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Early evidence for syntactic bootstrapping: 15-month-olds use sentence structure in verb learning

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1. Introduction

Infant language-learners receive input consisting of word sequences paired with world scenes. Based on these data, they start learning to understand sentences early in the second year, and ultimately build a lexicon and grammar that support broad generalization. Accounts of how they do so necessarily begin with the extra-linguistic world: The true novice, not yet knowing the words or syntax, must try to link input sentences with aspects of accompanying scenes. Top-down knowledge derived from the scene then 'supervises' word and syntax learning, investing words and their combinations with meaning. Views of language acquisition of all theoretical stamps thus assume that knowledge of word and sentence meaning drives syntax acquisition (e.g., Pinker, 1984; Tomasello, 2003).

However, aspects of verb meanings in particular challenge the assumption that children can recover word and sentence meanings based only on understanding scenes, and thus in turn challenge our theories of syntax acquisition (Gleitman et al., 2005). Verbs do not simply label events; rather, they denote abstract construals of them. To illustrate, pairs of verbs such as *feed* and *eat*, *give* and *receive*, take different perspectives on the same events. Scene feedback thus provides equivocal evidence for verb and sentence meaning (Gillette et al., 1999).

The syntactic-bootstrapping theory proposes that children use knowledge of syntax itself to decode sentence and verb meanings (e.g., Gleitman et al., 2005). Syntactic bootstrapping relies on tight links between verb syntax and meaning (Fisher et al., 1991; Levin & Rappaport-Hovav, 2005; Pinker, 1989). Part of the meaning of a verb is a semantic predicate-argument structure specifying the number and type of arguments that the verb's meaning implies. This semantic structure partly determines the syntactic structures licensed by the verb. For example, verbs entailing one argument take intransitive frames, with one noun phrase (NP) (*It fell*); verbs entailing two arguments take transitive frames, with two NPs (*I dropped it*). Toddlers use these links, assigning different meanings to verbs in different syntactic structures (Arunachalam & Waxman, 2010; Fisher, 1996; Naigles, 1990, 1996; Yuan & Fisher, 2009; Yuan et al., 2012).

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For example, Yuan, Fisher, and Snedeker (2012) showed 19-month-olds two side-by-side events: a two-participant causal event and a one-participant event. Children heard a novel verb presented in simple transitive (*He's gorping him!*) or intransitive sentences (*He's gorping!*). Children who heard a transitive verb looked longer at the two-participant event than did those who heard an intransitive verb. Thus, syntax begins to guide verb interpretation before age two.

Our work asks how syntactic bootstrapping begins. We have proposed a structure-mapping account on which syntactic bootstrapping originates in an unlearned bias toward one-to-one mapping between nouns in sentences and semantic arguments of predicate terms (e.g., Fisher et al., 2010). This represents (roughly) the theta-criterion of linguistic theory (Chomsky, 1981). Given this bias, children find the number of nouns in a sentence inherently meaningful. The structure-mapping account assumes that young children represent sentences abstractly in terms of their number of nouns, and create structured conceptual representations of events that make explicit their number of core participants. Given these representations, and armed with the proposed one-to-one mapping bias, children infer that a verb that licenses two nouns implies two participant roles, whereas a verb that licenses one noun implies one role.

This account makes a strong prediction about the development of syntactic bootstrapping: Given the proposed one-to-one mapping bias, infants should use the number of nouns to differentiate transitive from intransitive verbs as soon as they know some nouns, and represent them as parts of a larger sentence. Yuan et al. (2012) tested the youngest infants to date in a syntactic bootstrapping task, 19-month-olds; but several considerations suggest that younger infants, 15-month-olds, satisfy the prerequisites of structure-mapping. Thus a strong test of the predictions of this account required us to test younger infants.

