Syntactic Adaptation and Word Learning in Children and Adults

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Abstract

Syntactic priming may be a key mechanism underlying children's learning of novel words. Havron et al. (2019) exposed French-speaking children (ages 3 to 4) to a speaker biased by the use of either familiar verbs or nouns presented in the same syntactic context. This influenced participants' interpretations of ambiguous novel words presented in the same syntactic frame. In Experiment 1, we successfully replicated Havron et al. with 77 French-speaking adults, using a web-based eye-tracking paradigm. Experiment 2 adapted this paradigm to English: Repeated exposure to a syntactic structure induced 102 English-speaking adults to update their expectations about the meanings of novel words. Experiment 3 found similar evidence of syntactic adaptation in 74 3- to 5-year-old English-speaking children. The results indicate that participants adapted to the specific linguistic structure used, not just the speaker's tendency to mention actions or objects. These findings support the role of rapid adaptation during word learning.

Background

How do children learn language so quickly? In just a few years, children are able to learn how to segment a continuous speech stream into words and phrases, and map these utterances to their real-world referents. To do this, children cannot simply be passive observers of the world around them; they are instead flexible and active learners who draw on a variety of powerful learning mechanisms during language acquisition. One of these possible learning mechanisms is the ability for children to track linguistic patterns in the speech of those around them and rapidly adapt to these patterns.

Havron, de Carvalho, Fiévet, & Christophe (2019) specifically examined children's capacity to adapt to specific syntactic structures. Their findings demonstrated that French-speaking adults and children showed signs of rapid syntactic adaptation after repeated exposure to a particular sentence structure. Furthermore, participants drew on these expectations to guide their learning of unfamiliar words that were presented in the same syntactic context. In this paper, we describe three experiments that replicate and extend the findings of Havron et al. (2019). These studies build on two main lines of work: syntactic priming and adaptation, and syntactic bootstrapping during language acquisition.

Syntactic priming in adults is a well-established phenomenon in which exposure to a particular sentence structure increases the likelihood of participants producing that structure themselves (*syntactic alignment*) and expecting utterances they hear to contain the structure (*syntactic adaptation*). By reusing previously heard utterances, people can reduce their own or their conversation partner's computational load during sentence processing. On the production side, experimental studies have discovered that participants tend to align their syntactic structures in dialogue (Bock, 1986). For instance, adults who heard sentences containing dative verbs with either a prepositional object (e.g. *The pirate handed the cake to the sailor*) or a direct object (e.g. *The pirate handed the sailor the cake*) were more likely to subsequently produce descriptions of pictures that used the same dative structure they had heard previously (Branigan, Pickering, & Cleland, 2000; Cleland & Pickering, 2003). Participating actively in a dialogue, rather than listening as a side participant, has been linked to a greater degree of alignment (Branigan et al., 2007). Syntactic alignment effects have also been found with datives and verb particle placement (e.g., *John picked up the book* vs. *John picked the book up*) in a corpus of

naturalistic dialogue (Gries, 2005). This finding indicates that syntactic priming is not merely a product of experimental settings; it is reflected in natural communication.

In addition, syntactic priming effects have increasingly been investigated in comprehension (Pickering & Ferreira, 2008). Fine et al. (2013) used a self-paced reading paradigm to examine participants' comprehension of "garden path sentences," such as *The experienced soldiers warned about the dangers conducted the midnight raid,* which typically cause delays in language processing. After repeated exposures to these sentences, participants adapted to the new syntactic distribution, reducing or even eliminating the processing disadvantage (though cf. Harrington Stack, James, & Watson, 2018). Evidence from fMRI (Noppeney & Price, 2006) and from ERP (Ledoux, Traxler, & Swaah, 2007) studies corroborates the finding that syntactic priming facilitates comprehension of difficult-to-process sentences. Research involving eye-tracking has found that syntactic priming can also guide understanding of syntactically ambiguous utterances, with participants interpreting utterances as being consistent with the type of structure they previously heard (Kamide, 2012).

These syntactic priming effects appear to be not just the result of transient activation of representations, but rather a form of adaptation that can have long-term, cumulative effects. Using a similar picture task as Bock (1986) to elicit sentences containing dative verbs, Boyland and Anderson (1998) found that syntactic priming still occurred when there was a 20-minute delay between the priming stage and participants' productions. Even studies in which syntactic priming took place days before the test stage have reported that participants exhibited adaptation to difficult sentence structures, such as ambiguous relative clauses, and came to process them more quickly (Wells et al., 2009; Long & Prat, 2008). Furthermore, even rapid syntactic priming appears to be cumulative, meaning that greater exposure to a particular sentence structure leads

to an incrementally larger processing advantage. (Fine & Jeager, 2016; Kaschak, 2007). These cumulative and long-term effects support an explanation of syntactic adaptation that is linked to implicit learning about the distributions of sentence structures, rather than immediate, short-lived activation of representations (Bock & Griffin, 2000; Branigan & Messenger, 2016). Additional evidence for the implicit learning account stems from the finding that the change in listeners' syntactic expectations is influenced by the size of the error signal accompanying a particular syntactic prime (Fine & Jaeger, 2013). Recently, syntactic adaptation has also been modeled as a process of rational belief update, in which the reliability of a cue is taken into account to determine whether listeners should update their expectations (Kleinschmidt, Fine, & Jaeger, 2012). Moreover, some studies have suggested that syntactic adaptation is speaker-specific (Kamide, 2012; Kroczek & Gunter, 2017), though others have failed to find such effects (Liu et al., 2017; Ostrand & Ferreira, 2019). It is clear, however, that syntactic adaptation involves long-term and potentially sophisticated tracking of syntactic distributions.

Multiple studies have demonstrated that children can engage in syntactic adaptation, as well, although these effects can sometimes be more difficult to detect than with adults depending on the task demands (Shimpi et al., 2007). Peter et al. (2015) found that children ages three to six and adults showed effects of syntactic priming with datives, during a task where they were prompted to describe cartoon animations. Children have also been shown to adapt to active- and passive-voice sentences, producing more sentences of the type they were previously exposed to (Messenger, Branigan, & McLean, 2011; Bencini & Valian, 2008).

In addition to production studies, children are sensitive to syntactic priming in comprehension. Thothathiri and Snedeker (2008) used an eye-tracking paradigm to measure children's expectations about temporarily ambiguous datives (e.g., direct object: *Show the horse*

the book vs. prepositional object: *Show the horn to the dog*). When children had been primed with either DO or PO sentences, they were more likely to interpret a temporarily ambiguous phrase (such as *Show the hor—*) in a manner consistent with the structure used during priming. Like adults, children have also shown cumulative effects of syntactic priming over the course of an experiment (Huttenlocher, Vasilyeva, & Shimpi, 2004), including when the priming stimuli used nonsense verbs (Brooks & Tomasello, 1999). Branigan and Messenger (2016) found a difference between adaptation effects in children and adults: While both groups showed immediate effects of syntactic adaptation, only children demonstrated significant *cumulative* effects in a second session a week later. Relatedly, Rowland et al. (2012) demonstrated that the magnitude of the priming effect was larger for young children than for older children and adults. These results suggest that, at least in some contexts, children's expectations about sentence structure may be more uncertain and/or more flexibly updated than adults' expectations. This greater ability to adapt could help children learn more quickly in unfamiliar linguistic contexts. Thus, it is reasonable to propose that syntactic adaptation may play a role in not just children's sentence processing, but also their acquisition of language.

To examine how syntactic adaptation may support language acquisition, our experiments also draw on work that shows evidence of syntactic bootstrapping in children's word learning. Syntactic bootstrapping is a process by which children can infer the meanings of unfamiliar words partially based on their syntactic characteristics (Gleitman, 1990). For example, upon hearing a sentence such as *It's daxing*, a child can use the *-ing* affix to infer that *dax* refers to an action and is therefore a verb. Eye-tracking studies have shown that children as young as 24 months are sensitive to the syntactic context of novel words and draw on syntactic cues to help them construe images of scenes (Waxman et al., 2009). Furthermore, while listening to

temporarily ambiguous utterances, preschoolers demonstrate predictive eye movements that are influenced by syntactic characteristics of words, such as transitive vs. intransitive verbs (Gambi, Pickering, & Rabagliati, 2016). Huang and Arnold (2016) found a correlation in which children who were more sensitive to syntactic cues had more accurate interpretations of novel words, which suggested that syntax may play an important role in successful word learning for children.

