Cognition xxx (2016) xxx-xxx

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com

Original Articles

Word learning in linguistic context: Processing and memory effects

Yi Ting Huang*, Alison R. Arnold

University of Maryland College Park, Department of Hearing and Speech Sciences, United States

ARTICLE INFO

Article history:
Received 25 August 2015
Received in revised form 22 July 2016
Accepted 25 July 2016
Available online xxx

Keywords:
Syntactic processing
Word learning
Memory
Syntactic bootstrapping

ABSTRACT

During language acquisition, children exploit syntactic cues within sentences to learn the meanings of words. Yet, it remains unknown how this strategy develops alongside an ability to access cues during real-time language comprehension. This study investigates how on-line sensitivity to syntactic cues impacts off-line interpretation and recall of word meanings. Adults and 5-year-olds heard novel words embedded in sentences that were (1) consistent with an agent-first bias (e.g., "*The blicket will be eatingthe seal*" → "*theblicket*" is an agent), (2) required revision of this bias (e.g., "*The blicket will be eaten bythe seal*" → "*theblicket*" is a theme), or (3) weakened this bias through a familiar NP1 (e.g., "*The seal will be eating/eaten bythe blicket*" → "*theseal*" is an agent or theme). Across both ages, eye-movements during sentences revealed decreased sensitivity to syntactic cues in contexts that required syntactic revision. In children, the magnitude of on-line sensitivity was positively associated with the accuracy of learning after the sentence. Parsing challenges during the word-learning task also negatively impacted children's later memory for word meanings during a recall task. Altogether, these results suggest that real-time demands impact word learning, through interpretive failures and memory interference.

1. Introduction

During word learning, children exploit predictable relationships between linguistic forms and meaning, a strategy known as syntactic bootstrapping (Fisher, Gertner, Scott, & Yuan, 2010; Gleitman, 1990). Successful bootstrapping requires that learners not only have relevant syntactic knowledge (e.g., active-passive alternation), but also access this information efficiently during real-time comprehension (e.g., perceiving "*eating*" in (1a) as different from "*eaten by*" in (1b), assigning appropriate roles to arguments, predicting likely referents of novel words).

(1) a. Active:	The blicket will be quickly eating the seal	
b. Passive:	The blicket will be quickly eaten by the seal	

However, little is known about how syntactic bootstrapping operates alongside a developing system for syntactic processing. It is often assumed that children learn by interpreting utterances in an adult-like manner (Fisher et al., 2010; Waxman & Booth, 2003). Yet, prior research reveals notable ways in which syntactic cues are often ignored during real-time comprehension (Choi & Trueswell, 2010; Huang, Zheng, Meng, & Snedeker, 2013; Hurewitz, Brown-Schmidt, Thorpe, Gleitman, & Trueswell, 2000; Omaki, Davidson-White, Goro, Lidz, & Phillips, 2014; Trueswell, Sekerina, Hill, & Logrip, 1999; Weighall, 2008). What do children learn in these contexts? How do limitations of syntactic parsing impact the informativity of syntactic cues?

The current study explores these questions by isolating the effects of syntactic processing on word learning in 5-year-old children. We reasoned that if syntactic bootstrapping depends on a developing system for accessing syntactic cues within utterances, then word learning should be challenging when these cues are hidden by real-time demands and more successful when these demands are removed. Parsing effects should also generate systematic relationships between on-line sensitivity to syntactic cues, off-line interpretation of words, and memory for meanings. In the remainder of the Introduction, we will briefly summarize prior research on children's use of syntactic cues during word learning and sentence comprehension. Next, we will discuss recent work suggesting that real-time comprehension has cascading impacts on language learning. Finally, we will consider why comprehension of passives may be particularly informative and sketch out how word-learning mechanisms will be isolated in the current study.

1.1. Syntactic cues in word learning and sentence comprehension

Children's use of syntactic cues is central to two parallel literatures, focusing on distinct time scales. In the field of language acquisition, previous research has explored how children learn the meanings of words via syntactic cues in sentences (Brown, 1957; Fisher et al., 2010; Gleitman, 1990; Waxman & Booth, 2003). For example, 3- to 5-year-olds' knowledge of the mass-count distinction generates inferences that "*a blicket*" refers to an individuated object (e.g., rock-like item) while "*some blicket*" refers to a less-coherent substance

* Corresponding author at: Department of Hearing and Speech Sciences, University of Maryland College Park, College Park, MD 20742, United States.
Email address: ythuang1@umd.edu (Y.T. Huang)

http://dx.doi.org/10.1016/j.cognition.2016.07.012
0010-0277/© 2016 Published by Elsevier Ltd.

(e.g., toothpaste-like item) (Barner & Snedeker, 2005; Bloom & Kelemen, 1995; Brown, 1957). Similarly, knowing the transitivity distinction allows 2-year-olds to infer that "*gorping*" refers to a causative event in a transitive structure (e.g., "*The rabbit is gorping the duck*" → a rabbit pushing a duck) but a self-propelled event in an intransitive one (e.g., "*The rabbit and duck are gorping*" → a rabbit and a duck swinging their arms) (Arunachalam & Waxman, 2010; Naigles, 1990; Yuan & Fisher, 2009). On the whole, research in language acquisition has focused on year-to-year differences that emerge during development (Fisher et al., 2010; Waxman & Booth, 2003). When do children first engage in syntactic bootstrapping? What cues do they rely on when they do so?

In contrast, more recent work has focused on how children interpret syntactic cues on a millisecond time scale (Omaki & Lidz, 2015; Snedeker & Huang, 2015; Trueswell & Gleitman, 2004). These studies have highlighted two characteristics of developmental sentence processing. First, like adults, children recruit reliable syntactic cues to incrementally predict who did what to whom (Choi & Trueswell, 2010; Huang et al., 2013; Snedeker & Trueswell, 2004; Snedeker & Yuan, 2008). For example, 5-year-olds infer that ambiguous prepositional phrases (PPs) refer to instruments following instrument-biased verbs (e.g., "*Hit the frog with the stick*" → Hit using the stick) and patients following modifier-biased verbs (e.g., "*Choose the frog with the stick*" → The frog that's holding the stick) (Snedeker & Trueswell, 2004; Snedeker & Yuan, 2008). However, unlike adults, children often ignore syntactic cues that conflict with an initial misinterpretation (Choi & Trueswell, 2010; Huang et al., 2013; Hurewitz et al., 2000; Omaki et al., 2014; Trueswell et al., 1999; Weighall, 2008). Trueswell et al. (1999) found that when presented with a temporarily ambiguous sentence like "*Put the frog on the napkin into the box*" adults and 5-year-olds initially look towards a plausible destination (e.g., an empty napkin), suggesting that both age groups misanalyze PP1 as a location for the verb. Following the onset of PP2, adults realize that PP1 is in fact a modifier that describes the target referent (e.g., frog *that's* on the napkin). Children, on the other hand, often ignore this late cue and generate incorrect actions on 60% of trials (e.g., putting the frog on a napkin, before moving it to the box).

Difficulties with syntactic revision occur despite the fact that children correctly interpret ambiguous (e.g., "*Choose the frog with the fork,*" Snedeker & Trueswell, 2004; Snedeker & Yuan, 2008) and unambiguous modifiers (e.g., "*Put the frog that's on the napkin into the box*," Hurewitz et al., 2000; Trueswell et al., 1999) and produce these structures to avoid referential ambiguity (Hurewitz et al., 2000). Taken together, prior findings suggest that even when children have relevant syntactic knowledge, they may not always effectively access it during comprehension. Importantly, parsing challenges have implications for learning since children often encounter complex constructions in their input, e.g., multiclause sentences, non-canonical word orders (Huttenlocher, Vasilyeva, Cymerman, & Levine, 2002; Huttenlocher, Vasilyeva, Waterfall, Vevea, & Hedges, 2007; Huttenlocher, Waterfall, Vasilyeva, Vevea, & Hedges, 2010; Newport, Gleitman, & Gleitman, 1977). Are these utterances informative for word learning? If so, how do children exploit relevant syntactic cues in their input?

1.2. Does syntactic processing impact language learning?

Indeed, recent studies suggest that developmental challenges with syntactic revision have cascading impacts on language learning. For example, causative verbal morphology reliably mark causal events in verb-final languages like Kannada and verb-initial languages like Tagalog. Nevertheless, when comprehension was assessed, 3- to 4-year-old learners of Kannada generated causative actions only 11% of the time (Lidz, Gleitman, & Gleitman, 2003) while learners of Tagalog did so 36% of the time (Trueswell, Kaufman, Hafri, & Lidz, 2012). This asymmetry suggests that cues that occur earlier in sentences (guiding initial interpretation) are easier to acquire compared to those that occur later in sentences (revising initial interpretation).

To test this hypothesis, Pozzan and Trueswell (2015) manipulated morpheme location within an artificial language task. English-speaking adults were taught that the marker "*ka*" was associated with an instrument interpretation in both verb-initial and verb-final versions of sentences like (2), i.e., to bounce the dolphin using the clothespin.

(2)	a. Verb-initial language:	Zumpi-ka fami nunu	(Bounce-ka dolphin clothespin)
	b. Verb-final language:	Nunu fami zumpi-ka	(Clothespin dolphin bounce-ka)

Over a 3-day period, learners of verb-initial languages demonstrated more successful learning compared to their verb-final counterparts. Following the onset of the marker, they generated more eye-movements to correct referents and revealed greater accuracy in final comprehension. Importantly, they also produced more accurate descriptions, suggesting that early cues facilitated the mastery of grammatical knowledge and not simply the ease of real-time comprehension. Finally, adults were asked to infer verb meanings based on the sentential and referential context, e.g., learning that "*zumpi*" in (2) means bounce. Once again, learners of verb-initial languages outperformed their verb-final counterparts. These findings suggest that real-time parsing can alter the informativity of syntactic cues, influencing the trajectory of learning.

Similar effects are also found in recent work on infant word learning (Lidz, White, & Baier, in preparation). Using a preferential-looking paradigm, 16-, 19-, and 26-month-olds were familiarized to sentences like (3), paired with a scene of a woman pushing a truck using a block.

(3)	a. Direct-object:	She's pushing the tiv
	b. Prepositional-object:	She's pushing with the tiv

During the test phase, infants saw a truck (patient) and a block (instrument) and were asked, "*Where's the tiv?*" Sixteen- and 28-month-olds looked to a truck following (3a) and a block following (3b), suggesting that they distinguished the syntactic contexts and generated correct referential expectations on this basis. Curiously, 19-month-olds consistently preferred patients, even when they heard the preposition in (3b). Lidz and colleagues (under review) argue that these errors reflect a period in which subcategorization frequencies of verbs strongly favor direct objects. This bias, paired with developmental difficulties with syntactic revision, lead 19-month-olds to maintain a direct-object interpretation, even after encountering conflicting cues.

Nevertheless, prior work leaves open two key questions. First, it remains unclear the extent to which unsuccessful learning is *caused* by insensitivity to late-emerging syntactic cues. Developmental research typically relies on the preferential-looking paradigm, which assesses novel-word interpretation after an initial familiarization phase (Arunachalam & Waxman, 2010; Lidz et al., in preparation; Naigles, 1990; Waxman & Booth, 2003; Yuan & Fisher, 2009). Similarly, in the artificial language task (Pozzan & Trueswell, 2015), adults' real-time sensitivity to cues was only assessed after input exposure was complete. However, without measures of processing during learning, it remains unknown whether parsing impacts interpretation or other downstream processes. For example, it is possible that 19-month-olds in Lidz and colleagues (under review) correctly mapped prepositional cues onto an instrument interpretation during the familiarization phase, but failed to retrieve this meaning during the test phase. Similar patterns have been found among 1- and 2-year-olds, who are often unable to recall meanings that were previously fast mapped (Bion, Borovsky, & Fernald, 2013; Goodman, McDonough, & Brown, 1998; Horst & Samuelson, 2008). This raises questions of whether real-time demands during learning have separable effects on interpretation and memory for word meanings.

Second, it is not always obvious whether non-adult interpretations reflect limitations in comprehension processes (e.g., challenges with syntactic revision) or developmental differences in syntactic knowledge (e.g., lack of underlying representations). For example, in Lidz and colleagues (under review), 19-month-olds' insensitivity to prepositional cues suggests that they, unlike 16-month-olds, are affected by subcategorization statistics. However, it is also possible that 19-month-olds, unlike 28-month-olds, are simply less knowledgeable about the sentential contexts associated with specific verbs. They may incorrectly assume that verbs like "*pushing*" must be followed by a direct object. Thus, their preference for a patient might not be caused by a failure to revise after a prepositional cue, but instead reflects a lack of knowledge of how this cue maps onto likely structures in the first place. This suggests that it can be difficult to distinguish effects of syntactic revision from those of incomplete syntactic knowledge during development.

