Priming Children's Interpretation of Globally Ambiguous Sentences

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Abstract

Language input is potentially ambiguous in a number of ways. In order to process language effectively, language users need to resolve these ambiguities quickly and efficiently. Many sources of information are recruited to complete this process including contextual constraints, prosody, and verb biases. The current work focuses on the development of verb biases given children's overreliance on them. To explore this issue, I examined the effect of syntactic priming on the interpretation of PP-attachment ambiguities by 5-year-old children. Three priming experiments utilized three different but related prime types: globally ambiguous PP-attachments, unambiguous attachments disambiguated by syntax, and unambiguous attachments disambiguated by pragmatics. Results demonstrated priming in all three experiments, although it was strongest when the primes themselves were ambiguous. This finding provides further evidence for comprehension priming in children, and suggests that their verb biases can be overcome given the appropriate resources.

Keywords: syntactic priming; language acquisition; ambiguity resolution

Introduction

In order to be able to communicate effectively, language users need to be able to understand sentences quickly and efficiently. To this end, our sentence processing mechanisms are incremental; we attempt to interpret words and build the internal structure of sentences as they unfold rather than waiting until the sentence is complete. One major aspect of this incremental interpretative process is the need to resolve ambiguities. Ambiguities derive from several sources: lexical items can have multiple meanings or senses (e.g., *bank* could mean both a place where you deposit money or the edge of a river) or the sentence can have multiple possible syntactic continuations (e.g., *The boy saw…* could continue with *his best friend* or *his mother leave for work*). Decisions about how to interpret ambiguous input must be made without the full context of a sentence, and we utilize information from a variety of sources including prosody, constraints imposed by the context, and verb biases to help us make informed decisions about how to interpret syntactic ambiguities incrementally (Gibson & Pearlmutter, 1998).

Children are known to be good at tracking statistical regularities in their input (e.g., Saffran et al., 1996, 1999; see Romberg & Saffran, 2010 for a review), so it would be reasonable to assume that they are able to reliably make use of statistical sources of information when processing ambiguous input. Therefore, investigating verb bias – the frequency with which a particular verb appears with a syntactic structure versus other competing structures – effects will help generate a more complete picture of the development of ambiguity resolution. Compared to adults, children have been shown to overly rely on verb biases when interpreting ambiguous sentences, even when other sources of information (e.g., referential context provided by a visual scene) conflict with those biases (Snedeker & Trueswell, 2004). Thus, children need to learn that verb biases are not always the most reliable source of information when resolving ambiguities in order to process language like adults.

The current study investigated the development of verb biases by leveraging the fact that language users tend to repeat syntactic structures across utterances, an effect known as syntactic priming (Bock, 1986; Chang et al., 2006 among many others). For example, you are more likely to produce a passive sentence (e.g., *The window was broken by my son*) if the sentence that you just produced or comprehended was also a passive sentence. The present work used syntactic priming to explore children's processing of ambiguous prepositional phrase (PP)-attachment in English. Sentences like *The boy saw the girl with the magnifying glass* are globally ambiguous because the PP *with the magnifying glass* could either attach at the verb phrase (VP) level (i.e., the boy used the magnifying glass to see) or at the noun phrase (NP) level (i.e., the girl had the magnifying glass). The syntactic structure of these PP-attachment ambiguities, and therefore their interpretation, has been successfully primed in adult comprehension (Boudewyn et al., 2014; Branigan et al., 2005). For example, in Branigan et al. (2005) participants were 18% more likely to select the interpretation associated with VP attachment in a picture selection task when they had been primed with the same interpretation.

While the syntax of these structures is ambiguous, lexical biases driven by individual verbs can affect the interpretation of these sentences. It has been argued that some verbs prefer VP attachment and its associated interpretation (e.g., *hit*, *tickle*), some prefer NP attachment (e.g., *choose*, *look at*), and some are equally likely to occur with either attachment site (e.g., *feel*, *turn over*). Snedeker & Trueswell (2004) examined how these verb biases affected adults' and 5-year-olds' interpretation of ambiguous sentences of this type in the absence of priming. Both age groups were sensitive to verb biases; instrument interpretations were more likely after verbs biased toward VP attachment, less likely after verbs biased toward NP attachment, and equally likely after equi-biased verbs.