Further studies have indeed confirmed that syntactic bootstrapping supports children's acquisition of novel words. Syntax appears to be one of the characteristics of words that children are sensitive to during word learning (Dautriche, Swingley, & Christophe, 2015). To directly examine the effects of cues from syntax, Yuan and Fisher (2009) played sentences containing novel words that were either transitive (e.g., *She blicked the baby*) or intransitive (e.g., *She blicked*). They found that two-year-olds who heard transitive sentences looked longer at pictures with two people in them rather than one, which indicated that they used syntactic cues (i.e. presence of a direct object in transitive sentences) to interpret the novel words. Using a similar eye-tracking paradigm, studies have reported that 18-month-olds (He & Lidz, 2017) and 23-month-olds (Bernal et al., 2007) can use syntactic cues from phrases such as *It's pooning* vs. *It's a poon* to map novel words to images portraying either actions or objects, respectively. This research provides evidence that children are not just sensitive to syntactic cues, but also actively draw on them during word learning. These findings have led researchers to propose a probabilistic model that uses syntactic bootstrapping to acquire syntactic categories, performing quite well (Christophe et al., 2016).

To sum up, both children and adults exhibit syntactic adaptation in comprehension and production. In addition, syntactic cues play a key role in children's word learning via a process of syntactic bootstrapping. Havron et al. (2019) brought these two lines of work together by

investigating whether syntactic adaptation could be a key factor in children's acquisition of novel words. There is some prior work that motivates the connection between adaptation and acquisition; Chang et al. (2006) developed a connectionist model of sentence production that used error-based learning to imitate the acquisition of syntax. That is, after encountering a violation of its predictions, the model adapted its expectations about upcoming syntactic material. This model was able to account for many syntactic priming effects in adults and children, including the finding that more surprising structures are associated with larger priming effects (Fine & Jaeger, 2013; Bernolet & Hartsuiker, 2010; Jaeger & Snider, 2013). Thus, there is reason to examine whether an unexpected distribution of syntactic structures could lead children to update their expectations and then, importantly, recruit these expectations during word learning. For instance, in a naturalistic context, a child might hear an adult describing a toy dog using repeated similar syntactic frames, such as *The dog is running, The dog is playing,* etc. Adapting to the use of this syntactic frame would allow the child to more easily learn a novel word presented in the same frame. This idea has the potential to unify accounts of adaptation in language processing with accounts of language acquisition, which was a key motivation of Havron et al. (2019).

Specifically, Havron et al. (2019) examined whether priming French children with a particular syntactic structure would influence how they assigned meaning to novel words in an ambiguous context. During training trials, three- and four-year-old children were exposed to repeated trials of a French phrase (*La petite*) that can be followed by either a noun or a verb (e.g., *La petite grenouille [The little frog]* vs. *La petite dort [The little one sleeps]*). On test trials, children heard novel words presented in the same syntactic frame (e.g., *La petite nuve*), and their eye movements were measured to see whether children looked more at an image depicting a

novel object or an image depicting a novel action. The results confirmed that children (and an adult comparison group) did indeed appear to alter their predictions about which syntactic structure a speaker would use, and to draw on these predictions to infer the meaning of a novel word.

The studies reported here build on the work of Havron et al. (2019) in several ways. First, in Experiment 1, we tested whether these results would directly replicate in a new context: an eye-tracking study conducted entirely online, with adults. Next, we conducted a crosslinguistic replication of the study in English, using a syntactic frame (*The girls/The girl's*) that can similarly be followed by either a noun or a verb (e.g., *The girls sleep* vs. *The girl's book*). We first ran this study online with adults (Experiment 2) and then carried it out with three- to five-year-old children (Experiment 3). These studies examined whether the results of Havron et al. (2019) would replicate using a different language and with a slightly modified design to suit the online context. As in the original study, we hypothesized that when participants encountered an unfamiliar word, they would look more at the image (action or object) that matched the type of phrases (verb or noun) they had heard during training trials.

Experiment 1

Experiment 1 was a direct replication of Havron et al. (2019) that was carried out using web-based eye-tracking. This served the dual purpose of both replicating the original study and validating web-based eye-tracking as a paradigm suitable for studying the interaction of syntactic bootstrapping and adaptation.

Methods

Participants

We collected data from 77 participants (31 female; 46 male) using Prolific, an online crowdsourcing website. All were adults who reported speaking French as their first language. Participants were randomly assigned to a condition (37 in the noun condition; 40 in the verb condition). They were told that the study had originally been designed for children to explain the child-friendly nature of the videos.

Measures

We carried out online eye-tracking using Webgazer, a program that runs a participant's webcam and estimates the coordinates of their eye movements (Papoutsaki et al., 2016). Participants needed a laptop or desktop computer with a screen width of at least 1280 pixels to complete the study. We followed the common practice of only analyzing looks that were to either the action video or the object video (45% of the total looks in the dataset). This high rate of data loss is due to a combination of factors: Some looks are directed to other areas of the screen; participants sometimes look away from the screen; and Webgazer sometimes loses track of participants' eyes during the experiment. In the analysis, we examine only looks to the action video, since any look not to the action video is to the object video. All stimuli, data, and analyses can be found at: https://github.com/eswanson166/havron-replication.

Procedure

The stimuli used in the study, as well as the structure of the trials, were identical to those used in Havron et al. (2019). Every participant was randomly assigned to either the noun

condition or the verb condition. Participants first completed a 9-point calibration, which was adapted from the original study to work with Webgazer. The study consisted of two phases: training trials and test trials. The total experiment included ten trials and lasted about twelve minutes.

During each training trial, all participants saw two videos. One showed a girl performing a familiar action (such as jumping), while the other was of the same girl holding a familiar object (such as a toy car). The structure of each training trial was identical. First, the participant saw a preview of one video only, followed by a preview of the other video. Then, during the contrast phase, the participant saw both videos together. For these parts of the trial, a female narrator told the child to look at the videos in a child-friendly voice, but she did not comment on what the videos depicted. The last part of the trial was the event phase, during which children saw both videos again, but the narrator described what was in just one of the two videos. If participants were in the noun condition, she said a phrase such as *La petite grenouille* ("The little frog"). If participants were in the verb condition, she said a phrase such as *La petite dort* ("The little one (fem.) is sleeping"). Thus, participants in both conditions heard the same syntactic context: *La petite [X],* but it was followed by either a noun (meaning "The little X") or a verb (meaning "The little one is Xing"). Participants were exposed to four training trials. The side the target video appeared on was counterbalanced, and the order of the training trials was randomized.

In between the first two training trials and the last two training trials, participants watched two filler trials. These trials had the same structure as the training trials except that the narrator referred to whichever type of video was *not* referred to in the training trials, using a structure that was unambiguous. Therefore, participants in the noun condition heard a description of the action video in a sentence such as *Elle écrit* ("She writes"), since *Elle…* cannot be

followed by a noun. Similarly, participants in the verb condition heard a description of the object video in a sentence such as *C'est une poussette* ("This is a baby-stroller"), because *C'est une…* cannot precede a verb. These filler trials were included so that participants would understand that the narrator could refer to either the action video or the object video. It was simply with the structure *La petite…* that the narrator was biased toward using either nouns or verbs. Also, we wanted to reduce the possibility that participants would look toward the action or object video on test trials purely because they were used to looking at that type of video.

After the training trials, all participants watched three test trials, which were identical regardless of condition (though the order was again randomized). Test trials had the same structure as training trials, but the two videos depicted a novel object and a novel action. Also, participants heard the narrator's description once before the event phase started so that we could start measuring looks from the beginning of the event phase. The narrator used the same *La petite…* context as before, but it was followed by an unfamiliar word that does not actually exist in French, such as *La petite nuve.* Since *La petite…* can be followed by a noun or a verb, participants could in principle interpret *nuve* as a noun or a verb. However, we hypothesized that participants would adapt to the structure preferred by the speaker during training trials. Therefore, participants in the noun condition were expected to interpret novel words as nouns, and therefore look more at the object video during test trials. Conversely, participants in the verb condition were expected to interpret novel words as verbs, and therefore look more at the action video during test trials. A key linking hypothesis was that more looks to a video indicated that participants interpreted the word as matching what was depicted in the video.

As in Havron et al. (2019), we also included one generalization trial at the end of the experiment. On this trial, participants saw a video with a boy in it and heard the sentence, *Le*

petit pirdal. Le petit is the masculine form of *La petite*, so it can similarly be followed by a noun, meaning "The little X," or a verb, meaning "The little one (masc.) is Xing." This was an exploratory trial intended to examine whether participants would generalize the predictions formed during training trials to a slightly different structure with the same underlying syntax.

Results

Test trials: Proportion of looks

We calculated each participant's proportion of looks to the action video on each test trial and then averaged these three proportions to obtain each participant's mean proportion of looks to the action video across the three test trials. This included only looks that occurred after the point where participants could likely guess which syntactic frame was being used; that is, after *La p-* in *La petite*…. Figure 1 shows the overall mean proportion of looks to the action video in each condition, as well as dots representing individual participants' mean proportions of looks. As hypothesized, participants in the verb condition (M = 0.585, SD = 0.171) were more likely to look at the action video than participants in the noun condition (M = 0.395, SD = 0.171).

