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Syntactic prediction adaptation accounts for language processing and language learning

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Keywords: Syntactic Priming, Language Acquisition, Child Language, Language Processing, Homophones, Syntactic Adaptation, Ambiguity Resolution.

Previous literature has shown that children use recent input to adapt their syntactic predictions, and use these adapted predictions to infer the meaning of novel words. The current study tested whether they could use this mechanism to disambiguate words that are ambiguous between a noun and a verb interpretation. We tested two-to-four-year-old French children using the phrase *la petite* followed by a homophone that could be interpreted as either a noun or a verb. Children were assigned to a noun group or a verb group. Before test, the noun group was exposed to sentences where *la petite* predicted nouns, and the verb group to sentences where *la petite* predicted verbs. At test, three- to four-year-olds, but not two-year-olds, from the verb group looked at the verb interpretation longer than the noun group. This suggests a progression in children's ability to rely on input to adapt their predictions in language comprehension.

Introduction

According to *error-based learning* models, in order to comprehend language children are constantly predicting what their interlocutors will say next, and when their predictions fail, they correct the model they rely on for prediction, to better fit upcoming input. Language learning is accomplished through this Bayesian optimization process, which serves to build a linguistic representation of children's native language(s). The suggestion that language learning happens through amending prediction, that is, linguistic representations, thus also predicts that the adaptation process will operate in the same way in language processing and language learning (Chang, Dell, & Bock, 2006; Chang, Kidd, & Rowland, 2013; Rabagliati, Gambi, & Pickering, 2016). In effect, according to these models, the traditional distinction between processing and learning is undermined. As the child listens to sentences, she processes these sentences to both comprehend them, and change the model she relies on for processing and learning novel linguistic materials. When sentences are processed, minor to no changes will be made to her linguistic representation if the sentence is fully predictable. However, unexpected or previously unencountered words or constructions result in changes to her representations, which can be described as language learning. Thus, whether the next sentence contains a word she knows or a novel word, she uses the exact same processes. To examine the hypothesis that these processes operate in the same way in learning and processing, however, in this study we will adopt the more traditional distinction between processing and learning, such that in the context of this study, interpreting novel words will be described as learning, and processing familiar words and structures will be described as language processing.

Error-based learning models also predict that children, whose linguistic representations are less robust, since they have had less experience with language, should be more prone to change their predictions in the face of prediction error (Peter, Chang, Pine, Blything, & Rowland, 2015). While interest in error-based models or in adaptation to linguistic context (henceforth, *prediction adaptation*) has been extant, direct evidence for these two key hypotheses remains scarce. First, there is little research directly comparing language processing and learning. Second, while there is some evidence for

developmental changes in prediction, there are only a few studies comparing prediction adaptation across age groups (Fazekas, Jessop, Pine, & Rowland, 2020; Havron et al., 2020).

Indirect evidence for prediction adaptation in children comes from studies showing that children can be structurally primed to produce a structure they were recently exposed to, such as the passive voice (e.g., Gámez, & Vasilyeva, 2015; Peter, Chang, Pine, Blything, & Rowland, 2015). The current central theory explaining structural priming effects states that children show priming effects as a byproduct of error-driven learning. As they successfully process incoming input they change the model they rely on for prediction to incorporate the primed structures (Branigan & Messenger, 2016; Chang et al., 2006; Kholodova, Peter, Rowland, & Allen, 2019; Peter, et al., 2015), thus, evidence of priming is taken to be evidence for adaptation. Some of these studies tested predictions stemming directly from the error-driven account of priming, such as long-term effects of priming, and stronger priming for more surprising primes – and found supportive results (e.g., Branigan & Messenger, 2016; Fazekas et al., 2020; Peter, et al., 2015). However, all these studies explored language production, without evaluating the impact of priming on either comprehension or language learning. Since production-comprehension asymmetries are abundant in child language, with comprehension abilities being generally faster developing than production skills (e.g., Fraser et al., 1963, though see also Grimm, Müller, Hamann, & Ruigendijk, 2011), one should not assume that priming effects from production can be directly translated to priming in comprehension. In adults, syntactic priming in production has generally been found to be larger and more abstract than in comprehension (in many comprehension priming studies, priming effects are found only when the same verb is repeated in the prime and the target sentence). These differences have been explained by appealing to methodological differences (including which structures tend to be used for priming when testing production or comprehension), because when the methodology is kept constant between comprehension and production, priming effects look similar (Segaert, Kempen, Petersson, Hagoort, 2012; Segaert, Menenti, Weber, Petersson, Hagoort, 2013; Tooley & Bock, 2014). Moreover, priming comprehension allows us to examine structures and cognitive effects that we would not be able to test in production (here, global ambiguity resolution).