1.3. Why passives may be informative

The following study takes a different approach and focuses instead on an area of syntactic processing that affects even highly experienced language users. Since there is little disagreement that adult native speakers have fully formed syntactic representations, evidence of interpretive challenges found in this population may shed light on parsing difficulties that are continuous throughout development. These are certainly *not* the only processing difficulties that children face during language acquisition. Nor are we arguing that they are necessarily the most important ones. Nevertheless, they may offer a minimally ambiguous test case for isolating parsing effects on word learning and provide a useful framework to guide future research.

To this end, we focus on the syntactic alternation between active and passive sentences. Both constructions express the basic relationship of who did what to whom. In active sentences like (4a), the first noun phrase (NP1) maps onto the agent ("*the seal*" = PREDATOR) while the second noun phrase (NP2) maps onto the theme ("*it*" = PREY). In passive sentences like (4b), this relationship reverses so that NP1 is now a theme while NP2 is an agent.

(4)	a. Active:	The seal is quickly eating it
	b. Passive:	The seal is quickly eaten by it

Young children face substantial difficulties comprehending passives, often misinterpreting them as actives (Gordon & Chafetz, 1990; Huang et al., 2013; Maratsos, Fox, Becker, & Chalkley, 1985; Messenger, Branigan, & McLean, 2012; Sudhalter & Braine, 1985). Notably, adults face challenges as well, typically in the form of increased reading times (Ferreira & Clifton, 1986; Gordon & Chan, 1995; Philipp, Bornkessel-Schlesewsky, Bisang, & Schlesewsky, 2008; Trueswell, Tanenhaus, & Garnsey, 1994) and sometimes as misinterpretations (Ferreira, 2003; Huang et al., 2013; MacWhinney, Bates, & Kliegl, 1984).

Importantly, this developmental continuity suggests that, beyond syntactic competence, properties of passives can pose challenges for real-time comprehension (Bever, 1970; Huang et al., 2013; Turner & Rommetveit, 1967). Since passives cannot be distinguished from actives until after the verb (see (4)), adults and children alike may initially analyze NP1s as agents. After all, most English utterances are actives (Gordon & Chafetz, 1990; Maratsos et al., 1985), thus most NP1s will be agents. Critically, unlike adults, developmental difficulties with syntactic revision may lead children to retain this misinterpretation, even after they encounter passive cues within the utterance (e.g., past participle, *by*-phrase). This predicts extensive errors when late-emerging cues conflict with an agent-first bias. However, if the agent-first bias can be weakened, then interpreting passive cues would no longer require syntactic revision. This may improve accuracy with passives and make them on par with actives.

Consistent with this hypothesis, Huang et al. (2013) found that inferences of plausible pronoun referents in Mandarin versions of (4) were less accurate for passives (e.g., "*it*" is an agent = shark) compared to actives (e.g., "*it*" is a theme = fish). This was true for both adults (passives: 79%; actives: 95%) and children (passives: 52%; actives: 74%). However, a different pattern emerged when full nouns and pronouns switched positions. In sentences like (5), inferences of pronoun referents for passives (e.g., "*it*" is a theme = fish) were as accurate as actives (e.g., "*it*" is an agent = shark). This was again true for both adults (passives: 78%; actives: 77%) and children (passives: 58%; actives: 59%). Taken together, these results suggest that properties of NP1 can modulate recruitment of an agent-first bias, which in turn impacts the accuracy of interpreting a late-emerging passive cue.

(5)	a. Active:	It is quickly eating the seal
	b. Passive:	It is quickly eaten by the seal

While the nature of these properties was left open by prior work, recent research suggests that discourse status may a role (Huang, Abadie, Hollister, & Arnold, 2016). In particular, the demands of incremental interpretation may pose unique challenges when NP1s are new discourse entities. Thus, when faced with uncertain role assignment, listeners may retreat to the statistical tendency for NP1s to be agents (see Bever (1970) for similar discussion). They may also be sensitive to linguistic cues that signal discourse status (Chafe, 1987; Gundel, Hedberg, & Zacharaski, 1993). Since full NP1s often introduce new entities, they may strengthen the agent-first bias in (4). In contrast, pronoun NP1s often refer to given entities, thus they may weaken this bias in (5). This predicts that whenever linguistic cues imply new NP1s, children will apply an agent-first bias and have difficulty revising this commitment for passives.

1.4. Current study

Building on prior work, the current experiments examine how challenges with syntactic revision impact the interpretation of novel words in active and passive sentences. Adults and 5-year-olds were presented with two tasks. First, in the word-learning task, they saw trials where a familiar object (e.g., the seal) interacted with two unfamiliar objects. Fig. 1 illustrates a sample trial where a large monster-

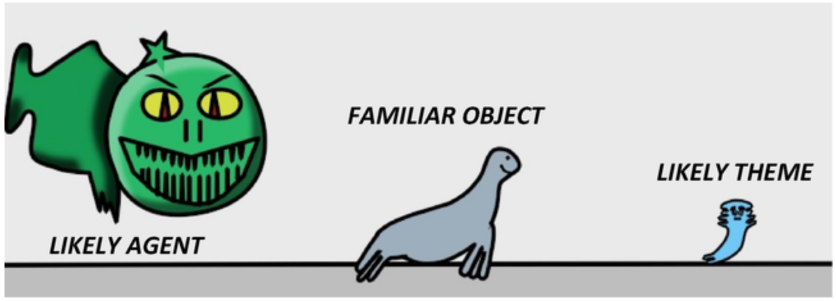


Fig. 1. In the word-learning task, sample test display featuring a familiar object (e.g., seal), likely agent, (e.g., large creature), and likely theme (e.g., small creature).

like predator (i.e., *likely agent*) chases a seal, and then a seal chases a small, wimpy prey (i.e., *likely theme*). After each animation, participants' eye-movements were measured to the unfamiliar objects, as they heard sentences featuring a novel word (Table 1). After each sentence, participants were asked to select the object corresponding to the novel word (e.g., "*Click on the blicket!*"). After completion of the entire word-learning task, participants took part in a recall task. They saw a series of trials where pairs of unfamiliar objects were presented and were asked for the novel word again (e.g., "*Which one is the blicket?*").

Unlike prior word-learning studies, this paradigm directly links on-line processing of syntactic cues (i.e., eye-movements in the word-learning task), interpretation of novel words (i.e., object selection in the word-learning task), and memory for meanings (i.e., object selection in the recall task). Following the disambiguating cues (e.g., "*eating*" in actives, "*eaten by*" in passives), preference for likely agents or likely themes will reveal whether participants assigned roles for familiar nouns (e.g., "*the seal*") and identified plausible referents for novel words on this basis ("*Target*" in Table 1). In the Novel-NP1 condition, active cues indicate that familiar nouns are themes, and so novel words should be likely agents. In contrast, passives cues indicate that familiar nouns are agents, and so novel words should now be likely themes. In the Novel-NP2 condition, the positions of novel and familiar words switch. Thus, there should now be a preference for likely themes after active cues and likely agents after passive cues.

This design yields two predictions for how properties of utterances may impact syntactic bootstrapping. One possibility is that children simply ignore novel words that occur in complex constructions like passives. They may consider this input to be less informative and focus their resources on learning words in simpler constructions like actives. However, another possibility is that children always attempt syntactic bootstrapping, but the success of this strategy is mediated by their ability to overcome real-time demands. By definition, novel words (e.g., "*the blicket*") are linguistic cues to new discourse entities. After all, if they had been encountered in the past, then their meanings would have likely been learned, and they would no longer be novel. Thus, when they occur in the Novel-NP1 condition, children may recruit an agent-first bias, leading to greater accuracy with actives (consistent with this bias) compared to passives (require revision of this bias). In contrast, known words (e.g., "*the seal*") are linguistic cues to given entities, since they refer to familiar concepts. Thus, when they occur in the Novel-NP2 condition, children may be less likely to adopt an agent-first bias. Importantly, this would allow them to recruit passive cues without syntactic revision, leading to accurate word learning for actives and passives.

In Experiment 1, we used this procedure to first examine comprehension in adults. The goals of this experiment were twofold. First, previous research has found that passives generate delays in on-line processing (Ferreira & Clifton, 1986; Gordon & Chan, 1995; Philipp et al., 2008; Trueswell et al., 1994) and errors in off-line interpretation in adults (Ferreira, 2003; Huang et al., 2013; MacWhinney et al., 1984). However, little is known about how novel words alter processing strategies. Thus, data from adults will reveal what performance looks like among mature language users and how syntactic revision can be assessed behaviorally. Second, our study adopts a recall task to assess how parsing during word learning affects subsequent memory for meanings. While the current materials were crafted with children in mind, data from adults can suggest ways in which parsing demands may impact the encoding and retrieval of meanings.

Table 1
In the word-learning task, sample sentences in the critical conditions. Targets refer to the plausible referent of the novel word (e.g., "*the blicket*") based on correct role assignment of the familiar noun (e.g., "*the seal*"). Competitors refer to the implausible referent of the novel word. In each sentence, the disambiguating cue is underlined.

Novel word	Construction	Sentence	Target	Competitor
NP1	Active	The blicket will be quickly eat**ing** the seal	Likely agent	Likely theme
NP1	Passive	The blicket will be quickly eat**en** by the seal	Likely theme	Likely agent
NP2	Active	The seal will be quickly eat**ing** the blicket	Likely theme	Likely agent
NP2	Passive	The seal will be quickly eat**en** by the blicket	Likely agent	Likely theme

2. Experiment 1

2.1. Methods

2.1.1. Participants

Forty English-speaking undergraduates at the University of Maryland College Park participated in this study for course credit. Half the adults were randomly assigned to the Novel-NP1 condition and the other half to the Novel-NP2 condition.

2.1.2. Procedure

Fig. 2 illustrates that the study involved two tasks, presented in a fixed order. First, in the word-learning task, adults sat in front of a computer monitor while an EyeLink 1000 desktop eye tracker (SR Research, Mississauga, Ontario, Canada) measured pupil location at the rate of 500 Hz and analyzed these samples as fixations and saccades. An experimenter monitored the location of adults' gaze using a second computer and ensured that pupil location was consistently calibrated throughout the study. At the beginning of the study, the experimenter told adults that they were going to see several familiar and unfamiliar objects on the display. Their task was to listen to sentences

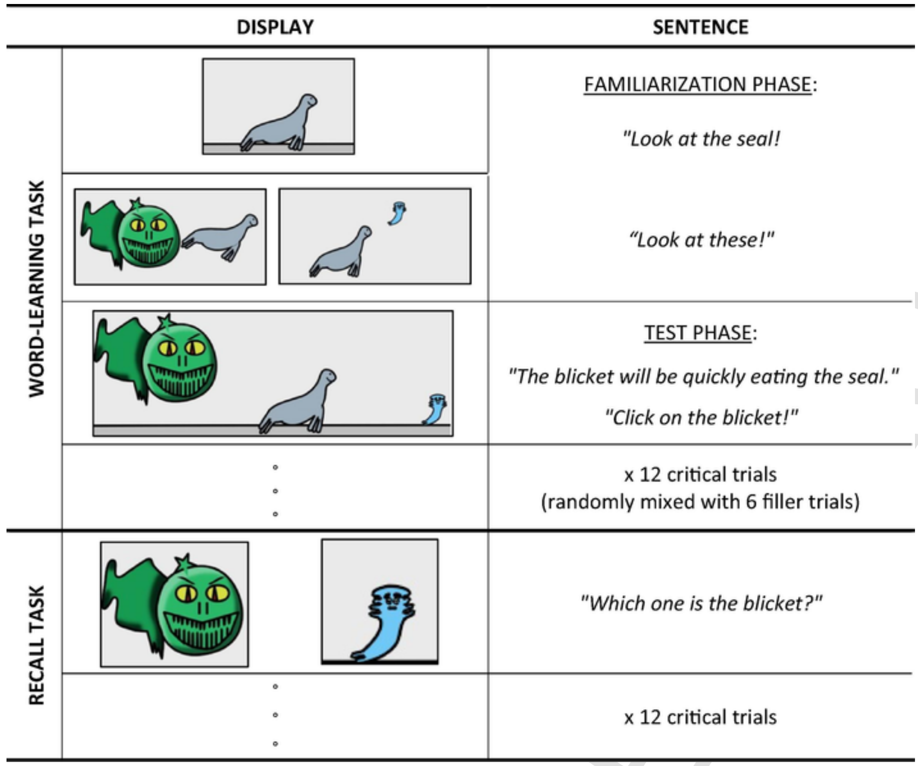


Fig. 2. The sequence of a sample trial within the word-learning and recall tasks.

and follow instructions to select one of the objects. Each trial began with a familiarization phase where adults saw short animated events where objects interacted with each other. This was followed by a test phase, where adults saw static displays of the objects and heard a sentence describing them. This was followed by instructions to select one of the objects (e.g., "*Click on the blicket*"). Adults then used the computer mouse to click on the appropriate object on the screen. Once they did this, the trial ended and the next trial began.

After adults completed *all* trials of the word-learning task, they moved on to the recall task. On each trial, adults saw static images of the unfamiliar objects from the word-learning task and were asked to select the one corresponding to the novel word (e.g. "*Which one is the blicket?*"). Once they did this, the trial ended and the next trial began. No feedback was provided on response accuracy in either task. The entire study took approximately 30 min.