To test this, we conducted two main analyses: a mixed effects linear regression predicting the proportion of looks to the action image during a trial (the same as in the Havron et al. study) and a mixed effects logistic regression analysis directly predicting individual looks to the action image. Each of these analyses has drawbacks, with proportion of looks collapsing information about individual looks and models of raw looks not fully accounting for correlations between neighboring looks (though we included previous look as a predictor). However, converging evidence from these two models would be a promising way to test our research question. The

lme4 package was used to conduct the regression analyses, and the reported p-values come from likelihood ratio tests of the described model compared to the model without the effect of interest.

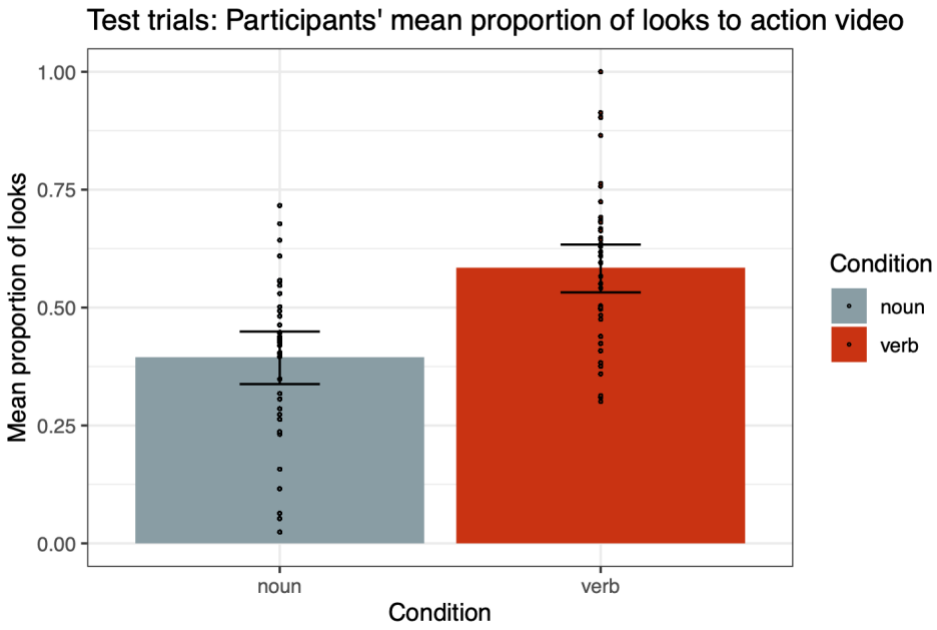

Figure 1. Mean overall proportion of looks to the action video in the noun and verb conditions during test trials, with bootstrapped confidence intervals. Black dots correspond to the mean proportion of looks for individual participants, averaged across the three test trials.

In the mixed effects linear regression, we predicted a participant's arc-sin transformed mean proportion of looks to the action video as a function of condition, with a random by-participant intercept. We did not include a random intercept for item because there were only three test items. There was a significant main effect of condition in the direction expected: Participants in the verb condition were significantly more likely to look at the action video than participants in the noun condition (β = 0.218, SE = 0.048, t = 4.575, $p < 0.001$).

The mixed effects logistic regression predicted the log odds of looking to the action video as a function of condition and previous look (to the action video or not). It included a random intercept for participant and a random slope that accounted for participant differences in the effect of previous look. There was a significant main effect of condition ($\beta = 0.855$, SE = 0.175, z = 4.891, $p < 0.001$), such that participants in the verb condition were more likely to look at the action video. There was also a significant main effect of previous look ($\beta = 4.761$, SE = 0.225, z = 21.154, $p < 0.001$) such that if a participant looked at the action video on their previous look, they were more likely to look at the action video on the following look as well.

Test trials: Time course

We also plotted participants' average proportion of looks to the action video by condition over the course of the trial. This time course plot is shown in Figure 2. Because participants heard the test trial audio once before the videos appeared onscreen, we do not have information on how their eye movements may have changed on the first instance of hearing *La petite [novel word]*. However, the time course plot suggests that participants in the verb condition were looking significantly more at the action video throughout most of the event phase of the test trial, and participants in the noun condition were consistently looking more at the object video.

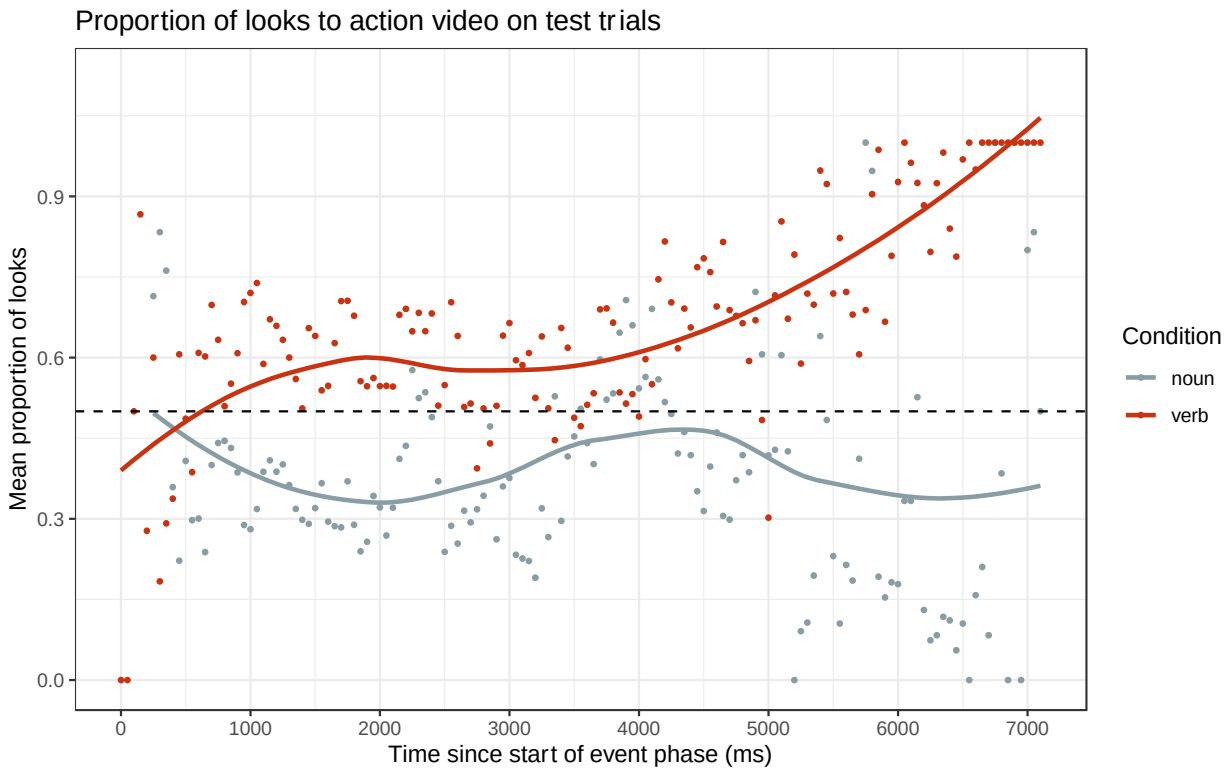

Figure 2. Time course plot of participants' mean proportion of looks to the action video on test trials. Gray areas represent overall confidence intervals and dots represent individual participants.

Training trials

We were also interested in participants' eye movements on training trials. We wanted to confirm that participants did, in fact, look at the video described during training trials in order to ensure that (a) the eye-tracker was reliably measuring their looks and (b) participants were reacting to the descriptions they heard.

In Figure 3, we present a visualization of participants' mean proportion of looks to the action video during training trials. We see that compared to the test trials, the training trials show an even larger difference between the noun condition (M = 0.308, SD = 0.145) and the verb condition (M = 0.728, SD = 0.142). As expected, participants in the verb condition looked more

to the action video than participants in the noun condition. This result is unsurprising given that the training trials used known words that clearly referred to one of the two videos.