Two previous studies have explored whether or not children's PP-attachment preferences can be primed (Havron et al., 2020; Qi et al., 2011). Qi and colleagues (2011) conducted an eye tracking study using a similar design to Snedeker and Trueswell (2004), but found mixed results, so little can be concluded from their findings. On the other hand,

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Havron and colleagues (2020) examined the French equivalent of this ambiguity in 5- and 6-year-olds and adults using a tablet-based picture selection task and found evidence for priming. Participants received VP attachment primes, NP attachment primes, or alternative primes. The groups primed with only NP attachments showed greater priming effects than those primed with alternatives. This suggests that children, or at least French-speaking children, should be able to have their interpretation of PP-attachment ambiguities primed.

Importantly, while Havron and colleagues recognized the effect of verb bias, this bias was not explicitly manipulated; in fact, all but one of the verbs that they used were biased toward VP attachment (10 of 11). Thus, the present studies employ similar logic to Havron et al. (2020) in that comprehension priming is used to determine which syntactic structure the child is assigning to the ambiguous target sentence. Unlike this previous work, the following studies were specifically designed to examine the priming of equi-biased verbs and whether they can be primed in both directions, i.e., toward VP attachment following VP attachment primes and toward NP attachment following NP attachment primes.

Method

Participants

Ninety-three English-speaking children participated in one of three priming studies (overall mean age=5;6, overall range: 4;1-6;8) and were randomly assigned to one of two priming groups. The three priming studies each utilized a different structure for the prime sentences: ambiguous sentences (N=32, mean age=5;7, range: 4;5-6;7), unambiguous sentences with syntax that differed from that used in the ambiguous condition (N=30, mean age=5;6, range: 4;4-6;5), and unambiguous sentences using the same syntax as the ambiguous condition (N=31, mean age=5;5, range: 4;1-6;8). Prime groups were between subjects, so each child either received VP attachment (ambiguous: mean age=5;7; unambiguous-different syntax: mean age=5;8; unambiguous-same syntax: mean age=5;4) or NP attachment (ambiguous: mean age=5;7; unambiguous-different syntax: mean age=5;4; unambiguous-same syntax: mean age=5;6) primes. An additional 16 children (mean age=5;4, range: 4;2-6;2) participated in a control task. These children were recruited from the Ann Arbor community via a partnership between the Living Lab (https://sites.lsa.umich.edu/livinglab/) at the University of Michigan and the Ann Arbor Hands-On Museum (AAHOM, https://www.aahom.org/). The UM Living Lab is a collection of developmental researchers that have set-up and maintained mutually beneficial community partnerships. These partnerships allow a pool of child participants to be readily available to researchers in exchange for science outreach being brought to the public. All of the children were AAHOM visitors and participated in a space designated for the Living Lab in the museum.

Materials

The priming experiments all consisted of 8 prime-target pairs (16 trials total). All target sentences contained a globally ambiguous PP-attachment ambiguity (1).

(1) The elephant blows on the monkey with the fan.

In (1), the PP *with the fan* has two possible attachment sites: 1) attached to the VP describing how the action is performed (i.e., the instrument of the action) as in (2), or 2) attached to the direct object NP and describing the patient (i.e., the PP modifies the NP) as in (3).

(2) *VP attachment / Instrument interpretation*
   a. [$_{VP}$ [$_{VP}$ blows on the monkey] [$_{PP}$ with the fan]]
   b. The elephant uses the fan to blow on the monkey.

(3) *NP attachment / Modifier interpretation*
   a. [$_{VP}$ blows on [$_{NP}$ the monkey with the fan]
   b. The elephant blows on the monkey that is holding a fan.

