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You Can Stipe the Pig and Nerk the Fork: Learning to Use Verbs to Predict Nouns

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Learning the meanings of words involves learning how those words can be combined into phrases and sentences. This is especially true for predicate terms such as verbs. A verb is the semantic and syntactic heart of a sentence. Each verb specifies how many and what kinds of participant roles are centrally involved in its meaning. Thus, a verb's meaning is intimately connected with the number and semantic categories of noun phrases that can co-occur in sentences with that verb.

Selectional restrictions are constraints that specify what is a semantically appropriate argument of a verb and what is not. Many verbs that children encounter frequently have strong selectional restrictions, such as 'eat,' 'drive,' and 'read.' 'Eat,' for example, specifies that the subject be some animate entity and that the object be some kind of food. While not all verbs have strong restrictions on the kinds of semantic categories their objects can take, we will review evidence below that children, like adults, are guided by verbs' selectional restriction information in many aspects of language processing and learning. The goal of this paper is to begin addressing the question of how children acquire knowledge of verbs' selectional restrictions.

Adults use detailed information about verbs' selectional restrictions in language comprehension (e.g., Altmann & Kamide, 1999; Ferretti, McRae, & Hatherell, 2001). A series of recent studies have shown that very young children are also guided by verbs' selectional restrictions in incremental sentence processing. For example, 2-year-old children more quickly comprehend nouns preceded by semantically related and constraining rather than semantically unconstraining verbs ("eat/take the cookie'), and use semantically constraining verbs to interpret pronouns ("Which one can you eat?"; Fernald, 2004). These results suggest that children use the verb to guide their attention to the visual world, perhaps by restricting the kinds of entities the verb could take as its direct object. The influence of verbs' selection restrictions on children's sentence processing is also evident via neural measures (Friedrich & Friederici, 2005; Pereyra, Klarman, Lin, & Kuhl, 2005): For example, 19- and 24-month-old children show an increased N400, an index of semantic processing, when listening to

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sentences containing direct objects that are inappropriate for the preceding verbs (e.g., "The cat will drink the ball"; Friedrich & Friederici, 2005).

The usefulness of knowledge of verbs' selection restrictions also influences children's sentence production, word learning, and grammar learning. For example, 2-year-olds have more difficulty repeating sentences in which the object violates the verb's selection restrictions (e.g., "The cat is eating a sock") than sentences with appropriate objects ("The cat is eating some food"; Valian, Prasada, & Scarpa, 2006). Toddlers also use a familiar, semantically restrictive verb to constrain the meaning of an unknown noun in object position (e.g., "You can eat the manju"; Goodman, McDonough, & Brown, 1998; Zangl & Fernald, 2005). Finally, selection restrictions provide information relevant to learning about syntactic-semantic subcategories of verbs. Children can learn, for example, which verbs can omit their direct objects based on how semantically restrictive each verb is (Medina, 2007).

Knowledge of each verb's selectional restrictions therefore seems to play a key role in many aspects of language development; thus it is important to ask how knowledge of verbs' selectional restrictions is acquired in the first place. How do children come to learn that 'eat' is closely associated with direct-object nouns that refer to food?

One possibility is that children learn these predictive relationships between verbs and nouns from world knowledge and verb meaning: Children think of edible things upon hearing 'eat' because they know what eating is. They have learned to associate the verb 'eat' with events of consuming edible things, thus knowing that it is more plausible to do the act of eating to food items as opposed to vehicles (e.g., Ferretti, Kutas, & McRae, 2007). Alternatively, children could learn verbs' selectional restrictions in part from linguistic distributional information in the input. By attending to the kinds of nouns a verb occurs with in sentences, children could develop expectations about what nouns are likely to follow that verb (e.g., Resnik, 1996; Willits, Sussman, & Amato, 2008).

These two possibilities—learning from event-derived information and from linguistic distributional information—are not mutually exclusive. In fact, they are related: One would indeed hear a verb used with nouns that are related to the verb's meaning (e.g., "I ate some cake") more frequently than with nouns that are unrelated to the verb's meaning ("I ate a car"). The goal of this paper is to explore whether linguistic distributional information might contribute independently of event-derived information to the learning of verbs' selectional restrictions. We are interested in this route because it does not assume that children have a priori knowledge of the verb's meaning and thus could be particularly useful for learning about a new verb.