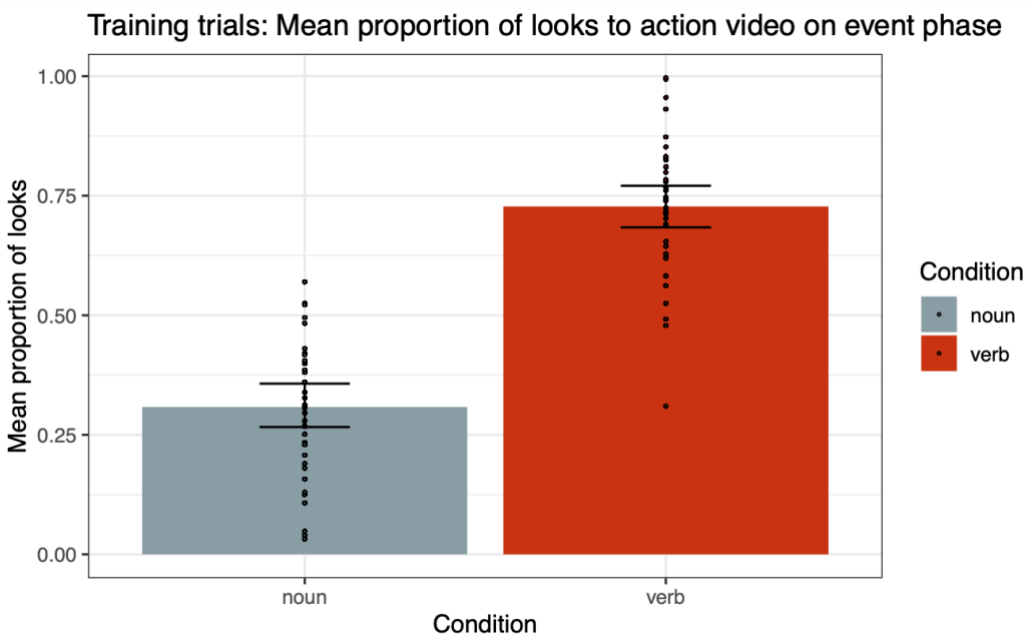

Figure 3. Mean overall proportion of looks to the action video in the noun and verb conditions during training trials, with bootstrapped confidence intervals. Black dots correspond to the mean proportion of looks for individual participants, averaged across the four training trials.

It is also important to ensure that the filler trials were effective, so participants would understand that the narrator could use a different linguistic structure to refer to the video that did not match the participant's condition. Figure 4 illustrates participants' mean proportion of looks to the action video during filler trials. It confirms that the pattern of results from test and training trials was switched, as intended: Participants in the noun condition (M = 0.682, SD = 0.194) looked more to the action video than participants in the verb condition (M = 0.332, SD = 0.179).

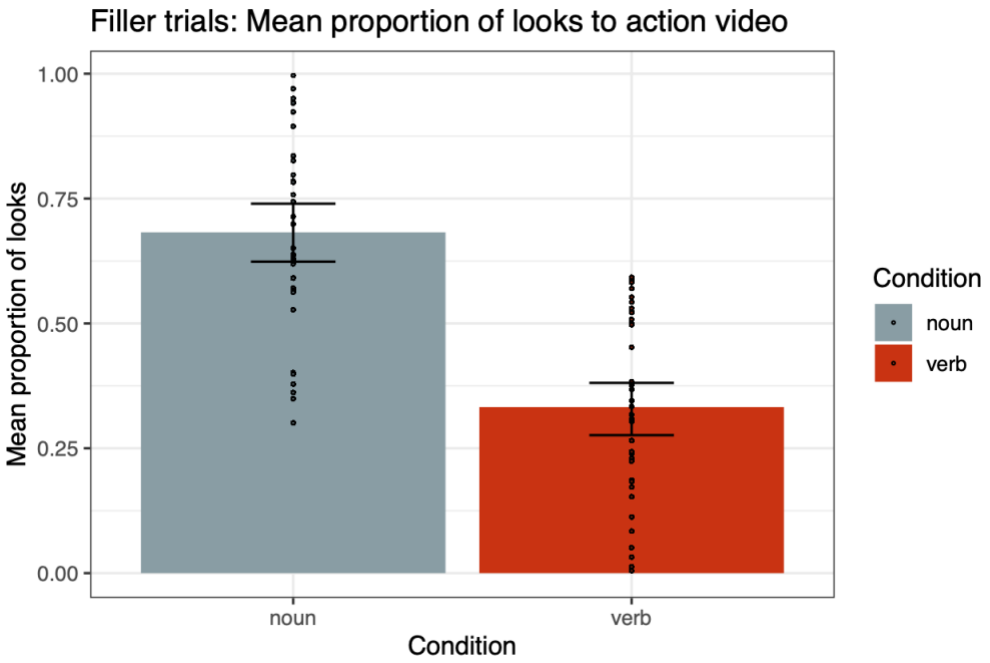

Figure 4. Mean overall proportion of looks to the action video in the noun and verb conditions during filler trials, with bootstrapped confidence intervals. Black dots correspond to the mean proportion of looks for individual participants, averaged across the two filler trials.

Discussion

This study replicated the adult results of Havron et al. (2019), which examined how syntactic priming influenced word learning. The original study found that participants adapted to a syntactic structure after hearing it repeatedly and that they used their adjusted expectations to interpret an unfamiliar word. Our results were similar: A significant effect of condition was found with both the mixed effects linear regression model and the mixed effects logistic regression model. That is, compared to participants who heard *La petite (noun)* on training trials, participants who heard *La petite (verb)* looked significantly more at the action video on test trials. Additionally, the time course data indicates that this effect remained consistent throughout

the trial. This suggests that participants were interpreting the ambiguous words on test trials to be consistent with the syntactic structure (noun vs. verb) that had previously been used by the narrator.

The difference we found between conditions appears to be smaller than in the original paper. Havron et al. (2019) reported a mean proportion of looks of 0.653 in the verb condition (compared to our 0.585) and 0.275 in the noun condition (compared to our 0.395); the size of the standard deviations was similar. However, given that this was a replication (Open Science Collaboration, 2015) and that it used online eye-tracking, which is noisier than an in-lab eye-tracking device, this observation is not surprising. In addition, the syntactic adaptation effect may be smaller for adults than for children, as found by Rowland et al. (2012); we will return to this in Experiment 3. Though the difference between the noun and verb conditions was smaller, the effect of condition was still significant.

It is encouraging that the results of the original paper replicated in an online eye-tracking context, where there is less direct control over participants' experience during the study. Furthermore, the fact that participants were quite clearly looking at the expected videos during both training and filler trials, when it was obvious which video was being described, lends support to the idea that online eye-tracking results can be fairly reliable, despite the somewhat high rate of track loss. Although calibration can sometimes be difficult for participants, Webgazer is in the process of becoming more streamlined, and we conclude that it is a feasible method for conducting online studies.

Experiment 2

Based on the promising French replication in Experiment 1, we created an English version of the study using the English syntactic frame *The girls/The girl's*. Like *La petite,* this frame can be followed by either a noun or a verb (e.g., *The girls sleep* vs. *The girl's book*). The cross-linguistic replication allowed us to test whether the adaptation effect observed in Experiment 1 would generalize to a new syntactic frame in a different language. This would provide evidence for the role of syntactic adaptation in language learning more generally.

Methods

Participants

We added an additional baseline condition for Experiment 2 and therefore recruited a total of 104 participants (57 female; 41 male; 6 other). Again, we collected data using Prolific, now specifying that participants had to speak English as their first language. Participants were randomly assigned to one of the three conditions (35 in the noun condition; 35 in the verb condition; 34 in the baseline condition).

Measures

This study was carried out on Webgazer using the same measures as Experiment 1. Again, we analyzed only looks to the action image or the object image (62% of the total looks in the dataset). The stimuli, data, and analyses for Experiment 2 and Experiment 3 can be found at: https://github.com/eswanson166/syntactic_adaptation.

Procedure

Though the procedure was similar to Experiment 1, we made several modifications to the design to reduce possible confounds and make the study easier to run online.

The study still consisted of a calibration phase, training trials, and test trials. However, the trials used object and action images rather than videos, which simplified the task. In addition, we increased the number of test trials from three to four. We also increased the number of filler trials from two to four in order to match the number of main trials during the training phase. This ensured that participants in the noun and verb conditions were not biased by looking at more of the type of image that matched their condition (action for verb; object for noun) during training trials. Now, participants were directed to look at equal numbers of action and object images during training trials; the only difference was in the linguistic content they heard. In the noun condition, they heard *The girl's (noun)* on main training trials, and in the verb condition, they heard *The girls (verb)* on main training trials.

We also added a baseline condition to the study to examine whether participants would show bias toward looking at a particular image type even if they did not hear the structure *The girls/Tbe girl's* at all before the test phase. In the baseline condition, participants' training trials included only the filler phrases used in both the noun and verb conditions (*They're Xing* in the noun condition and *She has an X* in the verb condition). Like the noun and verb conditions, the baseline condition was balanced so that participants would be directed to look at an equal number of action and object images.