These studies focus on the eight equi-biased verbs identified by Snedeker and Trueswell (2004): *scratch*, *throw*, *pinch*, *feel*, *drag*, *turn over*, *blow on*, and *point at*. These verbs were repeated across prime and target trials. Adult priming effects are often stronger when there is lexical repetition in this manner (e.g., Pickering & Branigan, 1998), so such repetition was included in the current design to maximize the likelihood that children would be primed despite inconsistent evidence for a lexical boost in children (Branigan & McLean, 2016; van Beijsterveldt & van Hell, 2009; cf. Peter et al., 2015; Rowland et al., 2012) and also in comprehension priming studies more generally (see Tooley, 2022 for a review).

In the ambiguous primes study, the prime sentences utilized the same pattern as the targets, i.e., the primes themselves were ambiguous, see (1). The two unambiguous prime studies used variations on this sentence type with slight differences to disambiguate between the two meanings. In the unambiguous-different syntax primes, the instrument interpretation was indicated by a *by*-phrase introducing the instrument (4a), while the modifier interpretation was indicated by a subject relative clause (4b).

(4) Unambiguous – Different Syntax
   a. *Instrument interpretation:* The elephant blows on the monkey **by using** the fan.
   b. *Modifier interpretation:* The elephant blows on the monkey **that has** the fan.

While the interpretation of these sentences is unambiguous, they do not have the same syntactic structure as each other or the ambiguous targets. The unambiguous-same syntax primes use the same structure as the ambiguous primes, and thus maintain the possibility of a PP-attachment ambiguity. Rather than being disambiguated by syntax, they are disambiguated by replacing the direct object NP with either a pronoun like *him* (5a) or the NP *the one* (5b), each of which only allow one of the two possible attachment sites for their accurate interpretation.

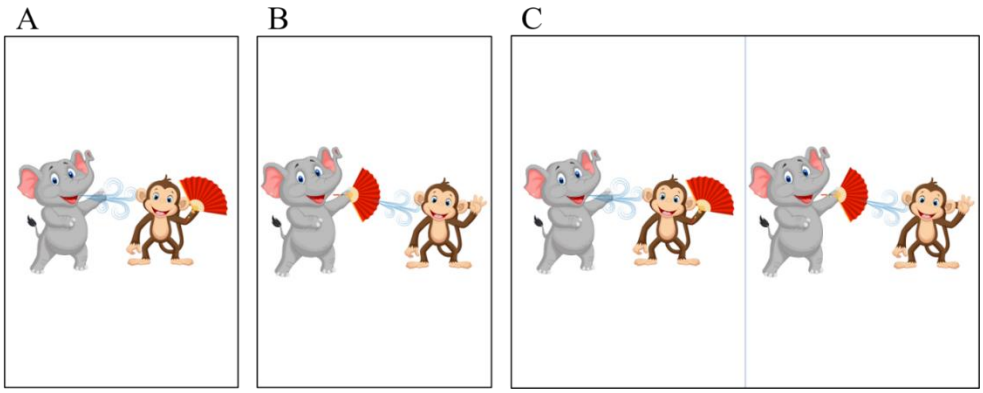

Figure 1: Experiment pictures associated with (1), *The elephant blows on the monkey with the fan*. Example singular prime pictures for the NP attachment / modifier interpretation (A) and VP attachment / instrument interpretation (B). Example paired target picture (C); the image on the left depicts NP attachment (same as A), while the image on the right depicts the VP attachment (same as B).

(5) Unambiguous – Same Syntax
   a. *VP attachment / Instrument interpretation:* The elephant blows on **him** with the fan.
   b. *NP attachment / Modifier interpretation:* The elephant blows on **the one** with the fan.

For each of the 16 trials, a picture unambiguously portraying each interpretation was combined on a single letter sized piece of paper divided down the middle (Figure 1C). These pictures provided the options for the picture selection portion of the task (i.e., the target trials). Prime trials consisted of a single picture representing one of the two possible interpretations based on the participant's assigned priming group (Figures 1A and 1B). The picture accompanying the prime provided the context to disambiguate the meaning of the PP-attachment ambiguity, and thus even the ambiguous primes were unambiguous in the context of their paired picture.