2.1.3. Materials

In the word-learning task, critical trial types represented the cells of a 2 × 2 design. The first factor, construction type, contrasted active versus passive sentences and was varied within subjects. The second factor, novel-word position, contrasted the novel word (e.g., "*the blicket*") in NP1 versus NP2 position. Since prior research suggests that children experience interference when NP1 status alternated across trials (Huang et al., 2013), this factor was varied between subjects. Each trial featured a 3-object set that paired a familiar object (e.g., the seal) with a likely agent (e.g., something that can plausibly act on the familiar object) and a likely theme (e.g., something that the familiar object can plausibly act on). During the familiarization phase, adults saw short, animated events where a likely agent acted on a familiar object (e.g., a large, menacing creature chasing the seal), and the familiar object acted on a likely theme (e.g., the seal chasing a small puny creature). Note that the opening scene refers to the familiar object (e.g., "*Look at the seal!*"), which appears in all subsequent scenes (Fig. 2). This discourse context further increases the giveness of the familiar object, relative to unfamiliar ones (Arnold, 2010). During the test phase, adults saw displays of the unfamiliar objects on either side of the familiar object (Fig. 1). Across trials, likely agents and likely themes appeared equally on both sides to ensure that correct responses could not be predicted based on the display arrangement.

Each display was paired with test sentences similar to those in Table 1. Twelve unique, novel words were selected from the ARC non-word database (Rastle, Harrington, & Coltheart, 2002). All novel words were two syllables in length to make them phonologically distinct from known words. Auxiliary verbs and adverbs were embedded between NP1s and verbs to create a period of ambiguity in which role assignments could not be informed by verb meanings (e.g., "…*will be quickly/gently/quietly*…"). Four versions of each critical item were used to create four presentation lists, such that each list contained six items in each construction type and each item appeared just once in every list. A complete list of the materials for the 12 critical items is provided in Appendix A. In each list, six filler trials were also included to divert attention away from the manipulated variables. Filler trials were similar in structure to critical trials but recruited familiar objects only. Test sentences in filler trials embedded familiar words in active sentences (e.g. "*The sheep will be slowly eating the grass. Click on the grass.*").

All test sentences were initially recorded by a female actor who spoke in slow, clear, and consistent manner. From this initial set of recordings, final sound files were selected to minimize possible predictions of conditions based on extraneous acoustic cues. Final files roughly equated for the length of: (1) construction type, from sentence onset to the adverb (e.g., "*The blicket/seal will be*"); (2) all sentences, from the adverb to the disambiguating cue (e.g., "*quickly* *eat*"); (3) novel-word position, from the disambiguating cue to NP2 (e.g., "*-ing/-en by the*"); and (4) construction type, from NP2 to sentence offset (e.g., "*seal/blicket*"). Table 2 lists the average durations of these time windows across the 12 critical items. Within the set of final sound files, follow-up analyses confirmed no differences in duration along the dimensions specified above (all p's > 0.15). No subsequent adjustments were made to the audio.

In the recall task, images of the unfamiliar objects were presented side-by-side on printed card stock. Across trials, likely agents and likely themes appeared equally on the left and right to ensure that the correct response could not be predicted based on a side bias. In both the word-learning and recall tasks, the relative size of the unfamiliar objects provided a salient cue to their role assignment. Likely agents were larger than familiar objects, which in turn were larger than likely themes. Across both tasks, all trials were presented in semi-randomized order.

2.1.4. Coding

No trials were excluded from subsequent analyses because of experimenter error or eye-tracker malfunction. All data were coded in the following manner.

2.1.4.1. Eye-movements

During the word-learning task, eye-movements were continuously sampled from the onset of the test sentence to the execution of the action. Fixations were coded as looks to one of the three objects (i.e., familiar object, likely agent, likely theme) or missing due to looks away from these interest areas (e.g., looks to other parts of the display, blinking). Missing looks accounted for 11.5% of the sampled fixations. Remaining looks were recoded based on the trial condition (Table 1). "*Target fixations*" were looks to the unfamiliar object that were consistent with correct role assignment of the familiar object. "*Competitor fixations*" were looks to the unfamiliar object that were inconsistent with correct role assignment.

2.1.4.2. Actions

Following the instruction in the word-learning task, mouse clicks to the three objects were categorized based on the trial condition. "*Correct actions*" involved selection of the Target. "*Incorrect actions*" involved selection of the Competitor or the familiar object.

2.1.4.3. Recall

When asked for the novel word again in the recall task, selection of one of two unfamiliar objects was coded based on prior actions in the corresponding trial of the word-learning task. "*Matching responses*" involved selection of the same object as before (e.g., for the "*blicket*" item, selecting the likely agent in both the word-learning and recall tasks). "*Non-matching responses*" involved selection of a different object (e.g., selecting the likely agent in the word-learning task, but selecting the likely theme in the recall task).

Table 2
In the word-learning task, words and average durations (in milliseconds) of regions within the critical sentences by condition.

Condition	NP1 + AUX	Adverb + Verb	Disambiguation	NP2
Novel-NP1/Active	*The blicket will be* **1651**	*quickly eat* **931**	*-ing the* **378**	*seal* **553**
Novel-NP1/Passive	*The blicket will be* **1717**	*quickly eat* **995**	*-en by the* **716**	*seal* **502**
Novel-NP2/Active	*The seal will be* **1394**	*quickly eat* **955**	*-ing the* **370**	*blicket* **691**
Novel-NP2/Passive	*The seal will be* **1446**	*quickly eat* **921**	*-en by the* **769**	*blicket* **650**

2.2. Results

To isolate effects of parsing on bootstrapping, we analyzed performance in three ways. First, we examined eye-movements during test sentences to assess how syntactic cues were used to distinguish referents of actives from passives during real-time comprehension. Next, we examined actions following the instruction to assess the accuracy of final interpretations of novel words and their relationship to on-line sensitivity of syntactic cues. Finally, we examined recall of interpretations to assess how parsing demands during learning affected subsequent memory. Unless otherwise noted, dependent variables were analyzed using logistic mixed-effects models. Novel-word position (NP1 vs. NP2) and construction type (active vs. passive) were modeled as fixed-effects variables, and subjects/items were modeled as random-effects variables, with intercepts only.[1] Analyses were implemented through the lme4 software package in R (Bates, Maechler, Bolker, & Walker, 2013).

2.2.1. Word-learning task

2.2.1.1. Eye-movements

To assess on-line sensitivity to syntactic cues, our analyses focused on fixations from the onset of the disambiguating cue (e.g., "*-ing*" in "*eating*" vs. "*-en*" in "*eaten*") to sentence offset. The average length of this period was approximately 1150 ms. To account for the time it takes to generate a saccadic eye-movement, all time windows were shifted 200 ms after the linguistic cues in the speech stream (Matin, Shao, & Boff, 1993). Fig. 3 illustrates increased looks to familiar objects in the Novel-NP1 condition compared to the Novel-NP2 condition. This corresponds to the fact that the Novel-NP1 condition explicitly mentions the familiar object during this post-disambiguation region (e.g., "*…(by) the seal*"). Moreover, eye-movements revealed rapid convergence to the Target within each condition. Following a Novel-NP1, there was a preference for likely agents in the active condition and likely themes in the passive condition. This pattern appropriately switches in the Novel-NP2 condition.

To directly compare fixations across conditions, we first examined looks to the familiar object (e.g., the seal), which accounted for 37.5% of the sampled fixations. To account for the saccadic nature of eye-movements, we converted average, continuous fixations into a binary variable (Jaeger, 2008). This binary variable best captured the underlying distribution of our

data.[2] If fixations were greater than 0.50 during this region, then values were coded as 1. If they were less than 0.50, then values were coded as 0. Approximately 2.8% of trials were excluded because of

[1] In a separate set of analyses, we had constructed models that included random slopes for effects of construction type. However, since none of these models resulted in a significant improvement in model fit ($p > 0.05$), we chose instead simpler models with random intercepts only.

[2] Even though the eye-tracker sampled eye gaze every two milliseconds, people typically make only one or two saccades in a single second. Consequently, most participants will only fixate on one of the possible objects in a time window, making any measure of fixation proportion within that window essentially binary. Nevertheless, in follow-up analyses, we found the same overall patterns of results when continuous variables were analyzed using linear models.

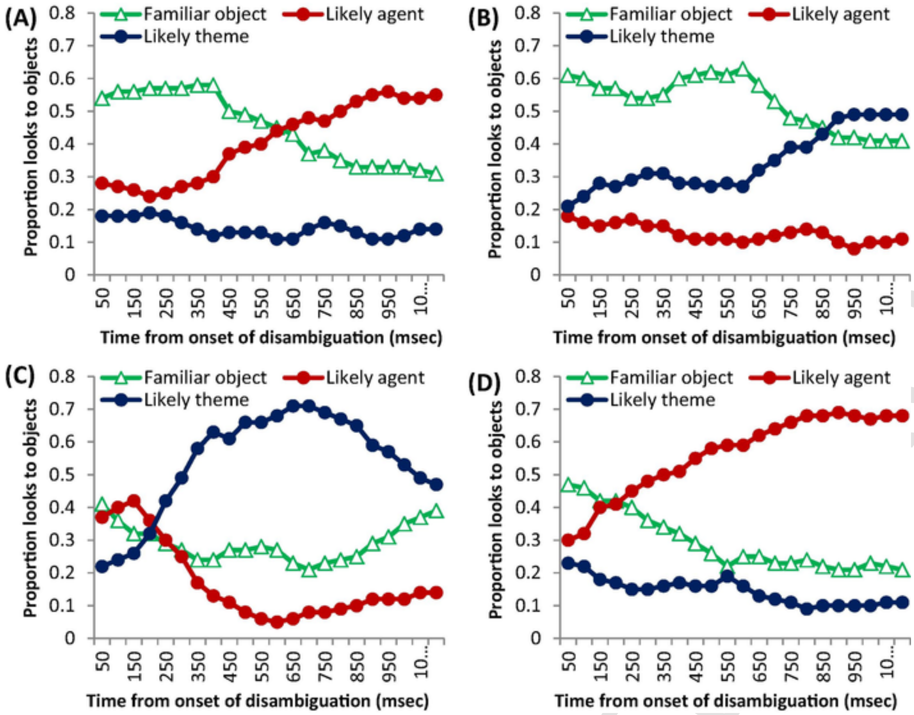


Fig. 3. In the word-learning task, adult fixations to the 3-object displays after the disambiguating cue in the (A) Novel-NP1/Active, (B) Novel-NP1/Passive, (C) Novel-NP2/Active, and (D) Novel-NP2/Passive conditions.

no looks to the familiar object or no numerical preference in either direction (i.e., average fixations of exactly 0.50). Overall, these analyses confirmed that fixations to the familiar object were greater in the Novel-NP1 condition (when the familiar noun had just been spoken) compared to the Novel-NP2 condition (45% vs. 18%; $z = 2.92$, $p < 0.01$). There was no additional effect of or interaction with construction type (all p's > 0.20).

Our primary analyses focused on looks to the Target and Competitor (i.e., the unfamiliar objects), which accounted for 62.1% of the sampled fixations. To assess on-line sensitivity to syntactic cues, we calculated preference scores that tracked the extent to which passives and actives were distinguished from each other. For passive trials, we subtracted looks to the Target minus Competitor, such that more *positive* values indicated greater sensitivity to syntactic cues. For active trials, we subtracted looks to the Competitor minus Target, such that more *negative* values indicated greater sensitivity. Fig. 4 illustrates that across both levels of word position, adults distinguished actives and passives shortly after the onset of the disambiguating cue. The magnitude of this sensitivity is captured by the area between preference scores in passive versus active trials. This difference was greater in the Novel-NP2 condition (when interpretation did not require syntactic revision) compared to the Novel-NP1 condition (when it did).

To compare across conditions, we again converted average preference scores on each trial into a binary variable. If scores were greater than 0, values were coded as 1. If scores were less than 0, values were coded as 0. Approximately 8.5% of trials were excluded because of no looks to the Target or Competitor or equal looks to both objects. Since adults often looked at unfamiliar objects when the novel word was being mentioned, excluded trials were marginally greater in the Novel-NP1 condition compared to the Novel-NP2 condition ($z = 1.80$, $p < 0.10$). However, there was no effect or interaction with construction type (all p's > 0.15).