One interesting proposal about how linguistic distributional information could play an independent role in the acquisition of verbs' selectional restrictions comes from Resnik (1996). Resnik proposed that selectional restrictions are probabilistic relationships between predicates and conceptual classes of arguments, and can be learned by keeping track of co-occurrence patterns between predicates and noun-phrase arguments in sentences. For example, from sen-

tences containing 'eat', a learner could encode direct-object nouns in terms of pre-existing conceptual classes, and learn to associate the verb 'eat' with the conceptual class of food. Subsequently, when the learner encounters the verb again, she can retrieve the conceptual-class information, activating members of the same class. This allows generalization to sentences containing direct objects that had not been used with the verb. Thus, even without a prior meaning representations for a verb, children might learn its selectional restrictions by observing its patterns of linguistic behavior, keeping track of relations between the verb and the semantic categories of its direct object nouns.

Here we asked whether 2-year-olds can learn an unknown verb's selectional restrictions by listening to sentences. Specifically, can children encode co-occurrence patterns between a new verb and the semantic category of nouns in direct-object position, and generalize the category information to new exemplars in direct-object position?

Success in our task required that children encode linguistic information about a new verb when they hear sentences. Recent findings suggest that children can do so. In one study, for example, 2-year-olds encoded the number of nouns that a novel verb occurred with via listening to dialogues describing unseen events, and later retrieved this information to guide interpretation of the same verb in a referential task (Yuan & Fisher, 2009; see also Arunachalam & Waxman, 2010). Other evidence from the same dialogue-and-test method shows that in addition to the number of nouns, children encode properties of the nouns that occur with novel verbs—such as the animacy of the subject noun phrase (Scott & Fisher, 2009). These findings suggest that toddlers routinely encode combinatorial information about a new verb from listening experience, and later retrieve this information to interpret the verb. The current study extended these findings by focusing on whether children can track the semantic range of direct-object nouns for a verb, without already knowing the verb's meaning.

Success in our task also required that children generalize the category information they encode about a new verb to new members of the category. Artificial-grammar learning experiments show that toddlers are capable of attaching semantic-category information to noun categories formed through distributional learning, and extending the category information to new instances of the noun categories (Lany & Saffran, 2010). The current study asked whether children can extend category-based combinatorial information about a new verb.

1. Experiment 1

In Experiment 1, we asked whether 2-year-olds could learn an unknown verb's selectional restrictions on its direct object from listening to sentences containing the verb. We used a two-phase procedure similar to that of Yuan and Fisher (2009), as shown in Figure 1. In the *listening phase*, children heard 2 novel verbs in transitive sentences. One verb always preceded direct objects referring to animals (e.g., "I stiped the pig"), and the other always preceded direct objects naming household objects (e.g., "She nerked the fork"). No pictures

of objects or events accompanied these sentences. Next, in the *test phase*, pairs of pictures of objects were presented side by side, accompanied by a prompt containing a verb. In each of the critical novel-verb test trials, children heard one of the novel verbs (e.g., "Which one would you stipe?") and saw pictures of a new animal and household object. Pictures in the test trials depicted animals and objects not mentioned in the listening phase.

