and Styles and Plunkett (2009), who found evidence for semantic organization of the infant lexicon toward the end of the second year. Our experiments expand upon their results by showing that by 24 months, toddlers' representations of words and the similarity structure between those representations (at least for highly frequent words) are easily retrievable. The effects of semantic similarity exist even when the stimuli are purely auditory words presented in isolation, without any enriching visual or sentential context. These results are also consistent with Torkildsen et al.'s (2007) EEG results, which also found that by 24 months of age, toddlers show differential brain activation as a function of words' semantic relatedness. Our findings further demonstrate that semantic relationships between words have behavioral consequences in the form of infants' listening times to words, and thus can be measured without more expensive and difficult to employ methodologies such as measuring EEGs.

A question that emerges from the results of Experiment 1 is whether the semantic relatedness effect is contingent on the specific experimental paradigm that was used. The method used in Experiment 1, in which we repeated a single word on each trial and manipulated the similarity between words across trials, is useful for gaining evidence concerning the development of semantic representations. However, most language input that infants receive does not consist of repetitions of individual words (e.g., "*dog, dog, dog*"), although it should not be discounted that infants do often hear words in isolation paired with the same words in fluent speech (e.g., "Giraffe! Look at the Giraffe!", Aslin, Woodward, LaMendola, & Bever, 1996; Brent & Suskind, 2001; Lew-Williams, Pelucchi, & Saffran, 2011). In order for the results of Experiment 1 to be generalizable, then, it is important to determine whether semantic relatedness

[2]Because mixed-effects models use both the number of participants and the number of items as random factors, the degrees of freedom in these tests are not straightforward as they are in typical significance tests, and thus, it is not standard to report them in the same manner (see Baayen et al., 2008 for details).

effects will emerge under other stimulus conditions. This issue is addressed in our second experiment.

EXPERIMENT 2

In Experiment 2, we examined lexical knowledge using a variation on the task used in Experiment 1. Rather than presenting a single word on each trial and testing the effects of relatedness across trials, we repeated word pairs on each trial and manipulated the relatedness within each trial. Observing effects of semantic relatedness within rather than across trials allows comparisons that may constrain inferences about the cognitive processes underlying the effects. Presenting two words on each trial reduces working memory load compared with Experiment 1, in which related stimuli occurred several seconds apart and were separated by an attention-getting stimulus. Although working memory demands did not preclude finding an effect in Experiment 1, this potential alternate explanation of null results could complicate the interpretation of future studies employing this methodology. It was therefore important to determine whether the priming effect also occurs when memory demands are minimized.

Additionally, for Experiment 2 we collected data concerning the participants' vocabularies. There has been much discussion in the literature concerning the relationship between overall vocabulary level and toddlers' performance in online tasks assessing familiar word recognition (Fernald, Zangl, Portillo, & Marchman, 2008; Swingley, Pinto, & Fernald, 1999) and novel word learning (e.g., Graf Estes, Edwards, & Saffran, 2011; Havy & Nazzi, 2009; Lany & Saffran, 2011; Nazzi, 2005; Werker, Fennell, Corcoran, & Stager, 2002). Parent report measures of toddlers' vocabulary levels were therefore used to assess whether semantic relatedness effects were correlated with vocabulary development.

METHOD

Participants

The participants were 32 monolingual English-learning toddlers (16 male) who had not participated in Experiment 1, with a mean age of 24 months (M = 24.5, range = 22.7–25.8). The participants were full term, were reported to have normal vision and hearing and had had a minimal amount of exposure to non-English languages (<4 h/week of exposure to another language). Three additional toddlers were tested but excluded from the analyses due to fussiness or crying during more than half of the trials during the experiment.

Stimuli and design

Each trial consisted of a word pair, repeated with a 750 ms pause between words (e.g., "*kitty…dog…kitty…dog…*"). The words were the same as those used in Experiment 1 (*dog*, *kitty*, *shoe*, *sock*, *juice*, *milk*, *mouth*, and *nose*), again paired to create a set of unrelated pairs (e.g., *dog*-*shoe*, *juice*-*kitty*) and a set of related pairs (e.g., *dog*-*kitty*, *juice*-*milk*). These pairs were used to create a different counterbalanced list for each participant. Each counterbalanced list contained 16 trials; half unrelated and half related. Within each list, the items were counterbalanced such that each participant heard each word twice in a related pair and twice as an unrelated pair and heard an equal number of related and unrelated trials on the left and right side. Between lists, the items were constructed such that the order of the pairs was pseudorandomized, each pair was played on each side for an equal number of participants, each pair occurred an equal proportion of times following a related and an unrelated trial, and the order within the pair (i.e., which word was said first) was balanced across participants. As in Experiment 1, the stimuli were also equated for volume, pitch, and the length of trials such that these factors were not confounded with relatedness condition. The stimulus characteristics for the items in Experiment 2 are shown in Tables 1 and 2, and a sample stimulus list is shown in the Appendix.