While there are multiple comprehension studies with adults (see Tooley & Traxler, 2010 for a review), studies on comprehension priming in young children are sparse. One study by Thothathiri and Snedeker (2008b), showed that three-to-four-year-old children can be primed to expect either a double-object construction (“give the cat the milk”) or a prepositional-object construction (“give the milk to the cat”). In target sentences, after hearing “give the...” children looked predictively at the recipient if they were primed with double-object constructions and at the theme if they were primed with prepositional-object constructions. However, this study focused on anticipation of an ending of a sentence, and not on interpretation of completed sentences – globally ambiguous sentences where both interpretations remain possible until the end. If priming is the result of changing your model to better comprehend language, then we would expect recent experience to also impact children’s interpretation of ambiguous sentences – that is, children should not only anticipate but also rely on their expectations to understand interlocutors when their intention can be understood in different ways. Recently, one study found such effects in five-to-six-old children (Havron et al., 2020). Both Thothathiri and Snedeker (2008b) and Havron and colleagues (2020) looked at language processing, but these studies did not ask whether language *learning* occurs through prediction adaptation.

A more direct piece of evidence that children are learning through prediction adaptation comes from two recent studies. Fazekas and colleagues (2020) primed five-to-six-year-old children and adults’ language production using more or less surprising sentences. Surprising prime sentences were those in which verbs appeared in less-expected syntactic structures. For example, the verb *give* is more frequently used with a double object construction (“Give the dog a bone.”) than with a direct object construction (“Give the bone to the dog.”). Participants who were primed with more surprising sentences showed larger change in their production of the primed construction in a post-priming testing phase. Participants in this experiment changed their production of familiar syntactic structures; an effect which suggests that surprising input (i.e., failed predictions) incites changes to underlying syntactic representations. Here, the primed construction and all target words were familiar to participants, and thus, learning was only revealed in the relative use of each sentence structure.

Another recent study tested the effect of prediction adaptation on children's learning of novel words. Havron, de Carvalho, Fiévet and Christophe (2019) found that 3-to-4-year old children can rely on their experience with familiar sentences to change their prediction of encountering either a noun or a verb after an ambiguous syntactic context. These children later relied on these predictions to infer the meaning of novel words. In French, the words *la petite* can be followed by either nouns or verbs, such that *petite* could act as an adjective describing a noun (e.g., *la petite grenouille*, "the little frog"), or act as a noun, short for *la petite fille*, "the little girl" (e.g., *la petite dort*, "the little one is sleeping"). During an induction phase, three-to-four-year-old French-speaking children were presented with familiar nouns or verbs following the syntactic context *la petite*, as in the examples above. At test, children were presented with a novel word, which could be interpreted as either a noun or a verb (e.g., *la petite nuve*, "the little nuve" or "the little one is nuving"). Participants who were exposed to four sentences where the word following *la petite* was a familiar verb were more likely to interpret a novel word appearing in the same syntactic context as denoting a novel action than children who were presented with sentences where the word following *la petite* was a familiar noun. This was the first demonstration that children can indeed rapidly change their predictions and use these updated predictions for language learning.