The individual trial structure of previewing each image, then seeing both images together, was the same as in Experiment 1. Trial order was randomized and image sides were counterbalanced using the same method as well. We did not include an exploratory trial with a

different syntactic frame (e.g., *The boys…*), but on the final trial we directly asked participants which image they thought the narrator was talking about. This provided an explicit measure of participants' comprehension of the phrase containing *The girls/The girl's.*

Results

Proportion of looks

Figure 5 shows the overall mean proportion of looks to the action image in each condition, with dots representing individual participants' mean proportions of looks. We included looks after the point where the syntactic frame was disambiguated: *The g-…* in *The girls/girl's….* As in Experiment 1, participants in the verb condition (M = 0.596, SD = 0.193) were more likely to look at the action image than participants in the noun condition (M = 0.389, SD = 0.212). These effects were very similar in size to those observed in Experiment 1. The proportion of looks to the action image in the baseline condition (M = 0.435, SD = 0.187) fell in between the noun and verb condition, but the confidence interval for the baseline condition overlapped with the confidence interval for the verb condition (though not with the noun condition).

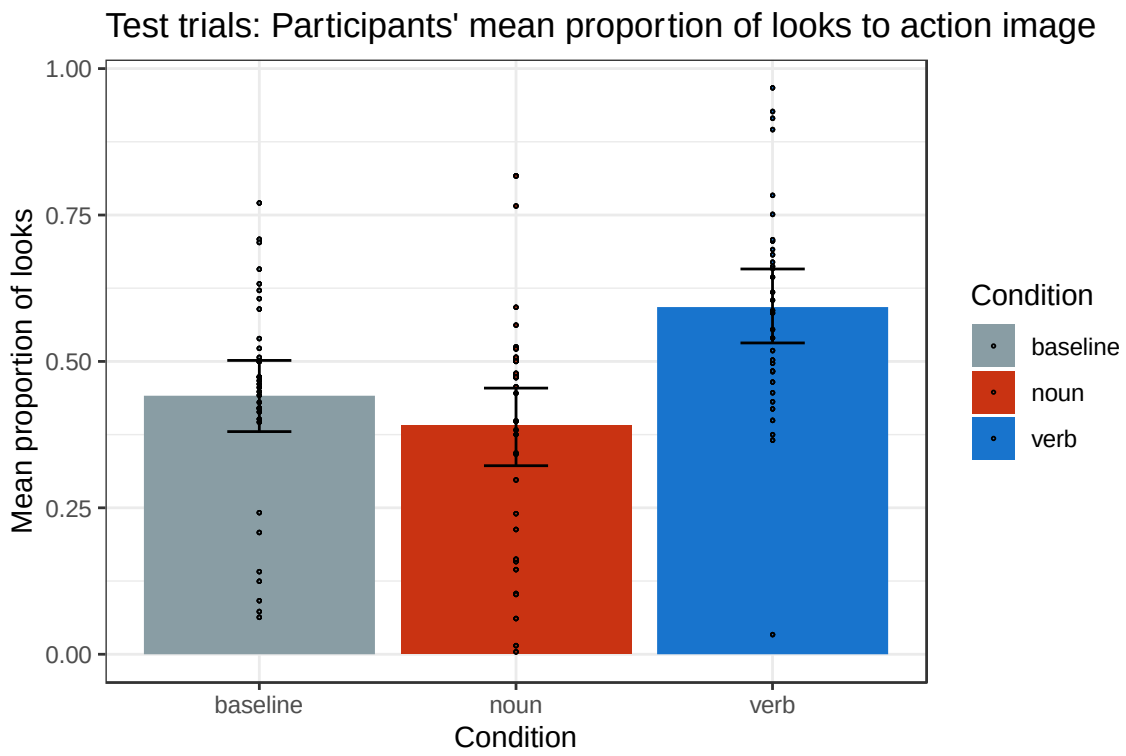

Figure 5. Mean overall proportion of looks to the action image in the noun, verb, and baseline conditions during test trials, with bootstrapped confidence intervals. Black dots correspond to the mean proportion of looks for individual participants, averaged across the three test trials.

For Experiment 2, we compared the noun and verb conditions to the baseline condition. As in Experiment 1, we first carried out a mixed effects linear regression model which predicted the arc-sin transformed mean proportion of looks to the action image as a function of condition, with a random intercept for participant. We found a significant main effect of condition such that participants in the verb condition had a higher proportion of looks to the action image compared to participants in the baseline condition (β = 0.195, SE = 0.063, t = 3.098, p < 0.01). However, there was not a significant difference between the proportion of looks to the action image in the noun condition compared to the baseline condition (β = -0.07, SE = 0.062, t = -1.137, p = 0.258).

We then conducted a mixed effects logistic regression analysis, which directly predicted

the log odds of looking to the action image as a function of condition and previous look. It included a random by-participant intercept and a random slope for previous look. There were marginally significant effects of condition, where participants in the noun condition were less likely to look at the action image compared to those in the baseline condition (β = -0.395, SE = 0.23, t = -1.172, p = 0.086), while participants in the verb condition were more likely to look at the action image (β = 0.441, SE = 0.231, t = 1.915, p = 0.056). There was also a significant main effect of previous look (β = 4.96, SE = 0.245, z = 20.239, p < 0.001) indicating that if a participant looked at the action image on their previous look, their next look was more likely to be to the action image as well.

Time course

To better visualize the time course of participants' looks, we plotted the mean proportion of looks to the action image over time, averaged across the four test trials, in Figure 6. This allows us to investigate at what point in the course of the test trial, and for how long, participants tended to look at the action image or the object image.

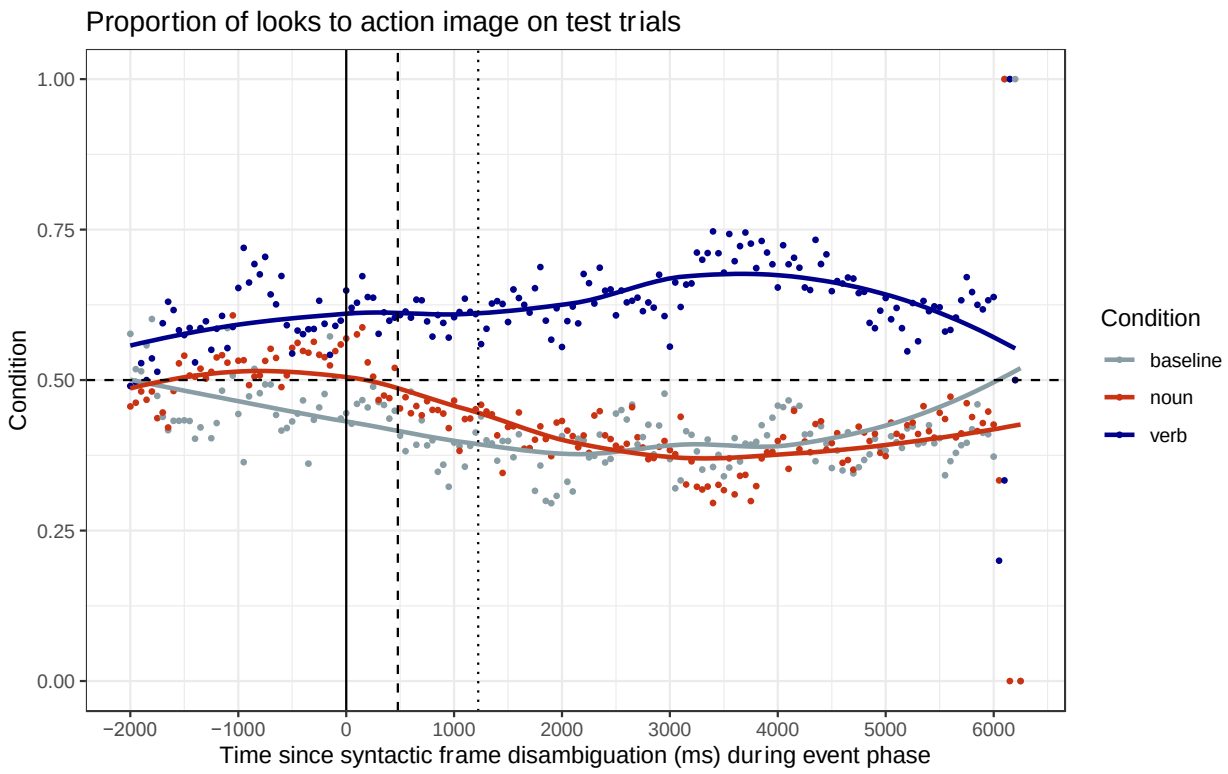

Figure 6. Time course plot of participants' mean proportion of looks to the action image on test trials. Gray areas represent overall confidence intervals and dots represent individual participants. The vertical black line corresponds to the point of disambiguation of the syntactic frame (*The g-*). The dashed line represents the mean time point of the end of the syntactic frame, *The girls/girls…*, and the dotted line indicates the mean end time point of the first utterance of the novel word, such as *The girls/girl's dax.*

The time course plot reveals several interesting patterns. First, participants in the verb condition in particular seemed to look significantly more at the action image even before hearing the key syntactic frame for the first time (*The girls/girl's [novel word]*). They were then more likely to look at the action image for almost the entire duration of the trial. Participants in the baseline condition, on the other hand, were more likely to look at the object image before the naming event occurred and throughout the trial. Finally, participants in the noun condition

looked significantly more at the object image than participants in the verb condition, but this effect appeared mostly *after* hearing the syntactic frame (*The girls/girl's*) for the first time. This raises the possibility that participants were making anticipatory looks to the action image in the verb condition, and to the object image in the baseline condition, even before hearing the syntactic frame and the novel word.