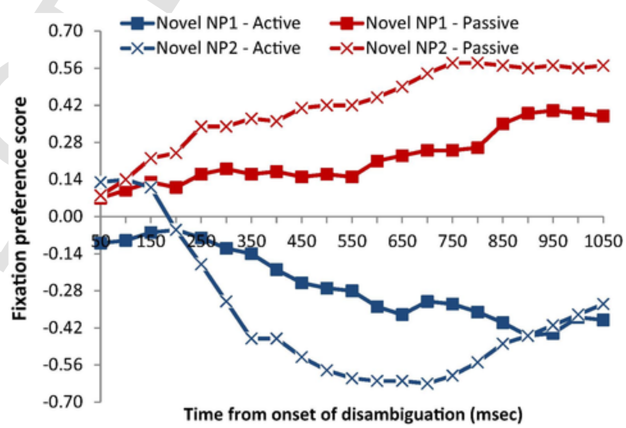


Fig. 4. In the word-learning task, adult preference scores after the disambiguating cue. Correct fixations to the Target are indicated by positive scores in passive trials (in red) and negative scores in active trials (in blue). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

In contrast, preference scores for included trials revealed a main effect of construction type ($z = 7.23$, $p < 0.001$) as well as a critical interaction with between construction type and novel-word position ($z = 2.21$, $p < 0.05$). There was no main effect of word position ($z = 0.81$, $p > 0.40$). Planned comparisons confirmed that preference scores were greater for passives compared to actives in both the Novel-NP1 ($z = 7.47$, $p < 0.001$) and Novel-NP2 conditions ($z = 9.12$, $p < 0.001$). Importantly, preference scores within passive trials were greater when syntactic revision was not required in the Novel-NP2 condition compared to when it was in the Novel-NP1 condition ($z = 2.05$, $p < 0.05$). In contrast, preference scores within active trials did not differ by novel-word position ($z = 0.79$, $p > 0.40$). These results demonstrate that adults rapidly recruit syntactic cues to infer possible referents of novel words. Moreover, they did so to a greater extent when syntactic revision was unnecessary.

2.2.1.2. Actions

We examined how final interpretation of novel words varied with the learning context. Fig. 5 illustrates high accuracy across all trials. Since adults always selected one of the two unfamiliar objects, we compared the likelihood of correct actions to 50%. These analyses confirmed above-chance accuracy for actives (95%; $t(19) = 23.24$, $p < 0.001$) and passives (93%; $t(19) = 14.23$, $p < 0.001$) in the Novel-NP1 condition as well as actives (98%; $t(19) = 42.14$, $p < 0.001$) and passives (99%; $t(19) = 59.00$, $p < 0.001$) in the Novel-NP2 condition. Comparisons across conditions revealed no main effects or interactions (all z's < 1.00, all p's > 0.20). These results demonstrate that adults were highly accurate at using syntactic cues to infer the meanings of novel words, even in contexts requiring syntactic revision.

We then examined the extent to which on-line sensitivity to syntactic cues was related to successful syntactic revision, specifically in the passive trials. For each participant, we correlated average accuracy for passives with average preference scores for passive minus active trials. This difference score corresponds to the area between fixations in passive and active trials in Fig. 4. It was greater when participants looked at Targets in passive (leading to more positive scores) and active trials (leading to more negative scores). While increased on-line sensitivity was associated with greater accuracy with passives in the Novel-NP1 condition ($r(18) = 0.30$, $p > 0.15$), this effect did not approach significance. Moreover, the same pattern emerged with passives in the Novel-NP2 condition, where syntactic revision was not necessary ($r(18) = 0.29$, $p > 0.20$). Altogether, these results suggest that among fully mature language users, variation in on-line processing is less closely tied to the accuracy of final interpretation.

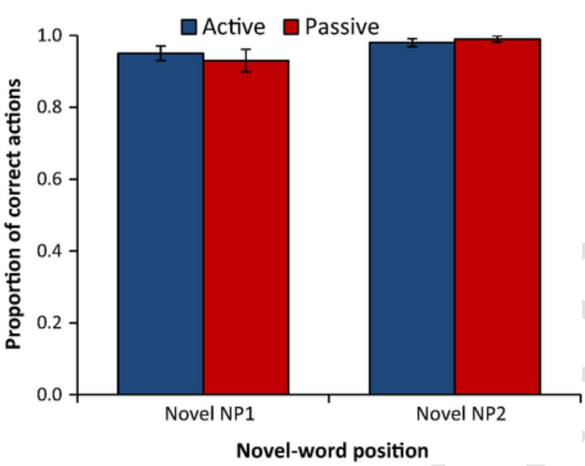


Fig. 5. In the word-learning task, adults' proportion of correct actions after sentence completion.

2.2.2. Recall task

We examined whether memory for word meanings varied with the learning context. The overall rate of matching responses was 72%. To equate the encoded meaning within a condition (e.g., likely agent or theme), we analyzed trials based on what was selected in the word-learning task. Correct-action trials accounted for 86.6% of trials. Fig. 6a illustrates that if correct meanings were mapped in the word-learning task, adults often remembered this selection in the recall task. In the Novel-NP1 condition, matching responses were above chance for both actives (64%; $t(19) = 2.55$, $p < 0.05$) and passives (71%; $t(19) = 4.09$, $p < 0.01$). Similarly, in the Novel-NP2 condition, the same was true for both actives (75%; $t(19) = 6.26$, $p < 0.001$) and passives (78%; $t(19) = 7.37$, $p < 0.001$). Comparisons across conditions revealed no main effects of construction type, word position, or interaction between the two (all z's < 1.50, all p's > 0.15).

However, a different pattern emerged in the Incorrect-action trials, which accounted for 13.4% of trials. Fig. 6b illustrates that if incorrect meanings were mapped in the word-learning task (i.e., choosing a Competitor), adults were less likely to select this meaning in the Novel-NP1/Passive trial (i.e., choosing a Target). Thus, in the Novel-NP1 condition, comparisons to chance revealed above-chance response matches for actives (90%; $t(4) = 4.00$, $p < 0.05$) but not passives (43%; $t(4) = 0.34$, $p > 0.70$). This pattern suggests that even when adults failed to revise passives during the word-learning task (leading to errors on 7% of trials), they often responded with the correct meaning during the recall task (leading to fewer matching responses). Due to the small sample size, this analysis could not be run in the Novel-NP2 condition. Comparisons across conditions revealed no main effects of construction type, novel-word position, or interaction between the two (all z's < 1.00, all p's > 0.60).

2.3. Discussion

In Experiment 1, adults rapidly recruited syntactic cues to generate real-time predictions of likely referents of novel words. However, they were less likely to fixate on correct referents when novel-word interpretation required syntactic revision. This pattern is consistent with well-documented processing delays associated with comprehending passives (Ferreira & Clifton, 1986; Gordon & Chan, 1995; Philipp et al., 2008; Trueswell et al., 1994). Unsurprisingly, final interpretations in adults were highly accurate across all conditions.

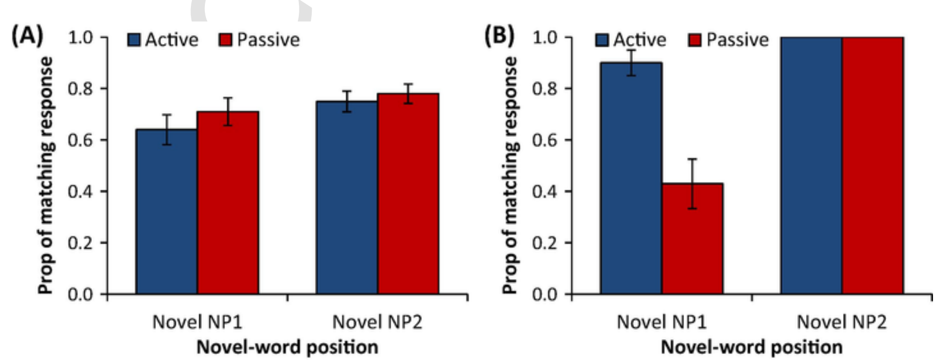


Fig. 6. In the recall task, adults' proportion of matching responses in the (A) Correct-action trials and (B) Incorrect-action trials of the word-learning task.

Since this current task was designed for children, it recruited simple sentences and offered plenty of time to respond. Similar asymmetries in adults' on-line versus off-line performance have been found in other studies using the visual-world eye-tracking paradigm (Choi & Trueswell, 2010; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995; Trueswell et al., 1999).

Nevertheless, adults' recall provides some hints that momentary parsing challenges can have lasting effects on memory. When presented with passives that require syntactic revision (Novel-NP1 condition), adults incorrectly selected the Competitor 7% of the time during the word-learning task. Yet, they revealed a surprising tendency to select the Target during the recall task, doing so 57% of the time. Notably, a different pattern emerged in active trials, which did not require revision. While action errors in the word-learning task were comparable to passive trials (selecting the Competitor 5% of time), subsequent recall rarely involved the Target (10% of trials). Taken together, these results suggest that partial revisions of passives may generate correct syntactic representations that persist in memory. Thus, even if this meaning is not selected during the word-learning task, it can be available during the recall task.

In Experiment 2, we turned to performance in 5-year-olds. Children at this age produce passives in elicited (Bencini & Valian, 2008; Huttenlocher, Vasilyeva, & Shimpi, 2004; Messenger et al., 2012) and spontaneous speech (Budwig, 2001; Harris & Flora, 1982; Horgan, 1978), suggesting an adult-like grammar. Nevertheless, they face difficulties comprehending passives (Gordon & Chafetz, 1990; Huang et al., 2013; Maratsos et al., 1985; Messenger et al., 2012; Sudhalter & Braine, 1985) that may be linked to challenges with syntactic revision (Choi & Trueswell, 2010; Huang et al., 2013; Hurewitz et al., 2000; Omaki et al., 2014; Trueswell et al., 1999; Weighall, 2008). Thus, if parsing challenges impact syntactic bootstrapping, then word learning should be more accurate when syntactic cues converge with an agent-first bias (Novel-NP1/Active trials) or when cues can be interpreted without the bias (Novel-NP2/Active trials, Novel-NP2/Passive trials). However, when interpretation requires revision of an agent-first bias (Novel-NP1/Passive trials), word learning in children may be less accurate.

3. Experiment 2

3.1. Methods

3.1.1. Participants

Forty English-speaking children were recruited from private schools in the Washington, D.C. metro area. The mean age was 5;4 (SD = 0;3, range = 5;0–5;11). Half the children were randomly assigned to the Novel-NP1 condition and the other half to the Novel-NP2 condition.

3.1.2. Procedure

The procedure was identical to Experiment 1.

3.1.3. Materials

The materials were identical to Experiment 1.

3.1.4. Coding

The data were coded in the manner described in Experiment 1. Approximately 1.8% of trials were excluded from subsequent analyses because of experimenter error. Missing looks accounted for 15.4% of the sampled fixations.

3.2. Results

All dependent variables were analyzed using the same approach as Experiment 1.

3.2.1. Word-learning task

3.2.1.1. Eye-movements

Fig. 7 illustrates that similar to adults, children generated more looks to the familiar objects when it was mentioned in the post-disambiguation region of the Novel-NP1 condition compared to the Novel-NP2 condition. Moreover, in the Novel-NP2 condition, children correctly looked to likely themes in the active trials and likely agents in the passive trials. In contrast, in the Novel-NP1 condition, they correctly converged on the likely agent in the active trials, but failed to switch to the likely theme in the passive trials. Fig. 8 confirms that children had difficulty interpreting passives that required syntactic revision. Approximately 400 ms after the disambiguating cue, children used syntactic cues to distinguish referents for actives across both novel-word positions (leading to negative preference scores). During the same period, they distinguished passives in the Novel-NP2 condition (leading to positive scores), but failed to do so for passives in the Novel-NP1 condition (leading to negative scores).

To examine these patterns in greater detail, we first compared looks to the familiar object, which accounted for 35.4% of all sampled fixations. Approximately 7.5% of trials were excluded because of no looks to the familiar object or no numerical preference in either direction. These analyses confirmed that like adults, children's fixations to the familiar object were greater in the Novel-NP1 condition (when the familiar noun had just been spoken) compared to the Novel-NP2 condition (51% vs. 20%; $z = 5.37$, $p < 0.001$). There was no additional effect of or interaction with construction type (all p's > 0.20).

Our primary analyses focused on Target and Competitor looks, which accounted for 64.5% of the sampled fixations. Approximately 10.0% of trials were excluded because of no looks to either object or equal looks to both objects. Similar to adults, there were more excluded trials in the Novel-NP1 condition (when the novel word occurred at sentence onset) compared to the Novel-NP2 condition (when it had just been spoken) ($z = 2.02$, $p < 0.05$). However, there was no effect or interaction with construction type (all p's > 0.40). In contrast, preference scores for included trials revealed an interaction between construction type and novel-word position ($z = 1.99$, $p < 0.05$). There were no additional effects of construction type ($z = 0.06$, $p > 0.90$) or word position ($z = 0.54$, $p > 0.50$). Planned comparisons confirmed that preference scores were greater for passives compared to actives in the Novel-NP2 condition ($z = 2.98$, $p < 0.01$) but not in the Novel-NP1 condition ($z = 0.07$, $p > 0.90$). Moreover, scores for passives were greater when syntactic revision was not required in the Novel-NP2 condition compared to when it was in the Novel-NP1 condition ($z = 3.09$, $p < 0.01$). In contrast, scores for actives did not differ by novel-word position ($z = 0.52$, $p > 0.50$). These results demonstrate that children, like adults, are less sensitive to syntactic cues when they occurred in contexts that require syntactic revision.