Procedure

The 5-year-olds played a picture-matching task with a puppet controlled by the experimenter (Mr. Monkey). The goal of this task was to select the picture that matched the sentence. The child and the puppet took turns producing a description of a picture for the other to match. A small occluding wall was placed between the child and the puppet so that the puppet could not see the picture that the child was describing and vice versa. Children always produced the prime trials, while the puppet always produced the target trials. Thus, the puppet only produced ambiguous sentences of the type in (1), while the structure of the child's production varied depending on which of the three priming experiments they were participating in. An example of a prime / target pair is given in (6).

(6) a. *Prime:* The elephant blows on the monkey with the fan.
   b. *Target:* The cow blows on the horse with the straw.

To ensure the children produced sentences of the correct type, a practice trial preceded the experimental trials in which the experimenter demonstrated the prime sentence structure for the particular condition using another equi-biased verb not used in the main experiment (*The leopard surprised the horse with the balloons*). Children were then asked to repeat this sentence. On subsequent trials, children were coached to use the intended structure if they attempted to describe the picture using alternative means. For example, children often omitted the prepositional phrase (e.g., *The elephant blows on the monkey*); the experimenter would then prompt the child with "with…" and they would usually complete the sentence as intended.

This is a non-traditional design for a priming study of this type. Typically, a production-to-comprehension priming task with children would involve the experimenter producing the sentence first, which the child would then simply repeat. This novel version requiring children to produce the sentence without experimenter scaffolding was adopted because previous findings indicated that being forced to generate and produce primes in this way may lead to better learning outcomes (Atkinson, 2016; Atkinson & Omaki, 2016). Given that children rely heavily on verb biases, this was another attempt to maximize the likelihood that priming would be successful.

Control Study Previous work demonstrated that 5-year-old children have access to both interpretations associated with the two attachment sites, but whether or not they have a baseline preference was not established (Zimmer, 2017). Although the current study make use of previously normed equi-biased verbs, this categorization was the result of adult sentence completions (Snedeker & Trueswell, 2004). This does not guarantee that children share this bias with this particular set of verbs. To address this issue, a separate group of children participated in a control condition. In this condition, children only answered prompts from the puppet (i.e., they did not produce any sentences). The 8 ambiguous target trials from the priming studies were each preceded by two unambiguous filler trials with a different structure and verb than the targets. This resulted in a total of 32 items.

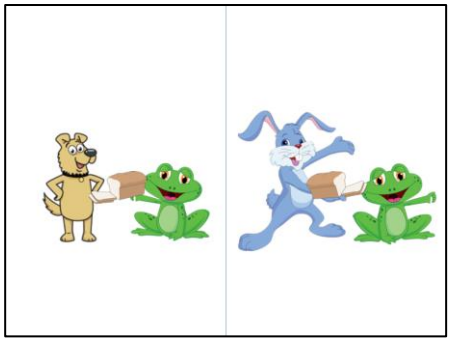

Figure 2: Example of the paired target pictures associated with *The frog and the rabbit eat the bread*, a collective action filler trial.

Examples of filler sentences included ditransitives (e.g., *The cow gives the balloons to the horse*) and collective actions (e.g., *The frog and the rabbit eat the bread*, Figure 2). These sets of three (two filler sentences + one ambiguous target) were quasi-randomized for each participant.

Results

Control Study

Children in the control group chose VP attachment (i.e., the instrument interpretation) 81% of the time. Table 1 summarizes the individual differences in the selection of this interpretation across the eight critical trials.

Table 1: Summary of VP attachment / instrument interpretation selections in the control study.

# Trials	Percent	# Participants
8	100%	6
7	87.5%	3
6	75%	3
4 or 5	50-62.5%	4

Overall, 75% of the children in the control group (i.e., 12 participants) selected the instrument interpretation in at least 75% of trials, which was well above what would be expected for verbs that were supposed to be equi-biased. Additionally, no child selected this interpretation less than 50% of the time. From this data, it is clear that the "equi-biased" verbs used in the present studies actually have a strong VP attachment / instrument bias for 5-year-olds. Thus, rather than assuming that children have a 50% chance of selecting either interpretation in the absence of priming, the analysis of the experimental data will compare interpretation selection levels to the baseline collected in this control experiment, i.e., 81% instrument preference.