The current study focuses on two central predictions of the error-driven-learning model, mentioned above. The first is that as children process sentences, they build a predictive model which will be used in the same way both when acquiring novel words and when processing familiar words. Thus, the very same effects that are shown in learning should be evident in processing. We use the design of Havron and colleagues' experiment (2019) to test children's processing of familiar sentences. Unlike Havron and colleagues, we do not present novel words at test, but ambiguous sentences containing noun/verb homophones. For example, the sentence *la petite ferme* can be interpreted either as "the little farm" or "the little one is closing". French-learning infants as young as 20 months have been previously shown to understand both the verb and noun meanings of these homophones, and to be able to use prosodic information to disambiguate between the two possible interpretations (de Carvalho, Dautriche & Christophe, 2016; de Carvalho, Dautriche, Lin, & Christophe, 2017). The current experiment uses a

prosody that is ambiguous between a noun and a verb interpretation, as in Havron et al. (2019). If children are relying on recent experience with linguistic input to infer the meaning of a word presented after the syntactic frame *la petite*, they should look more at an image depicting the verb interpretation of a homophone (e.g., in the case of *ferme*, a little girl closing a chest) when previously presented with familiar verbs than when previously presented with familiar nouns.

We test adaptation of expectations in language comprehension and compare the effect we find in the current study with the effect found in Havron et al. (2019). Finding a similar effect would suggest that as children successfully process sentences, they change the model they rely on for both processing and learning novel linguistic material. Whether the test sentence contains a word they know (processing) or they do not yet know (learning), they will rely on their adapted expectations, to predict the syntactic category of that word.

A second prediction of the error-driven-learning model is that children, whose prior knowledge is less robust, should be more prone to change their predictions in the face of prediction error (Peter, et al., 2015). We test this prediction by looking at two different age groups: 24-30-month-old toddlers and three-to-four-year-old children. We expect that the younger age group would show stronger adaptation than the older age group. However, as stated above, 24-30-month olds might be less able to rapidly integrate novel linguistic input than three- to four-year olds , due to their limited cognitive resources (e.g., memory, executive functions, language processing, see Diamond, 2013). If this factor is predominant, we might see a weaker effect in the younger group than in the older group, or even none at all. Despite the confound between the proposed underlying cognitive mechanism (prediction adaptation) and the cognitive resources allowing children to integrate linguistic input, we do hope to contribute to this literature by presenting two age groups with the same adaptation task, which should be simple and easy enough for 24-30-month-old toddlers to perform.

Method

All data and materials have been made publicly available via the Open Science Framework (OSF) and can be accessed at https://osf.io/qnt93/?view_only=3924e2941e9445a487181835b9f5322e. The experimental design and planned analysis were preregistered at the OSF and can also be accessed with the same link.

Participants

Children were recruited and tested in our babylab through direct contact with parents belonging to our database. We had two age groups: 24-30-month-olds (henceforth *two-year olds*) and three- to four-year olds. Our final sample for the two-year-old group consisted of 48 monolingual French-speaking toddlers between the ages of 24.26 and 29.92 months (22 in the verb condition, 11 girls, $M_{\text{age}} = 26.25$ months, $SD = 1.61$; and 26 in the noun condition, 12 girls, $M_{\text{age}} = 26.58$ months, $SD = 1.50$). Our final sample for the three- to four-year-old group consisted of 49 monolingual French-speaking children between the ages of 36.39 and 49.84 months (24 in the verb condition, 12 girls, $M_{\text{age}} = 42.45$ months, $SD = 4.35$; and 25 in the noun condition, 16 girls, $M_{\text{age}} = 42.73$ months, $SD = 4.17$). This sample size is similar in size to Havron and colleagues' (2019) study, which found an effect size of $d = 0.941$ with 45 participants.