3.2.1.2. Actions

Fig. 9 illustrates that children were less accurate with passives compared to actives when novel words occurred in NP2 position. This difference vanished when novel words occurred in NP2 position. We compared action accuracy in each condition to chance, which

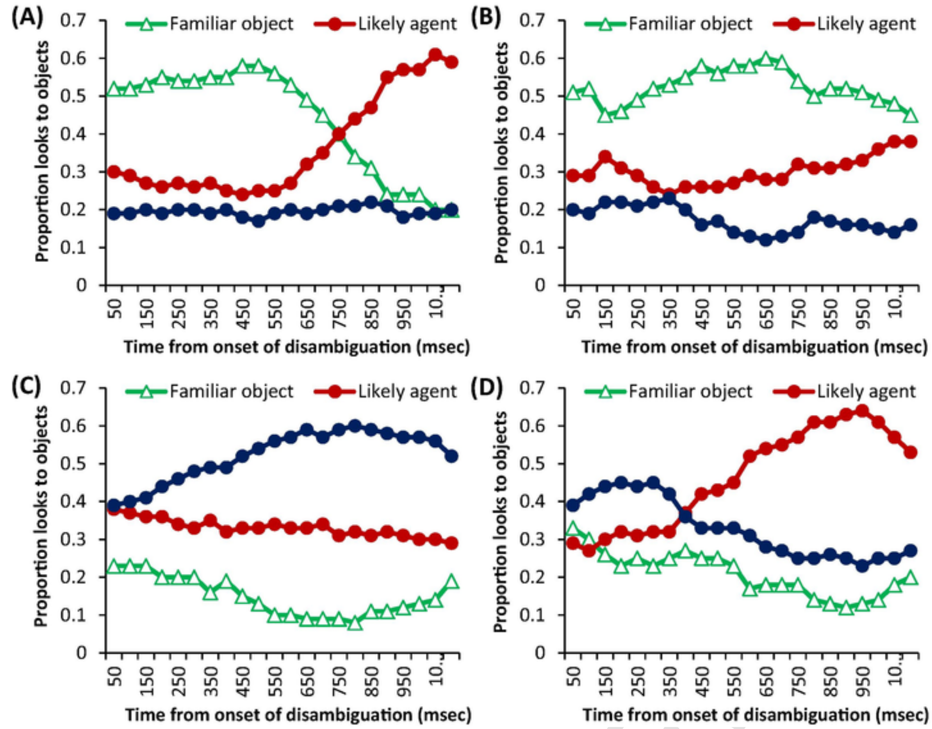


Fig. 7. In the word-learning task, child fixations to the 3-object displays after the disambiguating cue in the (A) Novel-NP1/Active, (B) Novel-NP1/Passive, (C) Novel-NP2/Active, and (D) Novel-NP2/Passive conditions.

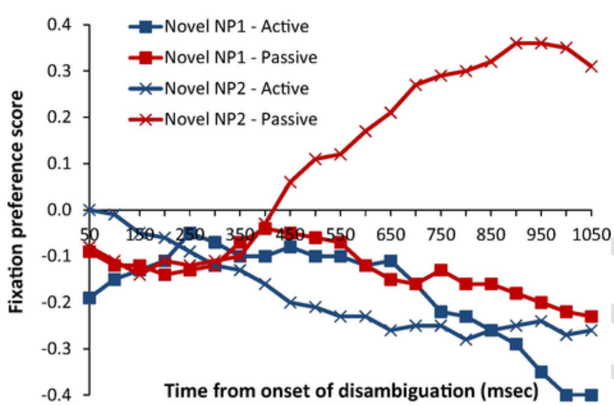


Fig. 8. In the word-learning task, child preference scores after the disambiguating cue. Correct fixations to the Target are indicated by positive scores in passive trials (in red) and negative scores in active trials (in blue). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

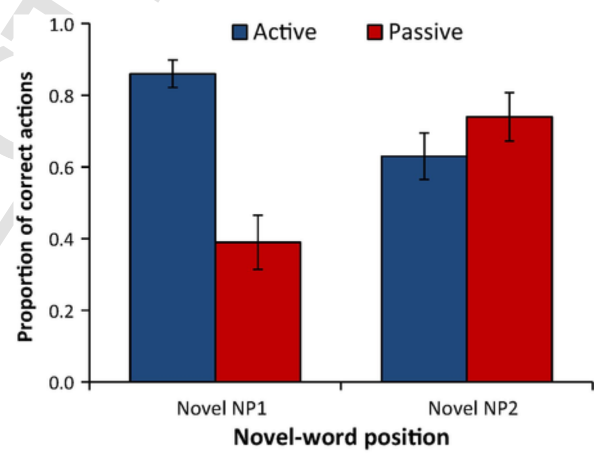


Fig. 9. In the word-learning task, children's proportion of correct actions after sentence completion.

was set at 50%. While children sometimes selected familiar objects, these errors accounted for only 1.7% of trials. Above-chance accuracy was found for actives in the Novel-NP1 (86%; $t(19) = 9.79$, $p < 0.001$) and Novel-NP2 conditions (63%; $t(19) = 2.67$, $p < 0.05$) and passives in the Novel-NP2 condition (74%; $t(19) = 3.68$, $p < 0.01$). However, when syntactic revision was needed for passives in the Novel-NP1 condition, selection was at chance (39%; $t(19) = 1.43$, $p > 0.15$).

Comparisons across conditions confirmed effects of construction type ($z = 7.58$, $p < 0.001$) and novel-word position ($z = 3.11$, $p < 0.01$), along with an interaction between the two ($z = 7.21$, $p < 0.001$). Within levels of construction type, planned comparisons revealed that accuracy was greater in the Novel-NP1 condition compared to the Novel-NP2 condition ($z = 3.30$, $p < 0.001$). This pattern reversed for passives ($z = 3.45$, $p < 0.001$). Within levels of novel-word position, accuracy was greater for actives compared to passives in the Novel-NP1 condition ($z = 7.60$, $p < 0.001$), but no difference was found in the Novel-NP2 condition ($z = 1.08$, $p > 0.20$). These results suggest that developmental parsing challenges lead to frequent mismappings of novel-word meanings when they occurred in passives that required syntactic revision.

Given the substantial variation in syntactic revision, we examined whether there was a systematic relationship between children's on-line sensitivity to syntactic cues and successful revision in the passive trials. Unlike adults, we found that individual differences in children's average preference scores (i.e., passive minus active trials) were positively associated with the average accuracy of their final interpretations for passives in the Novel-NP1 condition ($r(18) = 0.49$,

$p < 0.05$). In contrast, their fixations and actions were unrelated when syntactic revision was not necessary for interpreting passives in the Novel-NP2 condition ($r(18) = 0.06$, $p > 0.80$). This suggests that greater sensitivity to syntactic cues facilitates children's final interpretation of novel words, specifically in contexts that require syntactic revision.

3.2.2. Recall task

The overall rate of matching responses was 76%. We again split trials based on responses in the word-learning task. Correct-action trials accounted for 65.6% of trials. Importantly, Fig. 10a illustrates that matching responses were affected by the real-time demands of the learning context. They were above chance for actives in the Novel-NP1 (94%; $t(19) = 14.89$, $p < 0.001$) and Novel-NP2 conditions (66%; $t(18) = 2.14$, $p < 0.05$), as well as passives in the Novel-NP2 condition (79%; $t(18) = 4.02$, $p < 0.01$). Critically, they did not differ from chance for passives in the Novel-NP1 condition (47%; $t(16) = 0.35$, $p > 0.70$). Comparisons across conditions revealed main effects of construction type ($z = 5.05$, $p < 0.001$), novel-word position ($z = 3.36$, $p < 0.001$), and an interaction between the two ($z = 5.00$, $p < 0.001$). For actives, matches were greater in the Novel-NP1 condition compared to the Novel-NP2 condition ($z = 2.84$, $p < 0.01$). This pattern reversed for passives ($z = 3.19$, $p < 0.01$). In the Novel-NP1 condition, matches were greater for actives compared to passives ($z = 4.45$, $p < 0.001$), but no difference was found in the Novel-NP2 condition ($z = 1.32$, $p > 0.15$). These results demonstrate that even when children had correctly interpreted novel words in the word-learning task, they were less likely to remember these meanings when the words had occurred in contexts that required syntactic revision.

A different pattern emerged in Incorrect-action trials, which accounted for 34.4% of trials. Fig. 10b illustrates that children matched selections involving the likely agent, leading to above-chance responses in the Novel-NP1/Passive (92%; $t(16) = 9.62$, $p < 0.001$) and Novel-NP2/Active trials (90%; $t(15) = 7.01$, $p < 0.001$). However, matches did not differ from chance when prior selection involved the likely theme in the Novel-NP1/Active (55%; $t(10) = 0.10$, $p > 0.90$) and Novel-NP2/Passive trials (60%; $t(12) = 0.22$, $p > 0.20$). Comparisons across conditions revealed main effects of construction type ($z = 3.61$, $p < 0.001$), novel-word position ($z = 3.13$, $p < 0.01$), and an interaction between the two ($z = 3.92$, $p < 0.001$). For passives, matches were marginally greater in the Novel-NP1 condition compared to the Novel-NP2 condition ($z = 1.79$, $p < 0.10$). No difference was found for actives ($z = 1.19$, $p > 0.20$). In the Novel-NP1 condition, matches were greater for passives compared to actives ($z = 3.61$, $p < 0.001$). This pattern reversed in the Novel-NP2 condition ($z = 2.37$, $p < 0.05$). These results suggest that when children had misinterpreted novel words in the word-learning task, they based later recall on salient object properties (e.g., overall size, presence of teeth), leading to an advantage for likely agents.

4. General discussion

In two experiments, we examined the impacts of real-time language comprehension on syntactic bootstrapping in adults and 5-year-old children. In both groups, we found that the demands of syntactic revision negatively impacted on-line sensitivity to syntactic cues. During the word-learning task, predictions for novel-word referents were less robust when syntactic cues occurred in contexts requiring revision. However, while parsing challenges were momentary in adults, they had lasting effects in children. When revision was required, child-to-child variation in on-line sensitivity to syntactic cues was positively associated with off-line accuracy of final interpretations. Even when meanings were correctly bootstrapped in the word-learning task, children were less likely to remember this mapping when words had occurred in contexts that required syntactic revision. Altogether, these results demonstrate that real-time demands alter the informativity of syntactic cues, impacting children's word learning.

In the remainder of this discussion, we will focus on four additional issues related to the current findings. First, we consider the extent to which children's fixations were driven by strategies for tackling a word-learning task. Second, we revisit the question of why recruitment of the agent-first bias varied across contexts. Third, we will discuss how developmental challenges with syntactic revision might contribute to patterns of language learning during development. Finally, we will consider ways in which memory processes may influence what meanings are acquired (or not acquired) during word learning.

4.1. Are children simply playing a word-guessing game?

We have argued that developmental difficulties with word learning in the critical Novel-NP1/Passive trials result from decreased on-line sensitivity to syntactic cues when syntactic revision is required. However, it is possible that children's fixations instead reflect a narrower, task-specific strategy to identify novel-word referents using the first cue possible. One can imagine that over the course of the study, children picked up on the fact that most trials involved novel words. They can then develop a strategy to incrementally map these words onto possible referents as soon as they occur in the speech stream. Upon doing so, they can just ignore the rest of the sentence. In the Novel-NP1 condition, novel words occurred at sentence onset. Thus, use of the agent-first bias would allow children to restrict reference immediately and generate the patterns we find: More correct

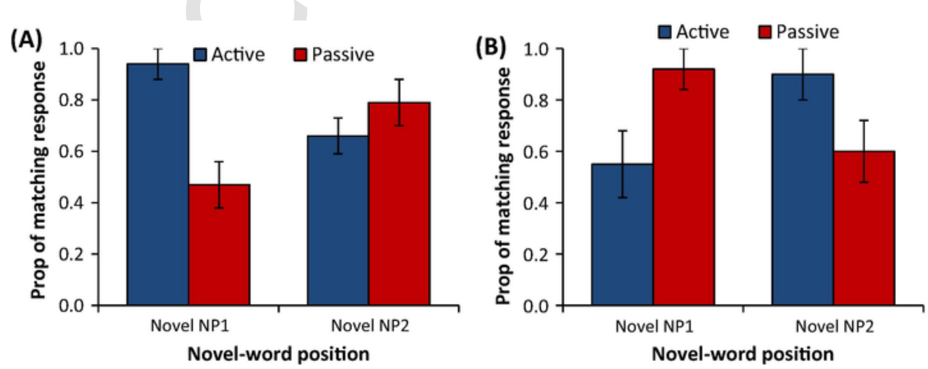


Fig. 10. In the recall task, children's proportion of matching responses in the (A) Correct-action trials and (B) Incorrect-action trials of the word-learning task.

looks for actives compared to passives. Importantly, this strategy would not require any analysis of the syntactic cues distinguishing actives and passives.