Explicit selection

The final trial of the experiment was identical to other test trials, but once it was completed, we directly asked participants which image they thought the narrator was talking about. Here, we found strong differences by participant condition, as shown in Figure 7. Participants in the baseline condition were about equally likely to select the action image (54.5%) or the object image (45.5%). However, 85.7% of participants in the noun condition selected the object image, and 70.1% of participants in the verb condition selected the action image. Thus, in their explicit judgments about the meaning of a novel word, participants appeared to interpret the word in line with the examples they had heard during training trials, which were presented in the same syntactic frame.

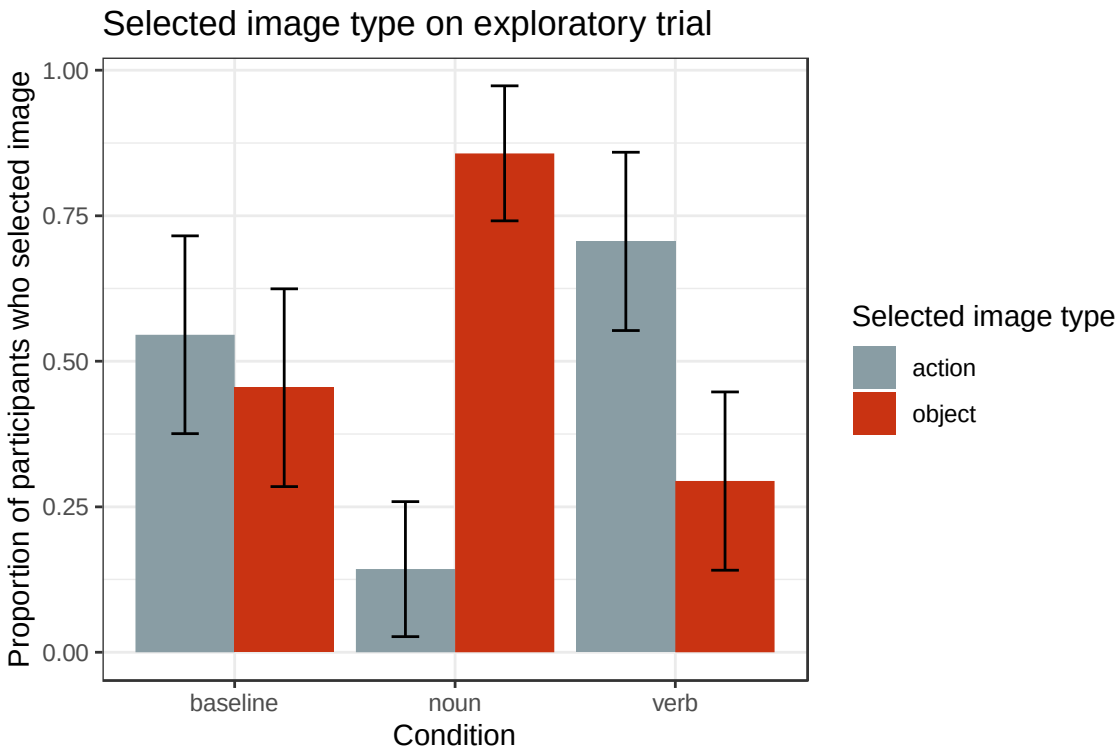

Figure 7. Proportion of participants who selected the action or object image when explicitly asked to click on the image they thought the narrator was talking about.

Discussion

Our results in the verb and noun conditions of this study were close to those obtained in Experiment 1. Participants' mean proportion of looks to the action image was highly similar in the verb (0.585 in Experiment 1 compared to 0.596 in Experiment 2) and noun (0.395 in Experiment 1 compared to 0.389 in Experiment 2) conditions. Again, this effect is not as large as the one observed in Havron et al. (2019), but this is likely due to the noisiness of online eye-tracking.

While participants in the baseline condition had a proportion of looks to the action image that fell in between participants in the noun and verb conditions, they appeared to show a slight preference (barely different from chance) for looking at the object image. This could be due to

several factors. Participants may have found the object images more interesting, or they may have thought that *The girls/girl's X* was more likely to refer to an object image than an action image. However, this second explanation seems unlikely, because we conducted a norming study before running the experiment which played participants audio clips from the test trials (such as *The girls/girl's dax*) and asked them whether they thought the novel words referred to actions or objects. Participants essentially performed at chance, stating that they thought the novel words referred to actions 51% of the time. This suggested that baseline participants were not biased by prosody or prior expectations about the meanings of the novel words; more likely, they found the object images to be more salient. We consider this a likely possibility because two norming studies found conflicting results about the salience of the object and action images: Participants in one thought a speaker would be more likely to talk about the object images, while participants in the other study thought a speaker would more likely refer to the action images. These findings indicated that participant preferences relating to the salience of the images is likely variable, and it is possible that participants in the baseline condition simply found the object images more interesting than the action images.

The results we obtained using explicit selection on the exploratory trial support the hypothesis that participants in the baseline condition were not drawing inferences about the meanings of the novel words. Participants in the baseline condition performed at chance when asked which image they thought the speaker was referring to, while a large majority (over 70%) of the participants in the noun and verb conditions selected the object image or the action image, respectively. This suggests that participants in the noun and verb conditions updated their expectations about whether the speaker was likely to follow *The girls/girl's* with a noun or a verb, while participants in the baseline condition maintained uncertainty.

The results from explicit selection therefore support the idea that in the baseline condition, early looks in the time course graph were likely due to greater salience of the object images. For participants in the verb condition, on the other hand, looks to the action image even before hearing the syntactic frame for the first time may have occurred in anticipation that the speaker would refer to an action rather than an object.

Experiment 3

Methods

In Experiment 3, we extended the paradigm from Experiment 2 to ask whether three- to five-year-old children would show similar patterns of syntactic adaptation during word learning. This would support the idea that adaptation may be an important mechanism during child language acquisition.

Participants

We collected data through the online Lookit platform, where children can easily participate in looking time experiments. There were 74 participants (42 female; 32 male). Children were assigned to the same three conditions as in Experiment 2 (27 in the noun condition; 23 in the verb condition; 24 in the baseline condition). Children had to be native English speakers to be eligible for the study.

Measures

Rather than using online eye-tracking, which is difficult to use with children, we took videos of children as they completed the study and hand-coded their eye movements as being

directed towards the left or right side of the screen. We did not know the child's condition or which image appeared on which side of the screen at the time of coding.

Procedure

Children either completed the study while sitting on their caregiver's lap, with the caregiver closing their eyes, or while seated on their own. The experiment procedure was nearly identical to Experiment 2, except that the instructions at the beginning of the study were made more child-friendly. We also added attention-getters at the beginning of each trial and took a calibration video of the child looking to the left and right sides of the screen, rather than using a 9-point automatic calibration. The trial structure was the same as in Experiment 2, and we maintained the same modifications to the Havron et al. procedure, implementing an equal number of filler and training trials and using image stimuli rather than videos.

Results

Proportion of looks

The overall mean proportion of looks to the action image in each condition is shown in Figure 8; black dots correspond to individual participants' mean proportions of looks. Children in the verb condition exhibited a significantly higher proportion of looks to the action image (M = 0.629, SD = 0.17) than children in the noun condition (M = 0.481, SD = 0.187). Children in the baseline condition had an average proportion of looks that fell in between the noun and verb conditions (M = 0.597, SD = 0.175). The confidence interval for the baseline condition overlapped with the intervals for both the noun and verb conditions.