What considerations lead us to predict that 15-month-olds should succeed in a syntactic bootstrapping task? First, foundational work on syntax-guided word learning in infancy shows that by 14 months, infants treat new nouns (e.g., *This is a blicket*), not just any new word (*This is blickish*), as referring to object kinds (Booth & Waxman, 2009; Waxman & Booth, 2001). Thus by 14 months, infants can use distributional information to identify nouns as such, distinct from other grammatical categories. Second, 15-month-olds understand multi-word sentences under some circumstances (Hirsh-Pasek & Golinkoff, 1996; Seidl et al., 2003). For example, Seidl et al. (2003) showed infants an event in which a book hit some keys. Infants then saw the book and keys side by side and heard either *What hit the keys?* or *Where are the keys?*. Infants tended to look at the book if they heard the first sentence, and the keys if they heard the second. These results suggest that 15-month-olds can identify multiple familiar words per sentence, and integrate their meanings to interpret the sentence. Younger infants may typically fail to understand multiple familiar words per sentence, limited by inefficient word recognition: Though even 6- to 8-month-olds understand some nouns, at 14 months infants show a substantial improvement in the speed and accuracy of word comprehension (Bergelson & Swingley, 2012, 2013). This improvement may result from growing knowledge of the distributional contexts of known

words, and in turn give infants a chance to identify multiple words per sentence.

In sum, given that 15-month-old infants can identify some nouns as such, and have some ability to understand multi-word sentences, the structure mapping account predicts that they should succeed in a simple syntactic bootstrapping task. By testing younger infants, we thus tested a core prediction of our account: Can infants use the set of nouns to tell transitive from intransitive verbs, from the start of multi-word sentence comprehension?

2. Experiment 1

In Experiment 1 we adapted the task of Yuan et al. (2012), simplifying the events and procedure for younger infants. In critical test trials, 15-month-olds saw two animated events side by side: a two-participant caused-motion event (a box bumped another box, causing it to move), and a one-participant action event (a ball jumped up and down; see Figure 1). These events were accompanied by a novel verb in Transitive (*He's kradding him!*) or Intransitive (*He's kradding!*) sentences, or by Neutral audio with no novel verb (e.g., *Which one do you like?*) to assess infants' baseline visual preferences between the two events.

Via structure-mapping, infants in the transitive condition should note the presence of two nouns in their test sentence, infer that the verb's meaning involves two participant roles, and therefore look longer at the two-participant event than would those in the intransitive or neutral conditions. Infants in the intransitive condition should note the presence of one noun in their test sentence, and infer that the verb's meaning involves one participant role. Notice the intransitive verb could refer either to the one-participant action event or to a component of the two-participant caused-motion event (Fernandes et al., 2006; Yuan et al., 2012). Thus, as in previous work, we predicted no systematic preference for either event in the intransitive condition, relative to the neutral condition.

2.1. Method

2.1.1. Participants

Thirty-six 15-month-olds (M = 15.4 months, range 14.0–17.0; 18 girls) participated; all were born full-term, and were learning English as their first language. One additional infant was excluded due to inattentiveness (looking at the test events for < 50% of the time during the novel-verb test item). Infants' productive vocabularies, measured by the short form of the MacArthur CDI (Level II; Fenson et al., 2000), ranged from 0 to 42, with a median of 6.5. Twelve infants were assigned to the Transitive, Intransitive, and Neutral conditions.

2.1.2. Apparatus

Infants sat on a parent's lap in a dimly-lit room, about four feet from a 50" TV screen. Soundtracks were presented from the television's speakers. A central camera concealed beneath the television screen recorded infants' faces. Parents were instructed to close their eyes.

2.1.3. Materials and procedure

The procedure included a monologue phase, two practice items, and one novel-verb test item. See Figure 1.