While this account explains why children often failed to fixate on correct referents in the Novel-NP1/Passive trials, other data patterns suggest sensitivity to late-emerging cues. First, if children had ignored the rest of the sentence in the Novel-NP1 conditions, then eye-movements in the post-disambiguation region should have been identical in the active and passive trials. Yet, visual inspection of Fig. 7a and 7b reveals greater looks to the likely agent in the active trials (37%; where it was the correct referent) compared to the passive trials (30%; where it was the incorrect referent). Follow-up analyses of likely-agent fixations confirmed a marginal effect of construction type in the Novel-NP1 condition ($z = 1.78$, $p < 0.10$).

Second, if our results were driven by task demands (e.g., encountering lots of novel-word trials), then we would expect that reliance on an agent-first bias and ignorance of disambiguating cues would become stronger as children gain more experience with our study. Yet, follow-up analyses revealed similar patterns across first- and second-half trials. In both fixation and action measures, there were no effects of or interactions with study half in Novel-NP1 and Novel-NP2 conditions (all p's > 0.15). Even among first-half trials only, interactions between construction type and novel-word position were marginally significant in fixation preferences ($z = 1.77$, $p < 0.10$) and statistically significant in action accuracy ($z = 5.85$, $p < 0.001$). Taken together, this suggests that children's interpretations were guided by biases that they possessed prior to the study and were unlikely to be learned based on properties of our task.

Finally, children's eye-movements exhibited systematic relationships with other aspects of performance. For example, their on-line sensitivity to disambiguating cues in the Novel-NP1 condition predicted their action accuracy with passives that required revision. This relationship would be somewhat mysterious if children simply failed to analyze post-NP1 cues or if they only did so for off-line responses but not for on-line processing. Similarities between children's and adults' fixations also suggest that both age groups were attending to disambiguating cues. While task challenges could have induced children to adopt simpler strategies, this account is less plausible for adults who breezed through our study. Yet, even when final interpretations were highly accurate among mature language users, analyses of fixations revealed greater difficulty inferring novel-word referents in contexts requiring revision.

Taken together, these data suggest that eye-movements in the current study reflect real-time prediction of novel-word referents via late-emerging syntactic cues. This interpretation is consistent with a literature demonstrating that fixations during spoken comprehension are tightly linked to language processing in both adults and children (Choi & Trueswell, 2010; Huang et al., 2013; Snedeker & Trueswell, 2004; Snedeker & Yuan, 2008; Tanenhaus et al., 1995; Trueswell et al., 1999). Moreover, novel-word paradigms are ubiquitous in language-acquisition research, applied to word learning in infants (Fennell & Waxman, 2010; Lidz et al., in preparation; Stager & Werker, 1997; Waxman & Booth, 2003; Werker, Fennell, Corcoran, & Stager, 2002; Yoshida, Fennell, Swingley, & Werker, 2009), toddlers (Arunachalam & Waxman, 2010; Bion et al., 2013; Goodman et al., 1998; Horst & Samuelson, 2008; Naigles, 1990; Yuan & Fisher, 2009), and preschoolers (Barner & Snedeker, 2005; Bloom & Kelemen, 1995; Brown, 1957). Given the similarities with prior tasks, we believe that children's performance in our study shed light on the mechanisms that are naturally recruited to learn words in the wild.

4.2. What factors generate an agent-first bias?

While children revealed decreased sensitivity to cues that conflict with an agent-first bias, it remains less clear why this bias was present in the first place. In the Introduction, we argued that an agent-first bias may be a heuristic for overcoming challenges associated with incremental interpretation of unfamiliar utterances. Since new discourse entities introduce greater uncertainty of grammatical roles, listeners may rely on the statistical tendency for NP1s to be agents. This explains why this bias was stronger for full NP1 s (e.g., "the *seal*") compared to pronoun NP1 s (e.g., "*it*") in Huang et al. (2013). It is also consistent with a stronger bias for novel NPs (e.g., "*the blicket*") compared to known NPs (e.g., "*the seal*") in the current study.

However, another possibility is that children's performance reflects a simpler strategy of mapping ambiguous NP1s to salient entities in the scene. In the current task, this corresponds to the likely agents, which were larger and more interesting than likely themes (see Appendix A). This explains why accuracy in the critical Novel-NP1/Passive trial (where Targets were likely themes) was lower than all other trials. It also raises the possibility that our patterns reflect task-specific properties rather than probabilistic, linguistic commitments. Nevertheless, this account fails to explain performance with ambiguous, pronoun NP1s (e.g., "*it*") in Huang et al. (2013). As in the current study, likely agents (e.g., a shark) there were more attention-grabbing than likely themes (e.g., a fish). Thus, if children adopted a salience-based strategy, they should have interpreted pronoun NP1s as likely agents and again made more errors with passives (since Targets were likely themes). Instead, Huang et al. (2013) found comparable accuracy across constructions in this context (passives: 58%, actives: 59%).

A related possibility is the agent-first bias varies with task goals. Huang et al. (2013) asked children to use objects to act out the meaning of the sentence. Importantly, unlike selection tasks (e.g., "*Click on the blicket!*"), act-out tasks may impose an additional requirement that all arguments to be identified before responses can be generated. Since pronoun NP1s were referentially ambiguous, their occurrence in an act-out task may have blocked an agent-first bias. However, this account is inconsistent with recent evidence from an act-out task (Huang et al., 2016). Here, children heard pronoun NP1s that were preceded by single-NP (e.g., "*The red seal is dancing*") or conjoined-NP primes (e.g., "*The red seal and the brown seal are dancing*"). The latter case introduced two prominent (given) entities, thus use of pronoun NP1s was ambiguous since referring to either entity would require a more specific description (Arnold, 2010; Givón, 1983). Indeed, children were more likely to select unmentioned (new) objects after conjoined-NP primes (17% actions with shark/fish) compared to single-NP primes (2%). Critically, consistent with a discourse account, conjoined-NP primes also strengthened an agent-first bias, leading to lower accuracy for passives (54%) compared to actives (88%). In contrast, single-NP primes generated similar accuracy across passives (82%) and actives (93%), demonstrating a weaker agent-first bias without referential ambiguity. Altogether, these results suggest that discourse status modulates recruitment of an agent-first bias and not task properties.

4.3. How do challenges with syntactic revision impact language learning?

Our findings suggest that over the course of development, parsing challenges can generate interpretive failures that lead to illusions of conflict across sentences in the input. For example, imagine learning the meaning of "*blicket*" given a set of sentences like (6).

(6)	a. Active:	The seal is quickly eating the blicket	("*blicket*" is a theme)
	b. Passive:	The blicket is quickly eaten by the seal	("*blicket*" is a theme)

A child who can revise misinterpretations will realize that both sentences provide converging evidence about the novel-word meaning (e.g., "*blicket*" is a theme, refers to something that seals can plausibly eat). In contrast, a child who has difficulty with syntactic revision may be confused since (6a) suggests that the novel word is a theme while (6b) suggests that it is an agent. Thus, even when children possess an ability to bootstrap word meanings from syntactic cues, real-time challenges may alter the informativity of these cues and interfere with efficient learning (see related discussion about acquiring syntactic knowledge in Omaki and Lidz (2015)).

These effects have implications for understanding sources of individual differences in language outcomes. While technological advances provide greater details of what caregivers say to children (Ford, Baer, Xu, Yapanel, & Gray, 2009; Weisleder & Fernald, 2013), far less is known about how this input is filtered through a developing system for comprehension. Notably, across socioeconomic status (SES) backgrounds, distinctions in the quantity of caregiver input are associated with well-known "word gaps" in children's vocabulary size (Hart & Risley, 1995; Hoff, 2003; Rowe, 2012). It is often assumed that this effect is driven by a lack of relevant input, e.g., not learning "*stethoscope*" if you've never encountered the word. Yet, our findings highlight how word learning can remain challenging despite encountering informative cues, e.g., not learning "*blicket*" in a context that requires syntactic revision. Recent work suggests that SES-related variation in syntactic revision is positively correlated with children's vocabulary size (Huang, Leech, & Rowe, in preparation). Future work will isolate the extent to which this relationship is mediated by real-time access to syntactic cues for syntactic bootstrapping.

Finally, while developmental difficulties with syntactic revision negatively impacts word learning via syntactic bootstrapping, it is possible that this limitation also provides a paradoxical advantage for mastering grammatical rules. In artificial language tasks, it is well-documented that adults often match the statistics of their input while children regularize underlying patterns (Culbertson & Newport, 2015; Culbertson, Smolensky, & Legendre, 2012; Hudson-Kam & Newport, 2005, 2009). For example, Hudson-Kam and Newport (2009) found that when a main determiner occurs 60% of the time, adults will produce similar probabilities later on. Five-year-olds, in contrast, prefer more systematic patterns, using or omitting the determiner 100% of the time. This developmental difference is often explained in terms of memory limitations (e.g., Newport's (1990) Less-is-More hypothesis). Rather than storing entire complex forms, children attend to smaller morphological units, boosting their sensitivity to regular patterns in the input.

However, beyond syntactic competence, the current study demonstrates that accurate utterance comprehension requires efficient retrieval of structures from memory during syntactic parsing. In this light, late maturation of cognitive-control abilities, which has been argued to cause developmental challenges with syntactic revision (Mazuka, Jincho, & Oishi, 2009; Novick, Trueswell, & Thompson-Schill, 2005; Woodard, Pozzan, & Trueswell, 2016), may play a key role in regularizing input to maximize retrieval of canonical structures. For example, in the current test case, relying on an agent-first bias and ignoring the past participle/*by*-phrase may boost input statistics in favor of active sentences. This negatively impacts comprehension of passives. Yet, it may serve a broader benefit by guaranteeing interpretation of actives from the earliest moments of acquisition. Moreover, to the extent that novel words are far more likely to occur in actives, this strategy may enhance the likelihood of syntactic bootstrapping. While this account needs to be fleshed out and rigorously tested, it suggests another dimension by which the minds of children may be optimized for tackling the unique challenges of language acquisition.

4.4. How do memory processes impact word learning?

Our findings suggest that parsing demands can also impact word learning through memory interference. One possibility is that syntactic revision reduces domain-general resources for encoding word meanings. Consistent with this pattern, research on adult memory has found more recall errors when attention is divided during encoding (Fernandes & Moscovitch, 2000). Importantly, these errors are unaffected by similarities between primary and secondary tasks, suggesting a domain-general competition for resources. Similarly, the developmental literature has found that while 14-month-olds distinguish phonetically similar sounds in a discrimination task (e.g., "*bih*" vs. "*dih*"), they fail to do so when these sounds are linked to referents (Fennell & Waxman, 2010; Stager & Werker, 1997; Werker et al., 2002; Yoshida et al., 2009). Slightly older 17-month-olds succeed at both tasks, suggesting that word-learning demands may limit encoding of phonetic details among novice learners. This pattern offers potential parallels with the current study. Five-year-olds' challenges with syntactic revision may increase memory demands during on-line comprehension and lead to more fragile encoding of meanings.

A second possibility is that our findings reflect a domain-specific competition between representations generated during syntactic parsing. In the memory literature, prior exposure to incorrect responses increases subsequent recall errors (Roediger & Bulter, 2011; Roediger & Marsh, 2005). Similarly, in the psycholinguistics literature, incomplete revision can generate multiple interpretations of distinct syntactic structures (Christianson, Hollingworth, Halliwell, & Ferreira, 2001; Ferreira, 2003; Slattery, Sturt, Christianson, Yoshida, & Ferreira, 2013). Thus, even when a correct syntactic parse leads to accurate interpretation during the learning context, an incorrect one can linger in memory and promote a different response during later recall. This account provides a natural explanation for why children's memory for word meanings was less accurate in contexts requiring syntactic revision, even when their off-line interpretations were correct. Future research manipulating real-time engagement of memory and inhibitory processes during comprehension may shed light on the contributions of domain-general versus domain-specific processes during word learning (see Hsu & Novick, in press).

Finally, while children's performance in the recall task suggests that memory limitations may negatively impact word learning, the same constraint may play a vital role in recovering from incorrect hypotheses (Medina, Snedeker, Trueswell, & Gleitman, 2011; Trueswell, Medina, Hafri, & Gleitman, 2013). Evidence for this comes from word learning in contexts where a low-informative context (e.g., hearing "*blicket*" when no objects are present) is followed by a high-informative context (e.g., hearing "*blicket*" when the speaker is looking at an object). Adults had difficulty learning correct meanings when these trials occurred within a single session. However, they were surprisingly more successful when there was a substantial delay in between (e.g., 1–3 days). This suggests that high-informative contexts promote learning when incorrect guesses from low-informative contexts were forgotten. These effects offer potential parallels with the current study. Recall that adults revealed a striking tendency to forget incorrect meanings that resulted from incomplete syntactic revision. This is unlikely to reflect general memory decay since they accurately recalled meanings in other conditions. While future work is needed to assess the stability of these effects, they may indicate an additional route by which memory limitations interact with the maintenance of hypotheses during word learning.