Priming Experiments

Given the strong preference for VP attachment / the instrument interpretation in the control group, the analysis of the prime interpretation groups (instrument vs. modifier) will be in terms of selections of the instrument interpretation during the testing phase (i.e., how often children selected the picture corresponding to VP attachment). Figure 3 presents the results for all three priming experiments.

For the ambiguous prime experiment, children selected the instrument interpretation 94% of the time following an instrument prime (*SE* = 2.3%), but only 68% of the time following a modifier prime (*SE* = 4.6%). This 26% difference is a large effect (Cohen's d = 1.26, 95% CI = 0.47 – 2.05). For the unambiguous-different syntax prime experiment, children producing *by*-phrases (i.e., instrument primes) selected instrument interpretations about 84% of the time, and those producing subject relative clauses (i.e., modifier primes) selected instrument interpretations 72% of the time. This 12% difference is a medium effect (Cohen's d = 0.69, 95% CI = -0.06 – 1.45). Finally, in the unambiguous-same syntax prime experiment, children who produced VP attachment (i.e., instrument primes) selected the instrument interpretation on 80% of target trials, while children who

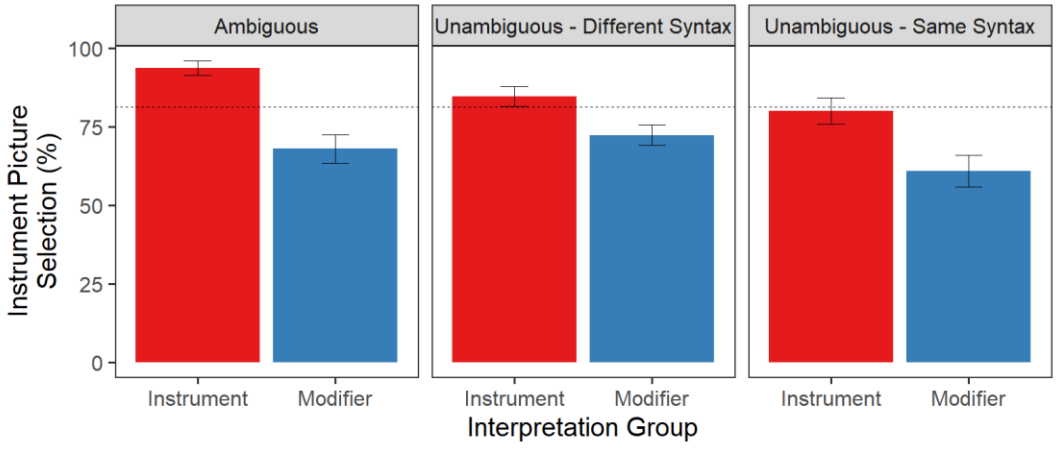

Figure 3: Percentage selection of the picture representing the instrument interpretation (VP attachment) by priming experiment and interpretation group. The dashed line represents the overall baseline rate for selecting this interpretation absent priming (81%).

produced NP attachment (i.e., modifier primes) selected it on 61% of target trials. Like the other unambiguous experiment, the 19% difference in selection rate is a medium effect (Cohen's d = 0.74, 95% CI = -0.04 – 1.51).