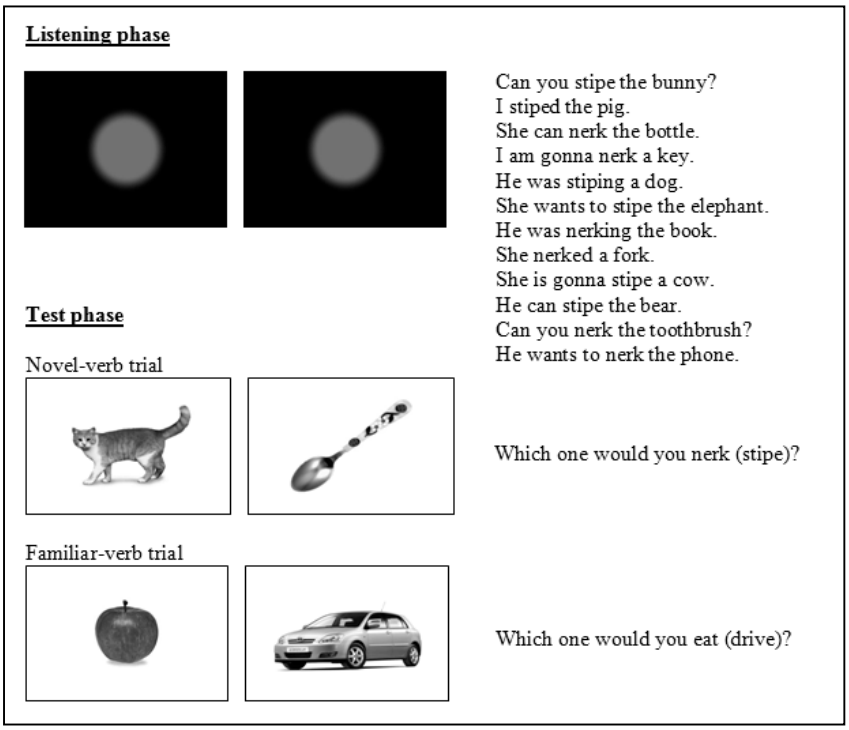

Figure 1: Listening and test phases in Experiment 1

If 2-year-olds can learn an unknown verb's selectional restriction from listening to sentences, then they should be able to encode the two different categories of nouns during the listening phase (animal versus objects), keep track of the co-occurrence of nouns of these categories with each verb, and later retrieve the relevant category upon hearing each verb and extend it to new members of that category. Thus, children should be more likely to look at the target picture appropriate for the verb upon hearing the verb.

1.1. Method

1.1.1. Participants

Thirty-two 2-year-olds (Mean 26.1 months; range 25.1-27.7; 16 girls, 16 boys), all native speakers of English, participated. Eight additional children were

eliminated due to fussiness (4), inattentiveness (3; see Procedure below), or low accuracy in familiar-verb test trials (1). Children's productive vocabularies, measured by the short form of the Bates-MacArthur CDI (Level II; Fenson et al., 2000), ranged from 14 to 100, with a median of 65.

1.1.2. Apparatus

Children sat on a parent's lap, facing two 20" color monitors, laterally separated by 12", about 30" away. The audio stimuli played from a speaker concealed between the monitors. A hidden central camera recorded the child's eye-movements. Parents wore opaque glasses.

1.1.3. Materials and Procedure

The stimulus materials consisted of videos of flashing red circles (for the listening phases) and still color pictures (for the preview and test phases), accompanied by a soundtrack recorded by a female native speaker of English. For the listening and test phases, the visual materials were combined into synchronized pairs, to be played side by side on the two video screens.

The procedure included a listening phase, a preview phase, a second listening phase, and a test phase. Figure 1 depicts the listening and test phases.

First listening phase. In an initial listening phase, the two novel verbs *stipe* and *nerk* were presented in transitive sentences. One verb was used in 6 sentences with direct objects referring to animals, and the other verb was used in 6 sentences with direct objects referring to household objects. Half of the children heard *stipe* used with animal nouns, and half heard it used with household-object nouns. The sentences were accompanied by videos of a flashing red circle, to maintain children's attention. The same video was shown on both video screens simultaneously.

The order of the 12 sentences in the listening phase was pseudo-randomized such that each verb was presented in 2 consecutive sentences, alternating with 2 sentences containing the other verb. The onset of one sentence was separated by 3.5 seconds from the onset of the next sentence, with the silent interval between sentences averaging about 1.6 seconds (range: 1.4-1.7). The entire listening phase was 42 seconds long.

Preview phase. Following a 2 s blank-screen interval, a preview phase began. During the preview phase, children were shown pictures to be shown in the test phase one at a time for 5 s, separated by 1-s blank screen intervals. Each picture was accompanied by a sentence calling attention to the picture (e.g., "Do you see the apple?"). The purpose of the preview phase was to provide the children with a respite from listening to sentences containing novel verbs, and to familiarize them with the pictures to be used in the later test phase. The entire preview phase lasted 48 s.

Second listening phase. Following a 2 s blank-screen interval, a second listening phase began. This phase was identical to the first listening phase, except

that the sentences followed a different pseudo-randomized order. Thus, together the two listening phases presented 12 sentences for each of the two novel verbs.