5. Conclusion

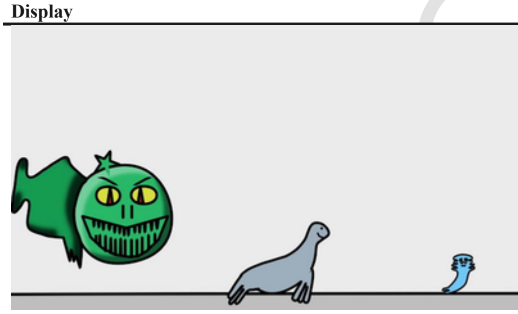
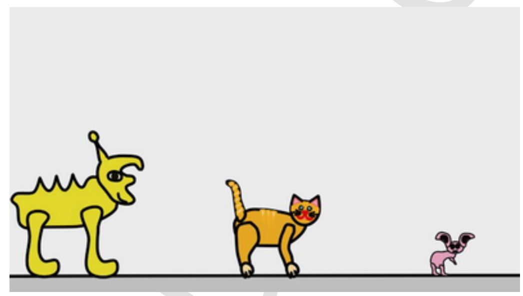
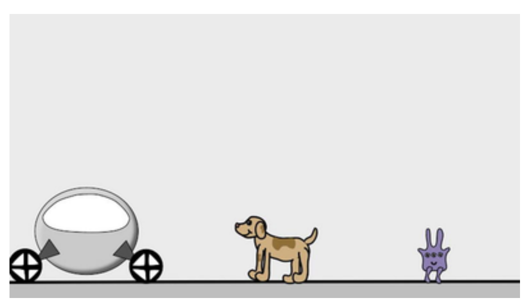
This study examined how syntactic processing in adults and 5-year-olds impacts the bootstrapping of novel-word meanings. Our findings suggest that children attempt to learn from all available cues within utterances. Nevertheless, their success in doing so varies with real-time parsing demands. Like adults, children's eye-movements were less sensitive to syntactic cues when they conflicted with initial syntactic analysis. However, unlike adults, children often mislearned the meanings of novel words on this basis. Child-to-child differences in on-line sensitivity were positively linked to accurate word learning. Finally, parsing challenges also generated subsequent memory errors in children, even when prior interpretations were correct. Altogether, these results demonstrate that syntactic bootstrapping depends, in part, on an ability to overcome the real-time demands of utterance interpretation. Inefficient parsing impacts word learning, through interpretive failures and memory interference.

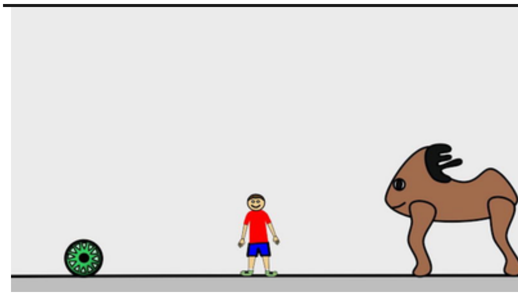
6. Uncited references

Acknowledgements

We are grateful to Erin Hollister and other members of the Language and Cognition Laboratory for their assistance in experiment set up and data collection. We would also like to thank Jeffrey Lidz, Aaron Steven White, Nan Bernstein Ratner, and Rochelle Newman for their suggestions for task design. Finally, we would like to thank the families and administrators at the St. Anne's School of Annapolis, Beddow School, Young School, and Bethesda Montessori School for taking part in this study.

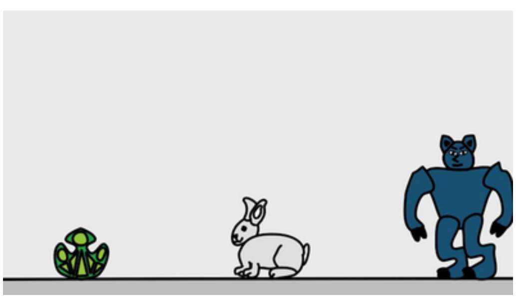
Appendix A. List of critical items

Display	Critical sentences (novel-word position/construction type)
	Novel word: "Blicket" NP1/Active: The blicket will be quickly chasing the seal. NP1/Passive: The blicket will be quickly chased by the seal. NP2/Active: The seal will be quickly chasing the blicket. NP2/Passive: The seal will be quickly chased by the blicket.
	Novel word: "Nedoke" NP1/Active: The nedoke will be quickly scaring the cat. NP1/Passive: The nedoke will be quickly scared by the cat. NP2/Active: The cat will be quickly scaring the nedoke. NP2/Passive: The cat will be quickly scared by the nedoke.
	Novel word: "Coopa" NP1/Active: The coopa will be quickly chasing the dog. NP1/Passive: The coopa will be quickly chased by the dog. NP2/Active: The dog will be quickly chasing the coopa. NP2/Passive: The dog will be quickly chased by the coopa.



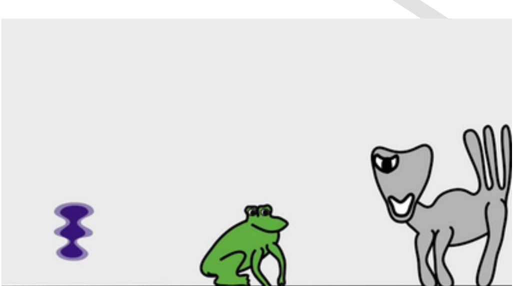
Novel word: "Hantil"

NP1/Active: The hantil will be gently kicking the boy.
NP1/Passive: The hantil will be gently kicked by the boy.
NP2/Active: The boy will be gently kicking the hantil.
NP2/Passive: The boy will be gently kicked by the hantil.



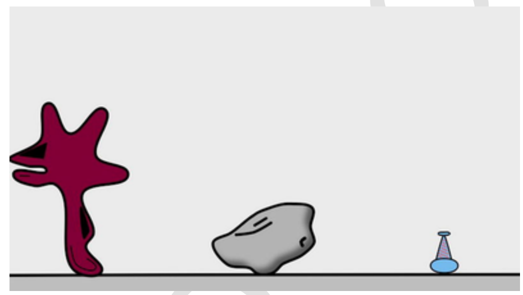
Novel word: "Leepo"

NP1/Active: The leepo will be slowly eating the rabbit.
NP1/Passive: The leepo will slowly eaten by the rabbit.
NP2/Active: The rabbit will be slowly eating the leepo.
NP2/Passive: The rabbit will be slowly eaten by the leepo.



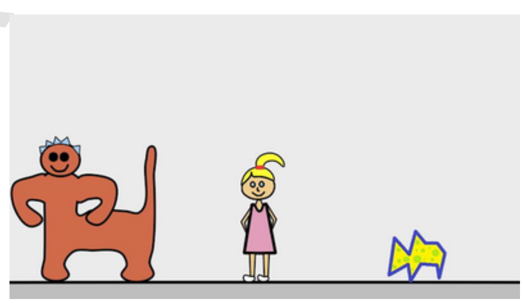
Novel word: "Daylon"

NP1/Active: The daylon will be quietly catching the frog.
NP1/Passive: The daylon will be quietly caught by the frog.
NP2/Active: The frog will be quietly catching the daylon.
NP2/Passive: The frog will be quietly caught by the daylon.



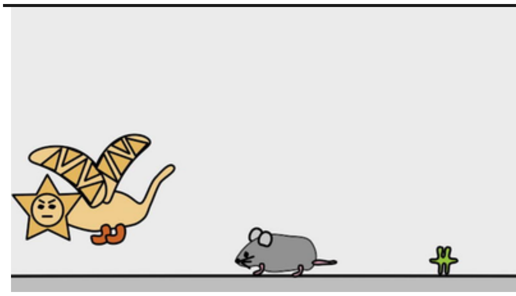
Novel word: "Tayvak"

NP1/Active: The tayvak will be loudly smashing the rock.
NP1/Passive: The tayvak will be loudly smashed by the rock.
NP2/Active: The rock will be loudly smashing the tayvak.
NP2/Passive: The rock will be loudly smashed by the tayvak.



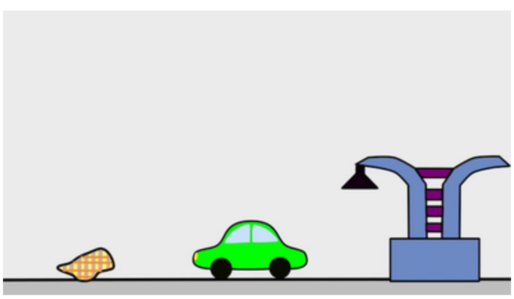
Novel word: "Chowvag"

NP1/Active: The chowvag will be carefully lifting the girl.
NP1/Passive: The chowvag will be carefully lifted up by the girl.
NP2/Active: The girl will be carefully lifting the chowvag.
NP2/Passive: The girl will be carefully lifted up by the chowvag.



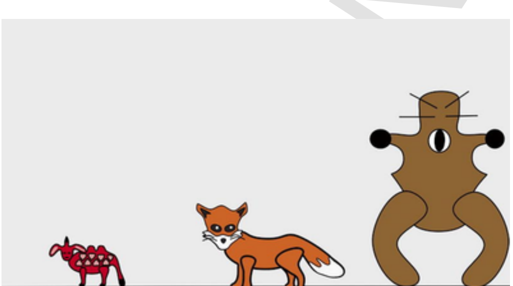
Novel word: "Vaychip"

NP1/Active: The vaychip will be quickly grabbing the mouse.
NP1/Passive: The vaychip will be quickly grabbed by the mouse.
NP2/Active: The mouse will be quickly grabbing the vaychip.
NP2/Passive: The mouse will be quickly grabbed by the vaychip.



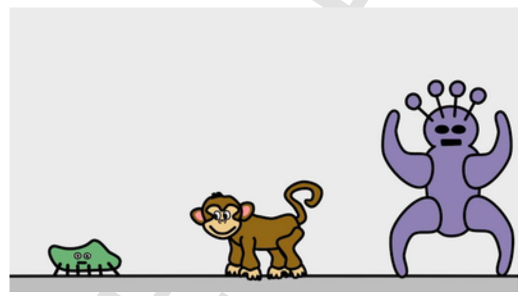
Novel word: "Noytoff"

NP1/Active: The noytoff will be loudly squishing the car.
NP1/Passive: The noytoff will be loudly squished by the car.
NP2/Active: The car will be loudly squishing the noytoff.
NP2/Passive: The car will be loudly squished by the noytoff.



Novel word: "Bellwer"

NP1/Active: The bellwer will be quickly chasing the fox.
NP1/Passive: The bellwer will be quickly chased by the fox.
NP2/Active: The fox will be quickly chasing the bellwer.
NP2/Passive: The fox will be quickly chased by the bellwer.



Novel word: "Furpin"

NP1/Active: The furpin will be quickly scaring the monkey.
NP1/Passive: The furpin will be quickly scared by the monkey.
NP2/Active: The monkey will be quickly scaring the furpin.
NP2/Passive: The monkey will be quickly scared by the furpin.

Appendix B. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cognition.2016.07.012.

References

Arnold, J.E., 2010. How speakers refer: The role of accessibility. Language and Linguistic Compass 4, 187–203.

Arunachalam, S., Waxman, S.R., 2010. Meaning from syntax: Evidence from 2-year-olds. Cognition 114, 442–446.

Barner, D., Snedeker, J., 2005. Quantity judgments and individuation: Evidence that mass nouns count. Cognition 97, 41–66.

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2013). lme4: Linear mixed-effects models using Eigen and S4. *R package version*, 1.

Bencini, G.M.L., Valian, V., 2008. Abstract sentence representation in 3-year-olds: Evidence from comprehension and production. Journal of Memory and Language 59, 97–113.

Bever, T., 1970. The influence of speech performance on linguistic structure. In: Flores d'Arcais, G.B., Levelt, J.M. (Eds.), Advances in psycholinguistics. North-Holland Publishing Company, Amsterdam.

Bion, R.A., Borovsky, A., Fernald, A., 2013. Fast mapping, slow learning: Disambiguation of novel word-object mappings in relation to vocabulary learning at 18, 24, and 30 months. Cognition 126, 39–53.

Bloom, P., Kelemen, D., 1995. Syntactic cues in the acquisition of collective nouns. Cognition 56, 1–30.

Brown, R., 1957. Linguistic determinism and the part of speech. Journal of Abnormal and Social Psychology 55, 1–5.

Budwig, N., 2001. An exploration into children's use of passives. In: Tomasello, M., Bates, E. (Eds.), Language development: The essential readings. Blackwell Publishers, Malden, MA, pp. 227–247.

Chafe, W., 1987. Cognitive constraints and information flow. In: Tomlin, R. (Ed.), Coherence and grounding in discourse: Outcome of a symposium. John Benjamins Publishing Company, Amsterdam/Philadelphia, pp. 21–51.

Choi, Y., Trueswell, J.C., 2010. Children's (in)ability to recover from garden paths in a verb-final language: evidence for developing control in sentence processing. Journal of Experimental Child Psychology 106, 41–61.