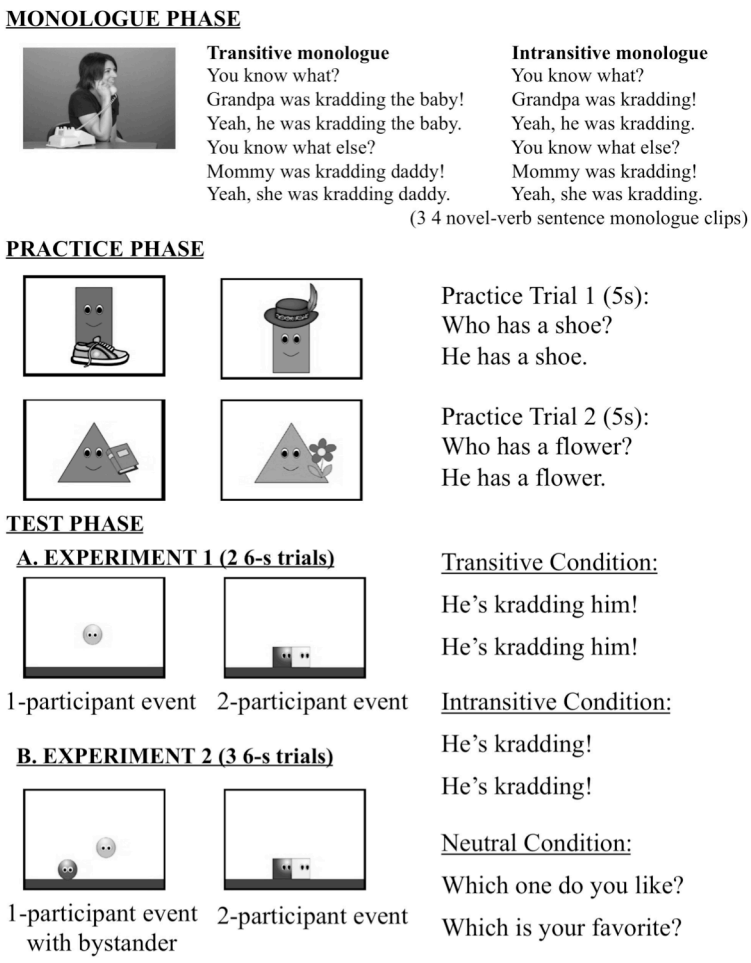

Figure 1. Sequence of events within the experiment.

In the monologue phase, infants saw videos of a woman talking on the phone, using the invented verb *krad* in sentences. Infants in the transitive condition heard the verb in transitive sentences (e.g., *Grandpa is gonna krad the baby*), and those in the intransitive condition heard it in intransitive sentences (*Grandpa is gonna krad*); half of the infants in the neutral condition heard tran-

sitive monologues, and half heard intransitive monologues. The monologues served to pre-familiarize infants with the novel verb and its syntactic contexts, easing processing of the test sentences to be presented later in the task.

All nouns in the monologue sentences had animate referents; these included proper names, pronouns, and common nouns (e.g., *baby, boy*). Infants saw three monologue video clips, each 24.7 to 31.7 s long, and each containing 4 novel-verb sentences. The three video clips were separated by 6-s intervals, each comprising a 1-s silent blank-screen interval, a 4-s presentation of a drawing of the sun accompanied by laughing-baby audio, and another 1-s blank-screen interval. The monologue videos and sun image appeared centered on the TV screen.

Next, after a 5-s blank-screen interval in which infants heard *Now let's watch this!*, two practice items followed, both involving the familiar verb *have*. Infants saw still pictures of geometric characters (e.g., a colorful rectangle with eyes and a mouth; see Figure 1) with familiar objects (e.g., a book or a hat). The practice items served to familiarize infants with the task, teaching them that one image matched the soundtrack on each trial.

The first practice item showed a rectangular character with a shoe, and another with a hat. Each picture was previewed alone (5s) on the left or right side of the screen, in counterbalanced order and separated by a 4-s interval, accompanied by descriptive audio (e.g., *He has a shoe!,* then *He has a hat!*). Next, during a 4-s blank-screen interval, infants heard *Who has a shoe?*; then infants saw the two pictures side by side (5s) and heard *Who has a shoe? He has a shoe*. After a 4-s black-screen interval, the second practice item was presented in the same manner. This item showed triangular characters, one with a book and one with a flower; infants were prompted to find the character with the flower.