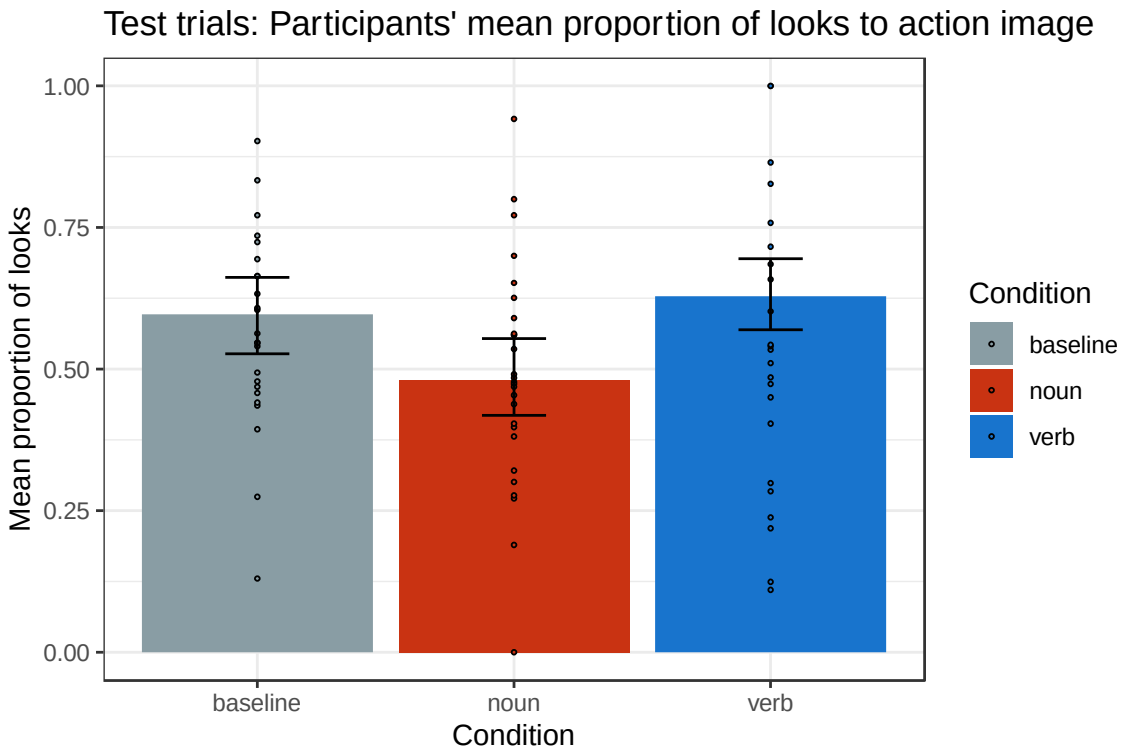

Figure 8. Children's mean overall proportion of looks to the action image in the noun, verb, and baseline conditions during Experiment 3 test trials, with bootstrapped confidence intervals. Black dots correspond to the mean proportion of looks for individual participants, averaged across the three test trials.

Repeating our analysis from Experiment 2, we conducted a mixed effects linear regression analysis which predicted the arc-sin transformed mean proportion of looks to the action image as a function of condition, with a random by-participant intercept. There was a significant main effect of condition such that children in the noun condition had a lower proportion of looks to the action image compared to children in the baseline condition (β = -0.134, SE = 0.047, t = -2.854, $p < 0.01$). There was not a significant difference in the proportion of looks between the verb condition and the baseline condition (β = 0.036, SE = 0.048, t = 0.756, p = 0.452).

The results from the mixed effects logistic regression model, which directly predicted the log odds of looking to the action image as a function of condition and previous look, were similar. As before, we included a random slope for participant and a random slope for previous look. This model also found a significant effect of condition, such that children in the noun condition were less likely than children in the baseline condition to look at the action image (β = -0.263, SE = 0.101, t = -2.597, $p < 0.01$). There was not a significant effect for children in the verb condition compared to children in the baseline condition (β = 0.138, SE = 0.106, t = 1.298, p = 0.194). The effect of previous look was also significant, such that if a child looked at the action image on their previous look, they were also more likely to look at the action image on their next look (β = 7.27, SE = 0.087, t = 83.402, $p < 0.001$).

Time course

The time course of children's looks to the action image over time, averaged across the four test trials, is depicted in Figure 9.

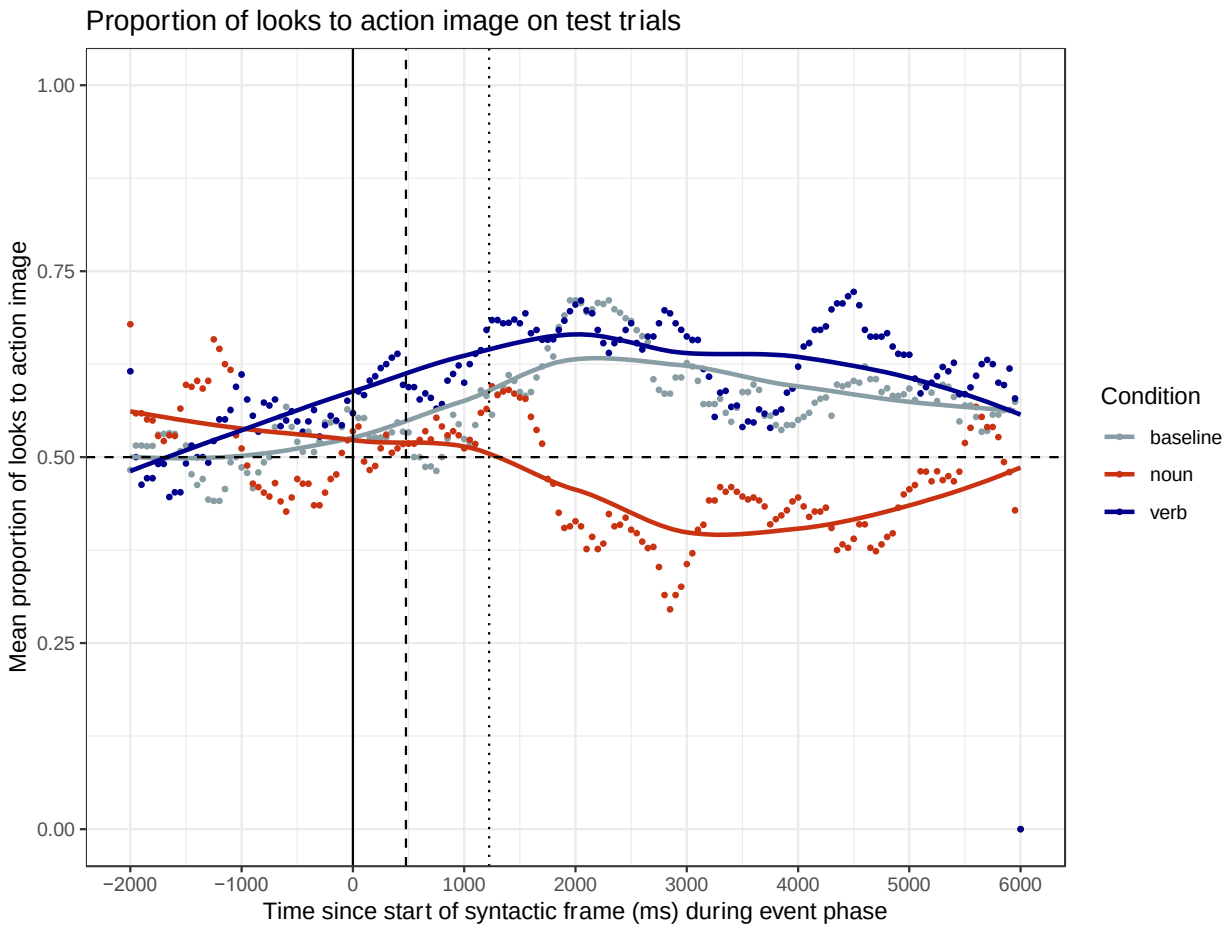

Figure 9. Time course plot of children's mean proportion of looks to the action image on test trials during Experiment 3. Gray areas represent overall confidence intervals and dots represent individual participants. The vertical black line corresponds to the point of disambiguation of the syntactic frame (*The g-*). The dashed line represents the mean time point of the end of the syntactic frame, *The girls/girls…*, and the dotted line indicates the end of the first utterance of the novel word, such as *The girls/girl's dax.*

In contrast to Experiment 2, it appears that in Experiment 3, children in all three conditions showed a slight preference for looking at the action image before hearing the key syntactic frame containing the novel word (e.g., *The girls/girl's dax*). This may have been due to the presence of two people in the action images, which could be more salient for children,

compared to just one person in the object image. However, shortly after the beginning of the syntactic frame, *The g-*, children began to diverge in their average proportion of looks to the action image. Children in the noun condition looked consistently less at the action image than children in the verb condition. Children in the baseline condition fell somewhere in between the two, though still with a preference for the action image. However, this preference appeared later in the course of the trial than it did for participants in the verb condition.