Christianson, K., Hollingworth, A., Halliwell, J.F., Ferreira, F., 2001. Thematic roles assigned along the garden path linger. Cognitive Psychology 42, 368–407.

Culbertson, J., Newport, E.L., 2015. Harmonic biases in child learners: In support of language universals. Cognition 139, 71–82.

Culbertson, J., Smolensky, P., Legendre, G., 2012. Learning biases predict a word order universal. Cognition 122, 306–329.

Fennell, C., Waxman, S.R., 2010. What paradox? Referential cues allow for infant use of phonetic detail in word learning. Child Development 81, 1376–1383.

Fernandes, M.A., Moscovitch, M., 2000. Divided attention and memory: Evidence of substantial interference effects at retrieval and encoding. Journal of Experimental Psychology 129, 155–176.

Ferreira, F., 2003. The misinterpretation of noncanonical sentences. Cognitive Psychology 47, 164–203.

Ferreira, F., Clifton, C., 1986. The independence of syntactic processing. Journal of Memory and Language 25, 348–368.

Fisher, C., Gertner, Y., Scott, R.M., Yuan, S., 2010. Syntactic bootstrapping. WIREs Cognitive Science 1, 143–149.

Ford, M., Baer, C., Xu, D., Yapanel, U., Gray, S., 2009. The LENATM language environment analysis system: Audio specifications of the DLP-0121. Retrieved from <http://www.lenafoundation.org/TechReport.aspx/Audio_Specifications/LTR-03-2>.

Givón, T., 1983. Topic continuity in discourse: A quantitative cross-language study, Vol. 3. John Benjamins Publishing.

Gleitman, L.R., 1990. The structural sources of verb meanings. Language Acquisition 1, 3–55.

Goodman, J.C., McDonough, L., Brown, N.B., 1998. The role of semantic context and memory in the acquisition of novel nouns. Child Development 69, 1330–1344.

Gordon, P., Chafetz, J., 1990. Verb-based versus class-based accounts of actionality effects in children's comprehension of passives. Cognition 36, 227–254.

Gordon, P.C., Chan, D., 1995. Pronouns, passives, and discourse coherence. Journal of Memory and Language 34, 216–231.

Gordon, P.C., Hendrick, R., Johnson, M., 2001. Memory interference during language processing. Journal of Experimental Psychology: Learning, Memory, and Cognition 27, 1411–1423.

Gundel, J. K., Hedberg, N., & Zacharaski, R. (1993). Cognitive status and the form of the referring expressions in discourse. Language, 69, 274-307..

Harris, F., Flora, J., 1982. Children's use of 'get' passives. Journal of Psycholinguistic Research 11, 297–331.

Hart, B., Risley, T.R., 1995. Meaningful differences in the everyday experiences of young children. Brookes Publishing Co, Baltimore, MD.

Hoff, E., 2003. The specificity of environmental influence: Socioeconomic status affects early vocabulary development via maternal speech. Child Development 74, 1368–1378.

Horgan, D., 1978. The development of the full passive. Journal of Child Language 5, 65–80.

Horst, J.S., Samuelson, L.K., 2008. Fast mapping but poor retention by 24-month-old infants. Infancy 13, 128–157.

Hsu, N. S., & Novick, J. M. (2016). Dynamic engagement of cognitive control modulates recovery from misinterpretation during real-time language processing. *Psychological Science*, 27, 572-582..

Huang, Y., Abadie, L., Hollister, E., & Arnold, A. (March, 2016). Novelty of discourse referents promotes heuristics in children's syntactic processing. In *Paper presented at the 29th annual CUNY conference on human sentence processing*. Gainesville, FL.

Huang, Y., Leech, K., & Rowe, M. L. (submitted). Exploring socioeconomic differences in language development through the lens of real-time processing. *Manuscript available*.

Huang, Y.T., Zheng, X., Meng, X., Snedeker, J., 2013. Children's assignment of grammatical roles in the online processing of Mandarin passive sentences. Journal of Memory and Language 69, 589–606.

Hudson-Kam, C.L., Newport, E.L., 2005. Regularizing unpredictable variation: The roles of adult and child learners in language variation and change. Language Learning and Development 1, 151–195.

Hudson-Kam, C., Newport, E.L., 2009. Getting it right by getting it wrong: When learners change languages. Cognitive Psychology 59, 30–66.

Hurewitz, F., Brown-Schmidt, S., Thorpe, K., Gleitman, L.R., Trueswell, J.C., 2000. One frog, two frog, red frog, blue frog: Factors affecting children's syntactic choices in production and comprehension. Journal of Psycholinguistic Research 29, 597–626.

Huttenlocher, J., Vasilyeva, M., Cymerman, E., Levine, S., 2002. Language input and child syntax. Cognitive Psychology 45, 337–374.

Huttenlocher, J., Vasilyeva, M., Shimpi, P., 2004. Syntactic priming in young children. Journal of Memory and Language 50, 182–195.

Huttenlocher, J., Vasilyeva, M., Waterfall, H.R., Vevea, J.L., Hedges, L.V., 2007. The varieties of speech to young children. Developmental Psychology 43, 1062–1083.

Huttenlocher, J., Waterfall, H., Vasilyeva, M., Vevea, J., Hedges, L.V., 2010. Variability in children's language growth. Cognitive Psychology 61, 343–365.

Jaeger, T.F., 2008. Categorical data analysis: Away from ANOVAs (transformation or not) and towards mixed effects models. Journal of Memory and Language 59, 434–446.

Jin, K.S., 2015. The role of syntactic and discourse information in verb learning (Unpublished doctoral dissertation). University of Illinois at Urbana-Champaign, Urbana, IL.

Lidz, J., White, A., & Baier, R. (submitted). The role of incremental parsing in syntactically conditioned word learning.

Lidz, J., Gleitman, H., Gleitman, L., 2003. Understanding how input matters: Verb learning and the footprint of universal grammar. Cognition 87, 151–178.

MacWhinney, B., Bates, E., Kliegl, R., 1984. Cue validity on sentence interpretation in English, German, and Italian. Journal of Verbal Learning and Verbal Behavior 23, 127–150.

Maratsos, M., Fox, D.E.C., Becker, J.A., Chalkley, M.A., 1985. Semantic restrictions on children's passives. Cognition 19, 167–191.

Matin, E., Shao, K.C., Boff, K.R., 1993. Saccadic overhead: Information-processing time with and without saccades. Perception & Psychophysics 53, 372–380.

Mazuka, R., Jincho, N., Oishi, H., 2009. Development of executive control and language processing. Language and Linguistics Compass 3, 59–89.

Medina, T.N., Snedeker, J., Trueswell, J.C., Gleitman, L.R., 2011. How words can and cannot be learned by observation. Proceedings of the National Academy of Sciences 108, 9014–9019.

Messenger, K., Branigan, H.P., McLean, J.F., 2012. Is children's acquisition of the passive a staged process? Evidence from six- and nine-year-olds' production of passives. Journal of Child Language 39, 991–1016.

Naigles, L., 1990. Children use syntax to learn verb meanings. Journal of Child Language 17, 357–374.

Newport, E.L., 1990. Maturational constraints on language learning. Cognitive Science 14, 11–28.

Newport, E., Gleitman, H., Gleitman, L., 1977. Mother, I'd rather do it myself: Some effect and non-effects of maternal speech style. In: Snow, C., Ferguson, C. (Eds.), Talking to children: Language input and acquisition. Cambridge University Press, NY.

Novick, J.M., Trueswell, J.C., Thompson-Schill, S.L., 2005. Cognitive control and parsing: Re-examining the role of Broca's area in sentence comprehension. Journal of Cognitive, Affective, and Behavioral Neuroscience 5, 263–281.

Omaki, A., Davidson-White, I., Goro, T., Lidz, J., Phillips, C., 2014. No fear of commitment: Children's incremental interpretation in English and Japanese wh-questions. Language Learning and Development 10, 206–233.

Omaki, A., Lidz, J., 2015. Linking parser development to acquisition of syntactic knowledge. Language Acquisition 22, 158–192.

Philipp, M., Bornkessel-Schlesewsky, I., Bisang, W., Schlesewsky, M., 2008. The role of animacy in the real time comprehension of Mandarin Chinese: Evidence from auditory event-related brain potentials. Brain and Language 105, 112–133.

Pozzan, L., Trueswell, J.C., 2015. Revise and resubmit: How real-time parsing limitations influence grammar acquisition. Cognitive Psychology 80, 73–108.

Rastle, K., Harrington, J., Coltheart, M., 2002. 358,534 nonwords: The ARC nonword database. Quarterly Journal of Experimental Psychology 55A, 1339–1362.

Roediger, H.L., Bulter, A.C., 2011. The critical role of retrieval practice in long-term retention. Trends in Cognitive Sciences 15, 20–27.

Roediger, H.L., Marsh, E.J., 2005. The positive and negative consequences of multiple-choice testing. Journal of Experimental Psychology: Learning, Memory, and Cognition 31, 1155–1159.

Rowe, M.L., 2012. A longitudinal investigation of the role of quantity and quality of child-directed speech in vocabulary development. Child Development 83, 1762–1774.

Slattery, T.J., Sturt, P., Christianson, K., Yoshida, M., Ferreira, F., 2013. Lingering misinterpretations of garden path sentences arise from competing syntactic representations. Journal of Memory and Language 69, 104–120.

Snedeker, J., Huang, Y., 2015. Sentence processing. In: Naigles, L., Bavin, E.L. (Eds.), The handbook of child language, 2nd ed. Cambridge University Press, Cambridge, UK, pp. 409–437.

Snedeker, J., Trueswell, J.C., 2004. The developing constraints on parsing decisions: The role of lexical-biases and referential scenes in child and adult sentence processing. Cognitive Psychology 49, 238–299.

Snedeker, J., Yuan, S., 2008. Effects of prosodic and lexical constraints on parsing in young children (and adults). Journal of Memory and Language 58, 574–608.
Stager, C.L., Werker, J.F., 1997. Infants listen for more phonetic detail in speech perception than in word-learning tasks. Nature 388, 381–382.
Sudhalter, V., Braine, M.D.S., 1985. How does comprehension of passives develop? A comparison of actional and experiential verbs. Journal of Child Language 12, 455–470.
Tanenhaus, M.K., Spivey-Knowlton, M., Eberhard, K., Sedivy, J., 1995. Integration of visual and linguistic information during spoken language comprehension. Science 268, 1632–1634.
Trueswell, J.C., Gleitman, L., 2004. Children's eye movements during listening: Developmental evidence for a constraint-based theory of sentence processing. In: Henderson, J.M., Ferreira, F. (Eds.), The interface of language, vision, and action. Psychology Press, New York, NY.
Trueswell, J.C., Kaufman, D., Hafri, A., Lidz, J., 2012. Development of parsing abilities interacts with grammar learning: Evidence from Tagalog and Kannada. In: Biller, A.K., et al. (Eds.), Proceedings of the 36th annual Boston University conference on language development. Cascadilla Press, Somerville, MA, pp. 620–632.
Trueswell, J.C., Medina, T.N., Hafri, A., Gleitman, L.R., 2013. Propose but verify: Fast mapping meets cross-situational word learning. Cognitive Psychology 66, 126–156.
Trueswell, J.C., Sekerina, I., Hill, N.M., Logrip, M.L., 1999. The kindergarten-path effect: Studying on-line sentence processing in young children. Cognition 73, 89–134.
Trueswell, J.C., Tanenhaus, M., Garnsey, S., 1994. Semantic influences on parsing: Use of thematic role information on syntactic ambiguity resolution. Journal of Memory and Language 33, 285–318.
Turner, E.A., Rommetveit, R., 1967. The acquisition of sentence voice and reversibility. Child Development 38, 649–660.
Warren, T., Gibson, E., 2002. The influence of referential processing on sentence complexity. Cognition 85, 79–112.
Waxman, S., Booth, A., 2003. The origins and evolution of links between word learning and conceptual organization: New evidence from 11-month-olds. Developmental Science 6, 128–135.
Weighall, A.R., 2008. The kindergarten path effect revisited: Children's use of context in processing structural ambiguities. Journal of Experimental Child Psychology 99, 75–95.
Weisleder, A., Fernald, A., 2013. Talking to children matters: Early language experience strengthens processing and builds vocabulary. Psychological Science 24, 2143–2152.
Werker, J.F., Fennell, C.T., Corcoran, K.M., Stager, C.L., 2002. Infants' ability to learn phonetically similar words: Effects of age and vocabulary. Infancy 3, 1–30.
Woodard, K., Pozzan, L., Trueswell, J.C., 2016. Taking your own path: Individual differences in executive function and language processing skills in child learners. Journal of Experimental Child Psychology 141, 187–209.
Yoshida, K., Fennell, C., Swingley, D., Werker, J.F., 2009. Fourteen-month-olds learn similar-sounding words. Developmental Science 12, 412–418.
Yuan, S., Fisher, C., 2009. "Really? She blicked the baby?": Two-year-olds learn combinatorial facts about verbs by listening. Psychological Science 20, 619–626.