Finally, following a 4-s interval, the novel-verb test item was presented. The 6-s animated events included a two-participant causal event (a blue box repeatedly bumped a yellow box, causing it to move) and a one-participant action (a green ball repeatedly jumped up and down). Both events were previewed alone in counterbalanced order, separated by a 4-s blank-screen interval, accompanied by neutral audio (e.g., *Watch this*.). Next, during a 9-s blank-screen interval, infants heard a test sentence appropriate for their condition, twice (e.g., Transitive: *He's gonna krad him!*, Intransitive: *He's gonna krad!*, Neutral: *Which one do you like?*). Both events then played simultaneously (6s) while the infants heard two more test sentences (Transitive: *He's kradding him*, Intransitive: *He's kradding*, Neutral Condition: *Which is your favorite?*). Next, during a 6-s interval, infants heard another test sentence and a prompt (e.g., Transitive: *He kradded him. Find kradding!*, Intransitive: *He kradded. Find kradding!*, Neutral: *Did you find it? That was fun!*). Both test events then appeared again, accompanied by one more test sentence and a prompt.

The left/right position of the test events was counterbalanced with dialogue and test condition.

2.1.5. Coding and analysis

We coded where infants looked (left, right, away) during the two 6-s trials of the novel-verb test item, frame by frame from silent video. Reliability was assessed for 9 randomly selected infants (25% of the data); primary and reliability coders agreed on 96% of video frames. Individual test trials were dropped if the infant looked away for more than half of the 6-s trial (n = 1).

A preliminary analysis of time spent looking away revealed no effect of sentence condition (F < 1). Given the uniformity of time spent looking away, we conducted our main analyses on a single measure, looking time to the two-participant event as a proportion of total time spent looking at either test event, averaged across the two 6-s test trials. Preliminary analyses of the test data revealed no interactions involving sentence condition and gender, or whether the infant's vocabulary or performance in the practice trials was above or below the median (Fs < 2). The data were therefore collapsed over these factors.

2.2. Results

As shown in Figure 2a, the 15-month-old infants' looking preferences varied as predicted across conditions. An analysis of variance (ANOVA) revealed a significant effect of sentence condition on looking time to the two-participant event, $F(2, 33) = 3.62$, $p = .038$. Planned comparisons revealed that infants in the transitive condition ($M = .56$, $SD = .16$) looked reliably longer at the two-participant event than did those in the intransitive condition ($M = .40$, $SD = .16$), $t(22) = 2.41$, $p = .025$. Looking preferences in the neutral condition (M= .56, SD = .17) did not differ from the transitive condition, t < 1, but unlike in previous studies (Arunachalam & Waxman, 2010; Yuan et al., 2012), the neutral condition differed reliably from the intransitive condition, $t(22) = 2.31$, $p = .031$.

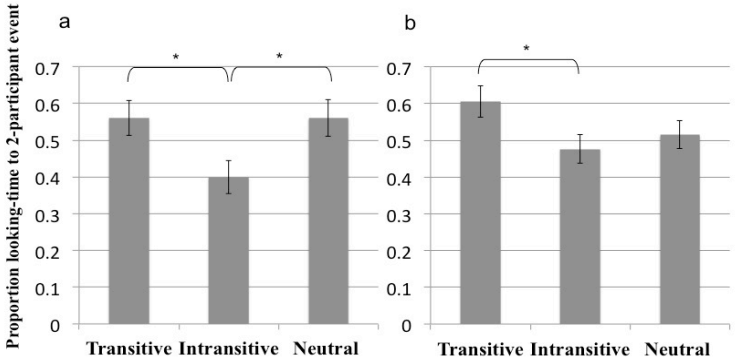

Figure 2. Mean (se) proportion looking time to the 2-participant event, Expt. 1

2.2.1. Replication

We tested 24 additional 15-month-olds (13.9–16.7 months, M =14.9 months, 12 girls), to confirm the key effect of transitivity in Experiment 1 and to probe

the unexpected difference between the neutral and intransitive conditions. These infants' productive vocabularies ranged from 0 to 29 with a median of 5. Eight infants were assigned to each of the three conditions. The procedure and materials were identical to those described above. Preliminary analyses again revealed no effect of sentence condition on look-away times in the test item ($F < 1$). Therefore, we again analyzed looking time to the two-participant event as a proportion of total time spent looking at either test event,.

As Figure 2b shows, the data from this replication experiment confirmed the key effect of transitivity in the main experiment, but did not replicate the unexpected difference between the intransitive and neutral conditions. Infants in the transitive condition looked reliably longer at the two-participant event (M = .61, SD = .12) than did those in the intransitive condition (M = .48, SD = .11), $t(14) = 2.24$, $p = .042$. The neutral condition (M = .51, SD = .11) did not differ significantly from either the transitive, $t(14) = 1.58$, $p > .05$, or the intransitive conditions $t(14) = .71$, $p > .05$.