Procedure

The procedure in Experiment 2 was identical to the procedure in Experiment 1, with the exception that word pairs rather than individual words were repeated on each trial. After the experiment, the caregiver was debriefed and given the questionnaire used in Experiment 1. All children but two were at ceiling for all of the words used in the study; near identical results were obtained when trials for words that children were reported to not know were excluded. In addition, caregivers filled out a productive vocabulary checklist (MCDI; Dale & Fenson, 1996).

RESULTS AND DISCUSSION

The mean looking times for each participant on related and unrelated trials collapsed across items are presented in Figure 2. Again in line with

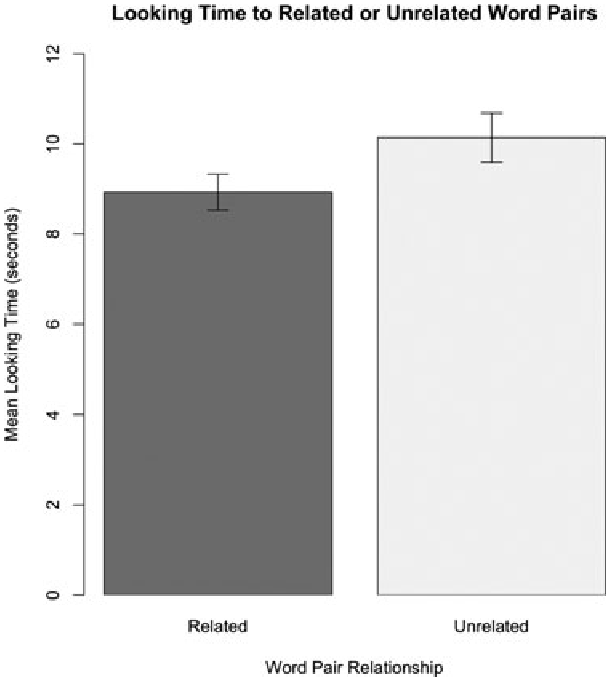

Figure 2 Mean looking times for trials containing related and unrelated word pairs.

our directional predictions, looking times were longer on unrelated trials (M = 10.3 sec, SE = 0.6 sec.) than on related trials (M = 9.0 sec, SE = 0.4 sec.), an effect that was significant when analyzed by participants, $F_1(1, 31) = 6.60$, $p < 0.05$, $\eta^2 = 0.18$, and was marginally significant when analyzed by items $F_2(1, 15) = 4.52$. $p = 0.052$, $\eta^2 = 0.23$. The results replicate the effect we observed in Experiment 1: looking times were shorter when a word was paired with a related word. Thus, relatedness affects the processing of words presented together, as well as on successive trials. As in Experiment 1, we conducted a mixed-effects model to rule out nonmeaningful effects on looking time, such as duration and amplitude. Again, only relatedness was a significant predictor of looking time ($t = 2.12$, $p < 0.05$).

We then examined correlations between a child's vocabulary size and the size of that child's semantic relatedness effect. For each participant, a relatedness effect was calculated by subtracting their mean on related trials from their mean on unrelated trials. In this analysis, there was a weak, nonsignificant correlation between vocabulary size and priming effect

(r = 0.*18*, p = 0.16). The failure to find a significant correlation between vocabulary (MCDI) and the semantic relatedness is consistent with Arias-Trejo and Plunkett (2009), Styles and Plunkett (2009), and Torkildsen et al. (2007) who also failed to find a relationship between vocabulary and time spent looking to a semantically primed target. An ERP study by Friedrich and Friederici (2004) *did* find that high vocabulary 19-month-olds showed stronger, more adult-like effects of semantic relatedness. It is thus possible that 24-month-olds perform at ceiling in our task; younger children (or an experiment using lower frequency words) may show differences in semantic relatedness effects based on vocabulary size. Future experiments can explore this possibility.

GENERAL DISCUSSION

Our knowledge of words includes extensive information about their meanings and how they relate to other words. These word meanings are part of a semantic system that also represents information about objects, individuals, and events. This knowledge is central to language, thinking, reasoning, and other cognitive functions. Many controversies in the study of psychological semantics turn on questions about the origins of this knowledge and how it develops. However, obtaining reliable information about early semantic knowledge is difficult. Our studies show that 24-month-olds' knowledge of word meanings is sufficient to produce relatedness effects both across events (words presented on successive trials) and within an event (word pairs presented within trials) in a purely auditory paradigm and without enriching sentential contextual information. By 24-months of age, toddlers' representation of word meaning, as well as the associative and similarity structures of words, are already quite rich, robust, and easily accessible. Our studies provide convergent evidence, along with studies by Arias-Trejo and Plunkett (2009) and by Torkildsen et al. (2007), that by this age, children are successfully representing the semantic relations between words when processing language.

Our findings also demonstrate that the extension of the HPP to the semantic realm has considerable promise. However, this work should not be taken as an argument that HPP is always the best method for investigating semantic development. Different methods have different advantages depending upon the questions being asked (as well as the resources that are available, in the case of studying ERPs). In principle, one important advantage of the IPL paradigm used by Plunkett and colleagues (as well as EEG studies like Torkildsen et al.'s) is that it tracks behavior over time, and thus, it provides a window into the time course of young children's online processing of primed words. The IPL priming papers published thus far, however, have not reported time-course analyses, making it difficult to ascertain whether or not the IPL procedure provides interpretable reaction time data in practice. Additional work is needed to explore this possible IPL advantage.