To test for priming and its differential effect across experiments, a logistic mixed effect models was run in R (R Core Development Team, 2022) using the *lme4* package (Bates et al., 2015). In the model, the effect of prime experiment on the likelihood of selecting the instrument interpretation was tested by treating the ambiguous prime experiment as the baseline and directly comparing both unambiguous prime experiments to it (treatment coded). In addition, this model tested the effect of interpretation group (sum coded: instrument primes = 1, modifier primes = -1), centered age, and their interactions. The maximal random effect structure that converged was used (Barr et al., 2013), which included a random intercept for verb identity and a random slope for interpretation group for verb identity. There were significant effects of interpretation group (β = 1.12, SE = 0.23, z = 4.84, p <0.001) and age (β = 1.42, SE = 0.41, z = 3.41, p < 0.001); children were primed in these experiments, although older children were overall more likely to select the instrument interpretation regardless of interpretation group. Overall, children were marginally less likely to select the instrument interpretation in the unambiguous-different syntax prime experiment compared to the ambiguous prime experiment (β = -0.54, SE = 0.28, z = -1.91, p = 0.06) and significantly less likely to select it in the unambiguous-same syntax experiment (β = -0.86, SE = 0.27, z = -3.16, p < 0.01). Crucially, both interactions between interpretation group and unambiguous primes were significant (different syntax: β = -0.74, SE = 0.28, z = -2.66, p < 0.01; same syntax: β = -0.58, SE = 0.27, z = -2.12, p < 0.05) suggesting that the priming effects for both of these experiments were smaller than that for the ambiguous prime experiment. This was also reflected in the effect sizes for each experiment (large for ambiguous primes versus medium for both unambiguous primes).

As an additional test of priming, Bayes factors (BFs; the ratio of the likelihood of the alternate hypothesis to the likelihood of the null) were calculated for a Bayesian alternative to a one-sample *t*-test (Rouder et al., 2009; with priors consistent with Morey et al., 2011; Morey & Rouder, 2011) to compare each interpretation group to the baseline of 81% instrument picture selections collected from the control group. BFs were calculated using the *BayesFactor* package (Morey & Rouder, 2018) set to 100,000 iterations. BFs can range from less than 1/100 to greater than 100. A BF of one indicates no evidence for either hypothesis because the likelihoods are the same. A BF less than one indicates evidence for the null, while a BF greater than one indicates evidence for the alternative hypothesis.

For the ambiguous prime experiment, the VP attachment / instrument interpretation group's BF of 24.56 ±0% indicates strong evidence for priming above the baseline, while the NP attachment / modifier interpretation group's BF of 1.35 ±0.0% indicates anecdotal evidence for priming below the baseline (see Lee & Wagenmakers, 2014 for these designations). For the unambiguous-different syntax prime experiment, the instrument interpretation group had a BF of 0.33 ±0.02% indicating moderate evidence for the null (i.e., no difference from the baseline), and the modifier interpretation group had a BF of 1.07 ±0.02% indicating anecdotal evidence for priming below the baseline. This later BF is so close to one, however, it is best interpreted as no evidence for either hypothesis.[1] Finally, for the unambiguous-same syntax prime experiment, the BF of 0.27 ±0.01% for the VP attachment / instrument interpretation group indicates anecdotal evidence for the null hypothesis, while the BF of 4.15 ±0% for the NP attachment / modifier interpretation group indicates moderate evidence for priming below the baseline. In other words, children who produced prime sentences with instrument interpretations were only primed above the baseline level if that prime was itself ambiguous. Conversely, children who produced prime sentences with modifier interpretations were only clearly primed below the baseline level if the prime was unambiguous with PP-attachment ambiguity structure (i.e., in the unambiguous-same syntax experiment), although there was anecdotal evidence for priming below the baseline when the prime was ambiguous.

Discussion

The present study demonstrated that English-speaking children's PP-attachment preferences can be primed using a comprehension priming methodology, which parallels and strengthens Havron et al.'s (2020) findings. In this picture matching task, children between the ages of 4 and 6 produced prime sentences of one of three types – ambiguous, unambiguous-different syntax, or unambiguous-same syntax – that were associated visually with either an instrument or modifier interpretation. Then, children comprehended sentences with ambiguous PP-attachments and chose the picture that matched the structure that they assign to it. How often the instrument interpretation was selected varied based on the structure of the prime and the interpretation that they were exposed to. The strongest priming effect was found when children produced ambiguous primes, while the weakest effect was found when children produced unambiguous primes that did not share syntax with PP-attachment ambiguities. Also, children were only primed above the 81% baseline threshold, i.e., increased their VP attachment / instrument interpretations following instrument interpretation primes, when the primes were ambiguous; however, they did not reliably decrease their instrument interpretation selections when primed with the NP attachment / modifier interpretation in this priming experiment. When the primes were unambiguous but used the

[1] This is especially true because the range for anecdotal evidence for the alternative hypothesis is a Bayes factor of between one and three.

same underlying syntactic structures as PP-attachment ambiguities, VP attachment / modifier interpretations were primed.