2.2. Discussion

In Experiment 1 and its replication, 15-month-olds assigned different interpretations to transitive and intransitive sentences containing unknown verbs. Infants who heard the novel verb in transitive sentences (*He's kradding him!*) looked longer at the two-participant event than did those who had heard the novel verb in intransitive sentences (*He's kradding!*).

The results in the neutral condition were less stable. In the main experiment, looking preferences in the neutral condition resembled those in the transitive condition, and differed from those in the intransitive condition. However, the replication data did not confirm this unexpected result; as we shall see below, Experiment 2 also did not confirm this unexpected result.

The striking difference between the transitive and intransitive conditions yields powerful evidence for a key prediction of the structure-mapping account. Even 15-month-old infants, near the start of multi-word sentence comprehension, use sentence structure clues to differentiate transitive and intransitive sentences containing unknown verbs.

3. Experiment 2

As predicted by the structure-mapping account, the 15-month-olds in Experiment 1 assigned different interpretations to novel verbs in simple transitive vs. intransitive sentences. On our account, this inference results from a one-to-one mapping bias that prompts infants to align each noun in a stimulus sentence with a core participant role in a structured conceptual representation of one of the stimulus events. An alternative interpretation, however, is that the effects of sentence structure in Experiment 1 reflected an even simpler tendency to match the number of nouns in the sentence with the number of characters visible in the test videos. In Experiment 2, we sought both to replicate the findings of Experi-

ment 1 and to rule out this alternative interpretation.

To do so, we adopted the 'bystander' manipulation of Yuan et al. (2012), adding a second character (a bystander) to the one-participant test event (Figure 1). As a result, both test events showed two characters, but only the two-participant test event showed the two characters involved in a coherent interaction. If infants succeeded in Experiment 1 simply by aligning nouns with visible characters, then in Experiment 2 we should find no differences across conditions. Infants who heard transitive sentences (*He's kradding him!*) should show no strong preference for either event, because both show two characters, one for each noun. Similarly, infants who heard intransitive sentences (*He's kradding!*) should show no preference for either event, because both show at least one character. In contrast, if infants succeeded in Experiment 1 by aligning nouns with core participant roles in coherent conceptual representations of events, then infants in Experiment 2 should reproduce the results of Experiment 1. Infants in the transitive condition should seek a two-participant *relational* event as a referent for their novel verb, and thus look longer at the two-participant event than do infants in the intransitive condition.

3.1. Method

3.1.1. Participants

Thirty-six native English-learning 15-month-olds (M = 15.4 months, range 14.0–17.0; 19 girls) participated; all were born full-term. Four additional infants were excluded because they did not complete the experiment (n = 3), or looked away more than half of the time in two of the three test trials (n = 1). Infants' productive vocabularies, measured as in Experiment 1, ranged from 0 to 36, with a median of 6.5.

3.1.2. Materials and procedure

The materials and procedure were as in Experiment 1 with three exceptions. First, a second character, a ball-shaped character in a different color, was introduced into the one-participant test event (Figure 1). This bystander simply stood idly as the other character jumped. Second, a bystander was introduced to all practice-item pictures, to reduce the novelty of the bystander in the test item. For example, a second rectangular character without an additional object stood by the one with a shoe, and another by the one with a hat, in the first practice item. Third, infants received three 6-s trials instead of two; the third trial was provided to give infants more time to examine the more complex bystander event.

3.1.3. Coding and analysis

Coding and analysis were carried out as in Experiment 1. Individual test trials were dropped if a child looked away for more than 50% of the trial (n = 4). Reliability was assessed for 9 infants; coders agreed on 96% of video frames.

Look-away times in the test trials again did not vary with sentence condition ($F < 1$); we took as our main measure infants' looking times at the two-participant event, as a proportion of time spent looking at either event, averaged across the three 6-s test trials.