A clear benefit of the HPP method, on the other hand, is that it allows for the exploration of lexical knowledge without the presence of related visual stimuli, providing a more direct test of purely auditory lexical knowledge. The IPL priming methodology, along with other IPL designs, is limited to stimuli that are highly concrete and imageable, and in fact Arias-Trejo and Plunkett (2009) used imagability measures to choose their stimuli. Because HPP does not require visual representations of the stimuli, future studies can examine nonimageable, nonconcrete words that are not well suited to eye-tracking methods.

In addition to the IPL and HPP methods, the ERP paradigm used by Torkildsen et al. (2007) is also applicable to the study of the development of semantic relationships. Corroborating behavioral data are often useful to confirm that neurological activity translates to expected behavioral outcomes (Picton & Taylor, 2007), and thus, the HPP provides a nice compliment to ERP findings. It should also not be discounted that the HPP design is considerably cheaper to implement and thus is accessible to more researchers. The greater sensitivity of infant ERP methods is important, though, and therefore the continuation of both neurological and behavioral research programs, and the integration of their respective findings, will lead to a deeper understanding of early semantic representations.

This extension of the priming methodology to young children has considerable potential as a tool for investigating semantic development. Lexical priming has been widely used in studies of the organization of semantic information in adults (McNamara, 1992; McRae et al., 1997; Moss et al., 1995) and its breakdown in cases of brain injury or disease (Chertkow, Bub, & Seidenberg, 1989). The modified HPP used in the present studies can be extended to shed light on many other aspects of young children's word and conceptual knowledge, allowing us to understand the development of the lexical system.

Future work can look at a number of different issues alluded to above, such as how word frequency, age of acquisition, and children's vocabulary size influence semantic priming effects. Future work can also explore the developmental underpinnings of issues that have been explored in the adult research, such as what types of semantic relationships yield an effect. The difference between the methodologies of Experiment 1 and Experiment 2, which manipulates the amount of time between the prime and the target, may also be useful for exploring issues related to retrieval mechanisms. In the adult literature, the duration between the prime and target has been found to affect whether one finds priming between words that are associatively related versus "semantically" related (see Hutchison, 2003; for a review). Likewise, this method may be useful for investigating the developmental underpinnings of other major debates, such as whether semantic priming effects are more likely due to a mechanism like "spreading activation" between related words in a semantic network (Collins & Loftus, 1975; McNamara, 1992) or due to related words forming better "compound cues" to memory (McKoon & Ratcliff, 1992; Ratcliff & McKoon, 1988).

In addition to issues concerning the processes and types of relations represented in toddlers' semantic memory, there are still outstanding questions about how this knowledge is used. One might describe our findings as a "purely lexical" semantic priming effect, in the sense that the children in our study activated and made use of knowledge of word meaning in the absence of nonlinguistic or referential information during the experiment, as well as in the absence of sentential contexts or other supportive linguistic information. However, this does not distinguish between different hypotheses about the locus of these effects. These priming effects could be due to knowledge about the relationships between words. Alternatively, these effects could be due to conceptual knowledge about the words' referents. Distinguishing between these two hypotheses is very difficult, and these two effects are almost always confounded in the adult literature (Willits, J. A., Amato, M. S., & MacDonald, M. C., 2012, in review).

A final outstanding question is the developmental trajectory of these effects. We have provided evidence that children's word knowledge is quite robust by 24 months of age and that it includes the relations between words. Figuring out exactly when these abilities emerge, and how that might differ as a function of the type of relationship (semantic versus associated) or the locus of the knowledge (word knowledge versus world knowledge) will be an important question to pursue in future work.

With basic relatedness effects in hand, future research can focus on further exploring these issues in the development of lexical semantic knowledge. Because of this methodology's simplicity and flexibility, it can be used to investigate many questions about semantic knowledge that could not otherwise be easily addressed.

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APPENDIX

Example stimulus lists for Experiment 1 and Experiment 2

Experiment 1	*Experiment 2*
Doggy	Doggy-kitty
Kitty	Shoe-sock
Shoe	Mouth-nose
Sock	Juice-milk
Juice	Kitty-doggy
Milk	Sock-shoe
Nose	Nose-mouth
Mouth	Milk-juice
Kitty	Doggy-juice
Doggy	Shoe-kitty
Sock	Mouth-sock
Shoe	Milk-nose
Milk	Juice-doggy
Juice	Kitty-shoe
Mouth	Sock-mouth
Nose	Nose-milk

Note. In Experiment 1, one particular toddler heard the words in the exact order shown above, and the other 31 heard pseudorandomized lists fulfilling the same properties (always having each set of two trials contain related words, with the result being that trials alternated in the relatedness of the previous trial (trial 2 was related, trial 3 unrelated, trial 4 related, etc.). In Experiment 2, all toddlers heard the items shown, and the trial order was randomized across participants.