Test phase. Finally, after a 2-s blank-screen interval, the test phase was presented. Children received 3 types of trials: novel-verb test trials (8), familiar-verb test trials (8), and filler trials (8). In all trials, a pair of pictures was presented side-by-side for 8 s, accompanied by prompts containing a novel or familiar verb (novel- and familiar-verb test trials) or prompts that directly named the object depicted in one of the pictures (filler trials).

In the *novel-verb test trials*, the pair of pictures consisted of one animal (cat or horse) and one household object (spoon or mug), accompanied by two prompts containing one of the novel verbs (e.g., "Which one would you stipe? What would you stipe?"). The target and distracter pictures in each trial were defined by the pairing between the novel verb and the conceptual category of direct-objects from the listening phases. Each novel verb was presented in 4 test trials, with each trial presenting a different picture-pair resulting from crossing the two animal pictures with the two object pictures. Across the 8 novel-verb trials, each picture served equally often as the target and the distracter.

The *familiar-verb test trials* presented 2 familiar verbs that placed strong restrictions on their direct objects (*eat*, *drive*). These trials permit a replication of Fernald's (2004) experiments demonstrating that 2-year-olds' visual attention is guided by the selectional restrictions of familiar verbs. The format was identical to that of the novel-verb test trials; the picture-pair in each trial included one food item (apple or banana) and one vehicle (car or truck), accompanied by prompts containing one of the familiar verbs (e.g., "Which one would you eat? What would you eat?"). As for the novel verbs, each familiar verb was presented in 4 test trials; each trial displayed a different combination of paired pictures.

For both the novel- and familiar-verb test trials, the onset of the critical verb in the first prompt was aligned 3 s into the 8-s trial, and the onset of the second question prompt was aligned 5 s into the trial.

In the *filler trials*, the picture pairs were selected from 4 pictures (shoe, flower, tree, doll). The accompanying prompts named one of the pictures (e.g., "Do you see the shoe? Look at the shoe!"). The fillers were included to increase the variety of the test phase, and to teach the children that only one of the pictures matched the audio on each trial.

The novel-verb test trials, the familiar-verb test trials and the filler trials were intermixed, with a 1-s blank-screen interval between trials. The entire phase lasted about 3.5 minutes. The trials were pseudo-randomized with the following constraints: The test phase began and ended with a filler trial; filler trials were inserted after every 2 or 3 main trials (novel- or familiar-verb); no more than 2 novel-verb test trials or 2 familiar-verb test trials took place in a row; trials containing each verb (novel or familiar) were distributed evenly between the first and second halves of the test phase. Each picture was shown equally often on the left and right video-screens. The side of target picture was never the same for more than 3 trials in a row.

Two orders of trials were created for the test phase, one the reverse of the

other. The order of the test-phase trials was counterbalanced with the verb-category pairing and the order of the listening-phase sentences.

1.1.4. Coding and Analysis

We coded where children looked (left, right, or away) during the 8-s novel-verb and familiar-verb test trials, frame by frame from silent video. To examine whether children's looking patterns changed in response to hearing the verbs, we defined two analysis windows in each trial: baseline and critical. The baseline window corresponded to the 1.5 s before the onset of the verb in the first prompt (1500-3000 ms from the trial onset). The critical window began 300 ms after the onset of the verb and ended 1.5 s later (3300-4800 ms from the trial onset), following Fernald et al. (2008; see also Lany & Saffran, 2010). Trials were excluded from analysis if the child was not looking at either picture for at least half of the critical window. Children were eliminated as inattentive if half or more of the novel-verb test trials were excluded.

For each of the baseline and critical windows in each trial, we calculated the proportion of time spent looking at the target picture out of the total time spent looking at either picture. These proportions were averaged across familiar-verb and novel-verb test trials separately.

1.2. Results

Figure 2a shows children's visual fixations as they heard the verb in the novel-verb and familiar-verb test trials. As the Figure shows, in both kinds of trials children began looking more at the target soon after they heard the verb. This effect was slower and smaller for the novel-verb test trials; this pattern is unsurprising, and mirrors the pattern found with adults in a pilot study using the same materials.