Taken together, these results suggest that the interpretation is not being primed independent of the underlying syntactic structure. If this were the case, the picture that guides the production of the prime sentence, which is itself unambiguous between the two possible interpretations, should be sufficient for priming in either direction. In other words, the structure of the prime sentence should not matter, and all three priming experiments should have generated similar results. As the experiment utilizing unambiguous primes with different syntax from the PP-attachment ambiguity resulted in the weakest priming effect (and in fact could be argued that no priming took place, as neither interpretation group differed reliably from the baseline), this is clearly not the case. Additionally, the lack of priming in this experiment suggests that it is not simply visual similarities between the images driving the effect. If this were the case, we would again expect to find similar effects in all three experiments (or at least some amount of priming).

The strength of the priming effect when the prime is ambiguous is somewhat puzzling. If priming of the interpretation of ambiguous PP-attachment is the result of the repetitive use of the same abstract syntactic structure (VP attachment or NP attachment), then the results for the ambiguous and unambiguous-same syntax should be similar as they have identical underlying syntactic structures. This suggests that there is a distinct effect of generating a potentially ambiguous sentence above and beyond standard syntactic priming effects. It is not immediately clear what this effect might be. One possibility is related to the findings that were used as justification for making the children produce the primes without a model, i.e., that production priming leads to greater learning (Atkinson, 2016; Atkinson & Omaki, 2016). In the interpretation of those results, it was suggested that it was the effort required to produce the intended sentences that led to the larger outcomes, not just the production alone. This follows from theories that the best learning outcomes derive from situations involving a certain degree of difficulty (*desirable difficulties*; Bjork, 1994). Perhaps, something about producing the ambiguous sentence represents a level of difficulty above that of producing a sentence with the same structure that is unambiguous, and thus leads to stronger priming effects. Clearly, further work is needed to explore what drives these differential effects and if they are only present when children produce the prime – a difference from Havron et al. (2020) – or whether it is also present in comprehension-to-comprehension priming. Future work is planned to investigate these issues.

These results also contribute to a very small but growing body of work examining comprehension priming in children. While there are many studies demonstrating syntactic priming in children's productions of structures with roughly equivalent meanings (e.g., Peter et al., 2015; Rowland et al., 2012 among many more), there are few comprehension priming studies examining children's selection of alternative meanings, which is also an obvious gap in the adult syntactic priming literature (see Atkinson, 2022; Branigan & Pickering, 2017 for review and discussion of these issues). When combined with Havron et al.'s (2020) findings, we have evidence that 5-year-olds are able to track and adjust their expectations and use this information in their comprehension processes.

Additionally, given that this work has demonstrated that the priming of the interpretation of PP-attachment is in theory possible, future work should examine whether priming can help children overcome their strong attachment biases associated with individual verbs. The current work purposefully used (alleged) equi-biased verbs to allow the possibility of priming in either direction, which was observed across the three priming experiments. Given children's demonstrated preference for VP attachment / instrument interpretations, it may be more difficult to prime them away from this interpretation and toward the NP attachment / modifier one. Conversely, if NP attachment is more novel and therefore more surprising, encountering these structures may lead to greater error signals and stronger priming effects (see Jaeger & Snider, 2013 for a related argument based on adult priming). If priming is able to overcome children's reliance on verb biases, then it may also help them learn to integrate other sources of information for ambiguity resolution earlier. These findings and future work will also need to be examined in light of theories that syntactic priming is a form of implicit learning (e.g., Bock & Griffin, 2000; Chang et al., 2000; Fine & Jaeger, 2013) as it may provide a mechanism for how children acquire verb biases in the first place as well as how they learn to overcome them in favor of additional linguistic and non-linguistic sources of information in their input.

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