Preliminary analyses of the test data revealed no interactions involving sentence condition and gender, whether infants' target preference in the practice trials was above or below the median, or whether infants' vocabulary was above or below the median (Fs < 1).

3.2. Results

As Figure 3 shows, infants' looking patterns again varied with sentence condition. An ANOVA revealed a significant effect of sentence condition on looking time to the two-participant event, $F(2, 33) = 3.41$, $p = .045$. Planned comparisons showed that infants in the transitive condition looked reliably longer at the two-participant event ($M = .56$, $SD = .15$) than did those in the intransitive ($M = .42$, $SD = .13$), $t(22) = 2.44$, $p = .023$, or the neutral condition ($M = .41$, $SD = .18$), $t(22) = 2.13$, $p = .045$. The intransitive and neutral conditions did not differ, $t(22) < 1$.

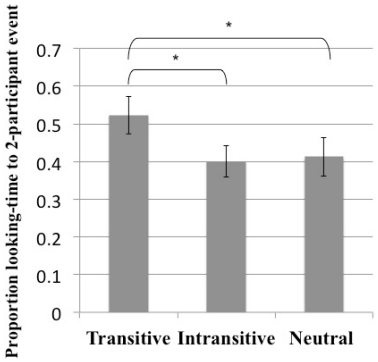

Figure 3. Mean (se) proportion looking time to the 2-participant event, Expt. 2

3.3. Discussion

Experiment 2 replicated and extended the findings of Experiment 1. Fifteen-month-olds again assigned different interpretations to novel transitive and intransitive verbs. Those who heard the verb in transitive sentences looked longer at the two-participant event than did those who heard intransitive sentences or neutral audio. In Experiment 2, this pattern held even in the bystander case, when both test events depicted the same number of characters. This tells us that 15-month-olds who heard transitive sentences looked longer at the two-participant event not simply because it showed two characters, one for each

noun, but because it showed a coherent two-participant event. This finding is important because it reveals the dependence of syntactic bootstrapping on structured conceptual representations of events (see Fisher, Gleitman & Gleitman, 1991; Landau & Gleitman, 1985).

4. General Discussion

In two experiments, 15-month-old infants used sentence-structure cues to interpret novel transitive and intransitive verbs. Infants who heard a novel verb in simple two-noun transitive sentences (*He's kradding him!*) looked longer at a two-participant event as opposed to a one-participant event than did those who heard the novel verb in one-noun intransitive sentences (*He's kradding!*). They did so even when the one-participant event included a second character, a bystander not engaged in any coherent relation with the other character. These results are just what we would predict on the structure-mapping account. They suggest that 15-month-olds assigned a relational meaning to a novel transitive verb, and did so by aligning each noun in a sentence with a core participant role in a coherent conceptual representation of an event.

These findings extend what we know about the origins of syntactic bootstrapping, and about early sentence interpretation, in two main ways.

First, these data confirm that children use sentence structure to guide verb learning well before two years of age (e.g., Yuan et al., 2012), and provide striking new evidence of the early onset of syntactic bootstrapping in infancy. We argued in the Introduction that our account of the origins of syntactic bootstrapping required us to test 15-month-olds. On the structure-mapping account, infants are innately biased to map each noun in a sentence onto a distinct participant role in a structured conceptual representation of an event. If so, then infants should find simple aspects of sentence structure inherently meaningful, as soon as they can identify some nouns as such, and can identify multiple words per sentence. We reviewed evidence that by 14 to 15 months of age, infants possess these prerequisite skills. Finding that 15-month-olds assign different interpretations to novel transitive and intransitive verbs thus provides strong evidence for a key prediction of the structure-mapping account. *Simple aspects of syntactic structure guide sentence comprehension from early in the second year of life, at or near the onset of multi-word sentence comprehension.*

Second, the present results provide new evidence that children can understand multi-word sentences early in the second year. As far as we know, only two prior reports demonstrate such early prowess (Hirsh-Pasek & Golinkoff, 1996; Seidl et al., 2003). Success in the present experiments, as in the two previous reports, required infants to identify multiple words per sentence and to integrate them in understanding the sentence; these data thus confirm that multi-word sentence comprehension becomes possible by 14 to 15 months of age. Moreover, our task required infants to identify two function words in the transitive test sentences, the pronouns *he* and *him*, and to do so despite the presence of a novel word. This ability should give toddlers access to powerful new con-

straints on word-learning, allowing them to use what they know about the meanings of other words in the sentence to guide learning of new words.