Due to logistical constraints running the experiment online, we were not able to ask children to explicitly select which image they thought the speaker was referring to.

General Discussion

These three experiments examined whether the results of Havron et al. (2019) would replicate: first, in a direct replication of the original study with French adults (Experiment 1), then in a modified crosslinguistic replication with English-speaking adults (Experiment 2), and finally with English-speaking children (Experiment 3). We expected that over the course of the experiment, participants would adapt to the usage of the syntactic frame they encountered (which in English was *The girls/girl's…*), such that participants in the noun condition would have a stronger expectation that the speaker would use *The girl's [noun]*, and participants in the verb condition would have a stronger expectation that the speaker would use *The girls [verb]*. We then predicted that these expectations would guide the interpretation of an ambiguous novel word presented in the same syntactic frame, such as *The girls/girl's dax.* This would be reflected by participants in the verb condition showing a higher proportion of looks to the action image than participants in the noun condition.

Figure 10 shows participants' proportion of looks to the action image in each condition, for all three experiments that we conducted. Across all three experiments, participants in the verb condition showed a consistent preference for looking at the action image on test trials. In the noun condition, French- and English-speaking adults had lower rates of looking at the action image than would be predicted by chance. However, for English-speaking children, participants in the noun condition did not show a strong preference for looking at the object image over the action image. The baseline condition also demonstrated variable results: English-speaking adults in the baseline condition appeared to show a preference for the object image, while English-speaking children in the baseline condition appeared to show a preference for the action image.

These results are fairly similar to the Havron et al. (2019) study, which found a larger priming effect for children in the verb condition, who were exposed to a less frequent syntactic structure. The noun structure we used is more frequent than the verb structure; there are 2,125 instances of *The girl's [noun]* in the Corpus of Contemporary American English, compared to 1,013 instances of *The girls [verb]*. Furthermore, speakers often use the structure *The girls are [verb]ing* rather than *The girls [verb]*, so the verb structure may have seemed more unusual to children in the verb condition than the noun structure did to children in the noun condition.

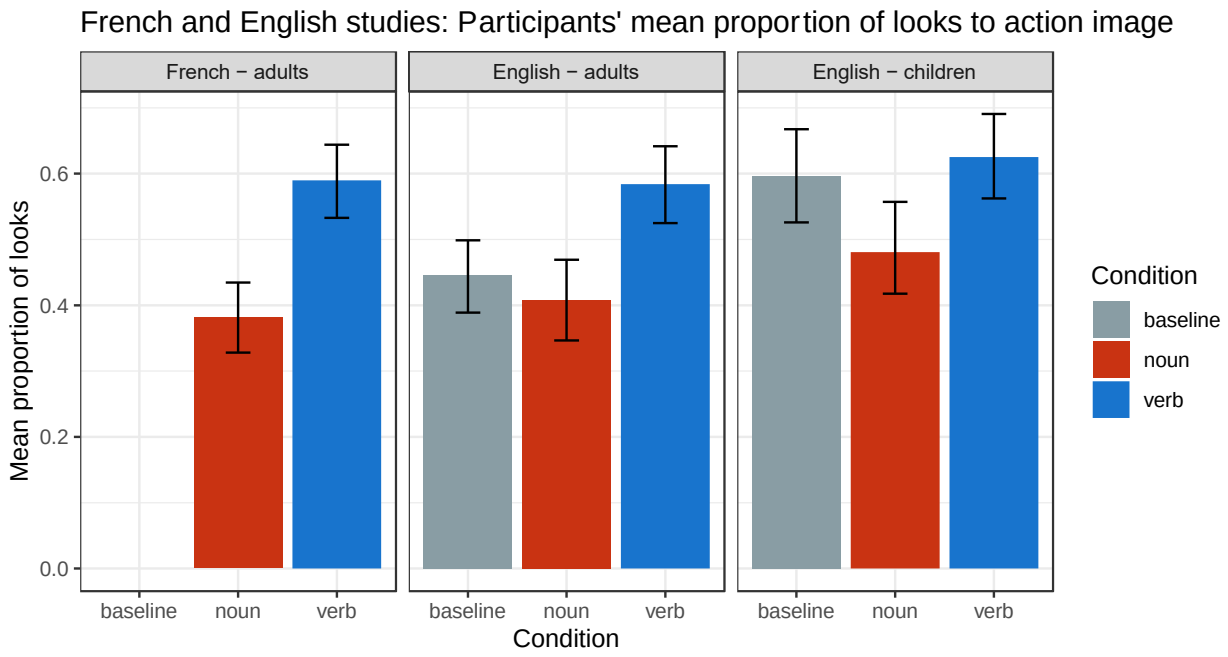

Figure 10. Comparison of participants' mean proportion of looks to the action image on test trials during Experiments 1, 2, and 3.

Importantly, we ensured that participants were not biased toward the verb interpretation based on factors such as prosody by running a norming experiment beforehand where we played only the audio clips (such as *The girls/girl's dax*) and asked participants whether they thought *dax* was an action or an object. Participants judged that the novel words referred to actions 51.1% of the time, suggesting that the verb and noun interpretations were about equally plausible. Thus, the more consistent adaptation effect in the verb condition does not simply appear to be due to a baseline bias toward the verb interpretation; it more likely represents stronger syntactic adaptation to the more surprising structure. This would align with Jaeger & Snider's (2013) finding that the strength of syntactic priming is affected by the prime's prediction error. Stronger priming in the verb condition could also help to account for the anticipatory looks that were observed in the verb condition, even before hearing the syntactic

frame, in Experiments 2 and 3; participants may have come to expect that the speaker was more likely to describe the action image due to the noticeable overrepresentation of the unusual *The girls [verb]* structure.

Although participants in the verb condition exhibited a higher proportion of looks to the action image than participants in the noun condition across all three experiments, participants in the baseline condition showed varying results in Experiments 2 and 3. In Experiment 2, the English-speaking adults in the baseline condition slightly preferred looking at the object image, while in Experiment 3, the English-speaking children in the baseline condition preferred looking at the action image. The explicit selection results from Experiment 2 suggest that adults in the baseline condition were not drawing inferences about the meaning of the novel word and that this effect was more likely due to participants finding the object image more salient. We were not able to ask the children in Experiment 3 to explicitly select the action or object image, but we suspect that salience also guided baseline children's looking preferences because the norming studies discussed in Experiment 2 also showed variable results in how salient the images were, and because baseline children showed the opposite pattern of looks (with a preference for the action image) than baseline adults (who slightly preferred the object image). Further studies, likely with higher numbers of participants, would be needed to examine baseline preferences for looking at action images vs. object images and to determine in which direction, if not both, participants are adapting.

Despite the variation in the baseline results, we observed across all three experiments that participants in the verb condition had a higher proportion of looks to the action image than participants in the noun condition. This replicated the key result of Havron et al. (2019) both directly and cross-linguistically in English, with children and adults. An important contribution

we added to build on Havron et al.'s work was the equal number of filler trials and training trials in Experiments 2 and 3. This ensured that participants heard the speaker refer to action and object images with equal frequency; it was only with the specific structure *The girls/girl's…* that participants developed an expectation about whether the speaker would use a noun or a verb. Thus, we can be confident that our results reflect adaptation to the usage of a particular linguistic structure and not to the speaker's general likelihood to talk about actions or objects. This adaptation then guided participants' interpretations of an ambiguous novel word that was presented in the same syntactic frame.

Overall, these results support and extend those of Havron et al. (2019). The similar findings across French and English, and between children and adults, lend support to the proposal that syntactic adaptation may be an important mechanism for guiding language acquisition. Future work can investigate adults' and children's baseline preferences relating to factors such as image salience and structure frequency, as well as how these preferences interact with new statistical information about a speaker's usage of syntax. With more studies that carefully tease apart these factors, we can work toward a formal model of expectation update during syntactic adaptation.

Future work can also further examine the specificity of syntactic adaptation in word-learning contexts. For instance, since we used the same speaker throughout the experiment, it remains an open question whether this adaptation effect is speaker-specific or whether it could generalize to other speakers. In addition, future studies could vary the particular lexical content used within the syntactic structure (e.g., *The boys/boy's X*) to determine whether participants would generalize their expectations about the underlying syntactic structure to a slightly different phrase. If children are likely to encounter repeated syntax in short bursts within specific contexts,

as in the example where a caregiver utters similar phrases such as *The dog is running*, *The dog is playing*, etc., then we might expect syntactic adaptation to be quite specific to the speaker and the lexical content.

While the role of syntactic adaptation in word learning merits further investigation, these experiments suggest that children and adults are able to not only flexibly update their expectations about a speaker's syntactic preferences, but also draw on these expectations to guide novel word learning.

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