We further compared children's proportion of looking to the target picture between the baseline and critical windows. In the familiar-verb test trials, children looked reliably more to the target picture in the critical (M = .66, SD = .15) than in the baseline window (M = .48, SD = .15; $t(31) = 4.79$, $p < .001$). Similarly, in the novel-verb test trials, children looked reliably more to the target in the critical (M = .56, SD = .10) than in the baseline window (M = .50, SD = .13; $t(31) = 2.18$, $p = .037$). Moreover, for the novel-verb test trials, children's proportion of looking to the target in the target window did not differ depending on whether the verb was linked with the animal noun category (M = .57, SD = .22) or with the household-object noun category (M = .53, SD = .17; $t(31) < 1$).

1.3. Discussion

Two-year-olds' visual fixations in the test phase were influenced by the verbs they heard. In both the familiar-verb and novel-verb trials, children's look-

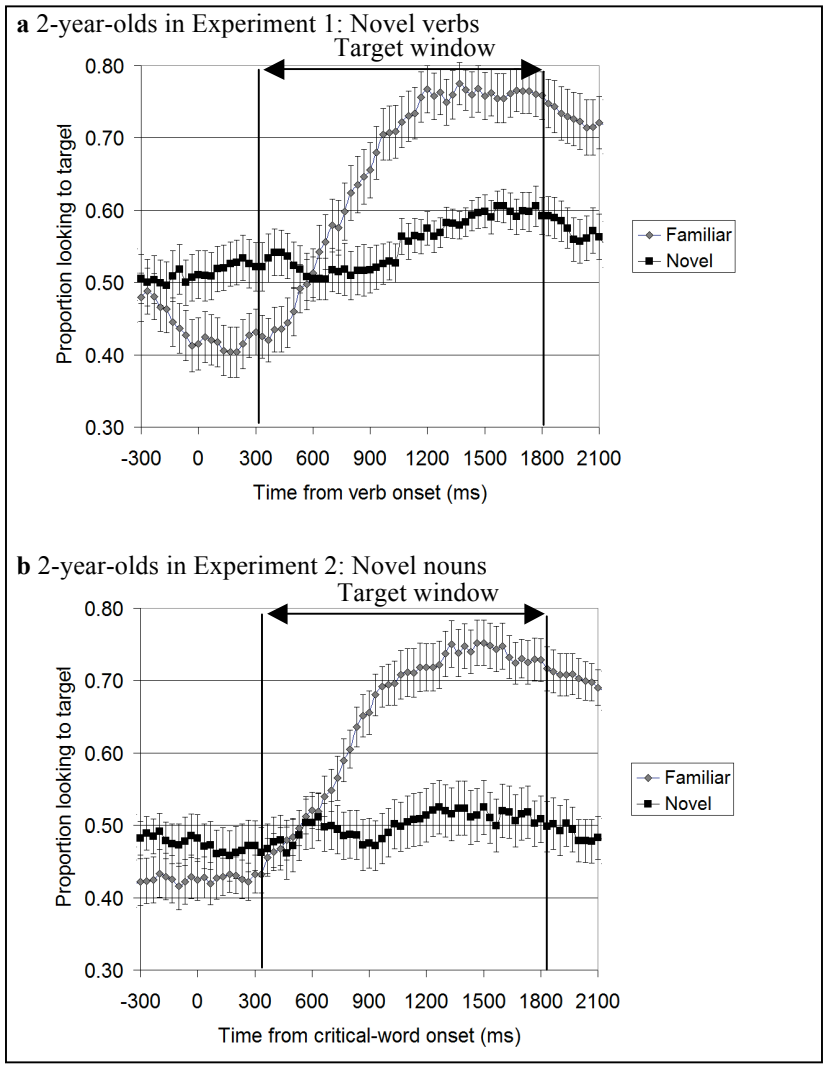

Figure 2: Mean proportion of trials on which children looked to the target picture relative to the onset of the critical word (the verbs *eat* and *drive* for familiar trials; *stipe* and *nerk* for novel trials). Error bars represent standard errors over participants. The target window is indicated by solid lines.

ing to the target picture increased shortly after hearing the verb. The familiar-verb results replicated findings by Fernald (2004) that 2-year-olds are guided by familiar verbs (e.g., *eat*) to attend to pictures of objects that serve as appropriate direct objects of the verbs (e.g., an apple, not a car). Critically, the novel-verb results suggest that 2-year-olds learned to associate an unknown verb with a

semantic category (animal versus household object) based on the distribution of direct-object nouns following the verb during the listening phase. They attached distinct semantic-category information to each of the two novel verbs, and retrieved the relevant category to extend to new category members when they heard these verbs at test. The current results yield evidence that children can learn selectional-restriction information about unknown verbs from listening to sentences, even without an informative referential context.