Finally, although our results are consistent with the structure-mapping account, other possibilities must be considered before we can take these data as direct evidence for the innate one-to-one mapping bias that is at the heart of the structure-mapping account. An alternative possibility is that infants used the familiar words in our test sentences as arbitrary distributional cues, to identify the novel verb as a member of a previously-learned category of words. For example, the frame *He___ him* could occur often enough in the input to become a "frequent frame" of a kind that provides useful data about grammatical categories (Mintz, 2003). Such frames have no inherent meaning, but become meaningful by virtue of their association with a set of words whose meanings are already known (e.g., Lany & Saffran, 2010; Maratsos & Chalkley, 1980). Infants might identify such distributional cues in the stimulus sentences, use them to put the new verb in a category of known verbs that share the same distributional contexts, and then interpret the new verb as having a meaning characteristic of the known verbs in that class (e.g., *hug*, *kiss, eat*). There is ample evidence that infants make such category-mediated inferences in interpreting new words, using function words to distinguish novel nouns from other words (e.g., Waxman & Booth, 2001), and proper names from count nouns (e.g., Hall & Lavin, 2004).

Could such learned categories alone explain our data, without appeal to an innate one-to-one mapping bias? A learned-category explanation implies an account of the origins of syntactic bootstrapping that relies on early abstract syntactic and semantic categories (needed for success in our task), but not on innate links between syntax and meaning. On such an account, *all* links between syntax and meaning would be learned. A firm answer to this question would take us beyond what is now known about early word knowledge and early distributional learning. Infants 12 to 18 months old do understand some transitive and intransitive action verbs (Hirsh-Pasek & Golinkoff, 1996; Huttenlocher, Smiley, & Charney, 1983), and even 10- to 13-month-olds distinguish the referents of a few common verbs such as *kiss* vs. *dance* or *eat* vs. *hug* (Bergelson & Swingley, 2013). Moreover, 12-month-olds have learned some of the distributional contexts of native-language verbs, and can use them to predict in which new linguistic contexts a novel word should appear (e.g., *to lonk it* → *you lonk the*; Mintz, 2006; but see Höhle et al., 2004). Further research will be needed to determine whether infants could use this nascent verb semantic and distributional knowledge to build categories that would support success in our task, prompting 15-month-olds to interpret a novel transitive but not intransitive verb as referring to a coherent two-participant relation.

However, several considerations cause us to prefer the structure-mapping account over an account that includes no innate links between syntax and semantics. For example, the sensible syntactic-semantic patterns that characterize the inventions of Home Signers (e.g., Goldin-Meadow, 2005) suggest that certain non-arbitrary links between syntax and semantics may not need to be learned, even if they could be (see Yuan et al., 2012, for discussion). In addition,

a learned-category account provides no solution to the learning problem with which we began—how verbs' abstract semantic structures are learned in the first place. As just noted, 10- to 13-month-olds can link some verbs with appropriate events (Bergelson & Swingley, 2013). But verb meanings do not simply label events; they represent particular perspectives on them, foregrounding the roles of varying subsets of event participants. To illustrate, a parent encouraging an infant to put a block in a shape sorter might say *Let's put that one here* or *That one goes here*. These two sentences take different perspectives on the same caused-motion event, reflecting the different semantic structures of the verbs *put* and *go*. Via syntactic bootstrapping, syntactic evidence informs learners about each verb's abstract perspective on events, including its number of participant-roles. This is the semantic structure knowledge infants needed to succeed in our task, and is just what we and others have argued is not readily available in observations of scenes alone (e.g., Fisher 1996; Gleitman et al., 2005).

The present results provide the first evidence that even 15-month-old infants use sentence structure cues to interpret new transitive vs. intransitive verbs. This extends what we know about the development of syntactic bootstrapping, and confirms a key prediction of the structure-mapping account: Infants use syntax to interpret verbs from the start of multi-word sentence comprehension.

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