2. Experiment 2

The findings of Experiment 1 suggest one route by which children can learn a verb's selectional restrictions: When listening to sentences containing an unknown verb, children spontaneously encoded the semantic category of nouns occurring as its direct objects and associated that category-information with the verb. Did the children in Experiment 1 encode and subsequently generalize this category information because of the structural relationship between a verb and its direct object? Or did the learning and generalization occur as a simple case of forming associative links among co-occurring words? If the latter, then we would expect children to learn as readily to link category-information with any word, such as an unknown noun as well as an unknown verb, and later retrieve the category information when they hear that word again. Experiment 2 tested this possibility. The results would shed light on whether the learning in Experiment 1 reflected associative priming more generally, rather than acquiring combinatorial information about verbs in particular (see Boland, 2005).

It strikes us as plausible that the learning in Experiment 1 could reflect general lexical co-occurrence learning. Recent results suggest that young children are influenced by semantic-associative links between familiar words in word identification (Arias-Trejos & Plunkett, 2009), word learning (Colunga & Smith, 2004), and language production (Matthews & Bannard, 2008). Words that are associated with similar sets of co-occurring words tend to be similar in meaning (e.g., Li, Burgess, & Lund, 2000); thus simple word co-occurrence patterns could help children to sort words into semantic clusters.

To test whether the learning in Experiment 1 was driven solely by a general ability to track category-based co-occurrence patterns for any type of novel word, in Experiment 2 we presented children with the two novel words (*stipe*, *nerk*) treated as nouns that systematically co-occurred with animal or household-object nouns in a coordinate structure. If children link semantic-category information to the novel nouns and generalize it at test just as they did with the verb-object relations of Experiment 1, this would suggest that the learning in Experiment 1 was an example of word-word associative learning in general. In contrast, if children fail to do so, this might suggest that the verb-object grammatical relations of Experiment 1 guided children to encode and generalize the relationship between the new word and its direct objects.

2.1. Method

2.1.1. Participants

Thirty-two 2-year-olds (Mean 26.5 months; range 25.2-28.4; 18 girls, 14 boys), all native speakers of English, participated. 1 additional child was tested but not included due to fussiness. Children's productive vocabularies ranged from 4 to 97, with a median of 60.5.

2.1.2. Apparatus, Materials and Procedure

The apparatus, materials, and procedure were as described for Experiment 1, with the following modifications. First, in the listening phases, the novel words (*stipe*, *nerk*) were presented as nouns in coordinated noun phrases: One novel noun was always followed by animal nouns (e.g., "A stipe and the bunny. A stipe and the pig…"), whereas the other novel noun was always followed by household-object nouns (e.g., "A nerk and the book. A nerk and a fork…"). Second, in the novel-word test trials, the novel words were presented as nouns (e.g., "Which one is a stipe?"). These modifications were made to preserve the relations between the novel words and the noun categories, without the predicate-argument structure of sentences in Experiment 1

Coding and analysis were as described for Experiment 1.

2.2. Results

As Figure 2b shows, children's looking to the target picture did not increase in the novel-word test trials after hearing the novel word. However, children's looking pattern in the familiar-verb test trials was similar to that in Experiment 1: they looked more at the target picture after hearing the familiar verb.

In the familiar-verb test trials, the children looked reliably more to the target picture in the critical (M = .65, SD = .13) than in the baseline window (M = .43, SD = .13; $t(31) = 7.86$, $p < .001$). However, in the novel-word test trials, children looked to the target about equally in the critical (M = .50, SD = .15) and baseline windows (M = .49, SD = .11; $t(31) = .38$, $p = .70$). Children's proportion of looking to the target picture in the critical window did not differ reliably depending on whether the novel word was associated with the animal noun (M = .47, SD = .20) or the household-object noun category (M = .54, SD = .20; $t(31) = 1.63$, $p = .11$), although the mean difference between the two suggested a slight overall bias to attend to the household-object test pictures.

2.3. Discussion

In Experiment 2, we presented the novel words as nouns rather than transitive verbs, in both listening (e.g., "A stipe and the bunny," "A nerk and the book,"…) and test (e.g., "Which is a stipe?") phases. During the novel-word test trials, children's looking to the target picture did not increase after hearing the novel noun. Thus, children either did not learn to associate a novel noun with the

semantic category of a nearby noun, or did encode the associated semantic-category information but could not retrieve it or generalize it when hearing the novel noun again. These questions warrant further investigation. However, the current results suggest that simple associative learning and priming are not sufficient to account for the learning and generalization observed in Experiment 1.

3. General Discussion

The current findings show that 2-year-olds learned about the semantic category of nouns serving as direct objects of a new verb from listening experience. Having heard a novel transitive verb used in sentences with object nouns of a particular category (e.g., animals) led to an increase in children's looking to a new category member upon hearing the verb again (Experiment 1). However, having heard a novel noun used near nouns of a particular category did not lead to increased looking to a new category member when hearing the novel noun again (Experiment 2).

The contrast in results between Experiments 1 and 2 suggests the children in Experiment 1 were not simply associating a category of nouns with any nearby word and retrieving the category information if they heard that word again. Instead, it might be that the verb-object relationship invited children to encode semantic category information about the nouns in object position, linked with the verb, and to retrieve the associated category when encountering the verb again. Verbs take arguments, thus any attempt to understand a sentence containing a verb centrally involves trying to learn about and integrate the noun-phrase arguments in the sentence.

Many questions remain regarding the nature of the information children encoded in the listening phase of Experiment 1, and the degree to which it depended on the intimate grammatical relationship between the novel verb and its direct object. For example, did it matter that the animal or object nouns were in direct object position? Would similar effects emerge if the prompts in the test phase queried the wrong argument (e.g., "Which one can stipe?")? Further investigations are underway to specify what about the syntax and semantics of a verb's arguments children learn from listening experience.

The current results suggest that linguistic distributional information can serve as an independent source of information about a verb's selectional restrictions. Without knowing a verb's meaning, toddlers can learn about the kinds of nouns that co-occur with the verb by observing how the verb is used in sentences, and later use this information to interpret the verb in a referential task. These findings add to recent reports that toddlers can encode useful combinatorial facts about a new verb from linguistic experience (Arunachalam & Waxman, 2010; Scott & Fisher, 2009; Yuan & Fisher, 2009). As children listen to sentences containing an unknown verb, they spontaneously encode information about its transitivity, and about the semantic categories of the nouns filling the argument slots.

What can be gained from learning about a new verb's selectional restric-

tions, without knowing the specific meaning of the verb? Knowledge of selectional restrictions can play an important role in learning verb meaning (Grimshaw, 1994; Resnik, 1996). Supporting evidence comes from a word-learning simulation study with adults by Gillette and colleagues (1999): Adults were significantly better at guessing what verb was uttered by a parent when the available information consisted of the structure the verb occurred in as well as the set of co-occurring nouns, compared to when the information consisted of only the sentence structure. Knowledge of selectional restrictions could help constrain verb learning in multiple ways. It could help rule out verb-meaning hypotheses inconsistent with the selectional facts, for example. Knowing that a verb takes direct objects of the liquid category (e.g., water, juice, rain), a learner could not infer the specific meaning of the verb (pouring, splashing, drinking) but could infer that the verb is not likely to mean pinching or saying. Knowledge of selectional restrictions can also be useful for sorting out verb senses: By observing that a verb co-occurs with direct-object nouns of two very different conceptual classes (e.g., grasping cups or toys versus grasping concepts or meanings), the learner could begin to segregate different meaning representations for polysemous verbs.

In conclusion, the current findings suggest that children can learn about a verb's selectional restrictions from observing how the verb is used in sentences, without further information about its meaning. In essence, when listening to sentences containing unknown verbs, children learn what they can, and begin to establish lexical entries for newly-encountered verbs that reflect their syntactic and semantic combinatorial privileges. These representations are necessarily incomplete, but they facilitate further learning about the words (see also Swingley, 2010).

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