Of the 62 two-year olds originally tested, seven were removed due to fussiness. Of the 57 three- to four-year olds originally tested, five had corrupted data files. Trials were excluded if there was more than 50% missing eye-tracking data, which led to 57 excluded trials for two-year-old participants (26 in the noun condition and 31 in the verb condition) and 42 excluded trials for three- to four-year-old participants (22 in the noun condition and 20 in the verb condition). Children were excluded from the final analysis if they had more than two test trials with more than 50% missing eye-tracking data – seven two-year olds and three three- to four-year olds were excluded for this reason. Twelve of the three- to four-year olds tested performed the experiment after having performed a different experiment which lasted about 5 minutes and which did not include homophones or the frame *la petite*. None of them were excluded. Written parental consent was obtained for all children. The study was approved by the local ethics committee (i.e. CERES IRB).

Design

In French, *la petite* can either be followed by a noun (e.g., *la petite grenouille*, “the little frog”) or by a verb (e.g., *la petite dort*, “the little one is sleeping”). A search in the Paris child-directed-speech corpus (Morgenstern & Sekali, 2009) found that this syntactic frame is more likely to be followed by a noun (720 instances) than by a verb (6 instances). We manipulated the syntactic category that this context predicted by randomly assigning children to one of two conditions—a verb condition and a noun condition. In the induction phase, children assigned to the verb condition were exposed to four sentences in which *la petite* was consistently followed by familiar verbs; whereas children assigned to the noun condition were exposed to four sentences in which it was consistently followed by familiar nouns. They additionally heard an equal number of filler sentences not using the phrase *la petite* and directing noun-condition children to look at verbs (always using the frame *elle VERB*, “she VERB”), and verb-condition children to look at nouns (always using the frame *c’est une NOUN*, “it’s a NOUN”). In the test phase, all children were exposed to four globally ambiguous sentences in which a noun-verb homophone could be interpreted either as a noun or as a verb (e.g., *la petite ferme*). We examined whether three- to four-year olds and two-year olds could use their updated expectations (built during the induction phase) to guide their syntactic analysis and thus infer the intended meaning of familiar noun/verb homophones at test. If this is indeed the case, at test, three- to four-year olds and two-year olds from the verb condition should be more likely to interpret the homophones as verbs than three- to four-year olds and two-year olds assigned to the noun condition.

Materials and procedure

Participants were tested individually in our babylab in a sound-attenuated double-walled booth. They were sitting facing a 27-in. screen positioned 70 cm away from them. Eye gaze was recorded by an Eyelink-1000 placed below the screen (operating in remote mode and collecting data every 2ms). We used a 5-point calibration. The induction phase included eight trials—four induction trials and four fillers. On all trials, the participant saw two images displayed side-by-side-on the screen: one depicting a little girl performing an action, and the other showing an object. During the presentation of the two images, a woman’s voice (the last author) asked the child to look at one of the images in a child-friendly fashion.

For instance, in an induction trial, for the pair of images involving an apple on one side, and a girl sleeping on the other side, participants assigned to the noun condition would hear the sentence *Oh, regarde, la petite pomme !*—“Oh look, the little apple!”. In contrast, participants assigned to the verb condition would hear *Oh, regarde, la petite dort !* —“Oh look, the little one is sleeping!”. The verb image always included a little girl, and the noun image never did. The prosody was the same for noun and verb sentences; this was done by intentionally picking a prosody that is appropriate for both nouns and verbs, in which the three words belong to the same prosodic phrase; otherwise it would have been possible to disambiguate using different prosodic structures (as it was shown in de Carvalho et al., 2016, 2017). Havron and colleagues pretested this prosodic contour with adults to make sure both interpretations were possible. Adults judged the novel word to have referred to an action 31% of the time and to a novel object 69% of the time, confirming that the novel word could be interpreted as either a noun or a verb, yet showing a clear noun bias consistent with the child-directed-speech corpus search (see Havron et al., 2019 for details). See figure 1 and table 1 for prosodic characteristics of the different types of trials.

Table 1: Acoustic measurements for the three types of experimental trials

	Noun trials	Verb trials	Test trials
Mean duration rime <i>petite</i> (in ms)	154.41	169.34	169.48
Mean F0 rime <i>petite</i> (in Hz)	326.47	361.71	383.83
Mean F0 <i>e</i> in <i>petite</i> (in Hz)	238.07	243.62	257.43

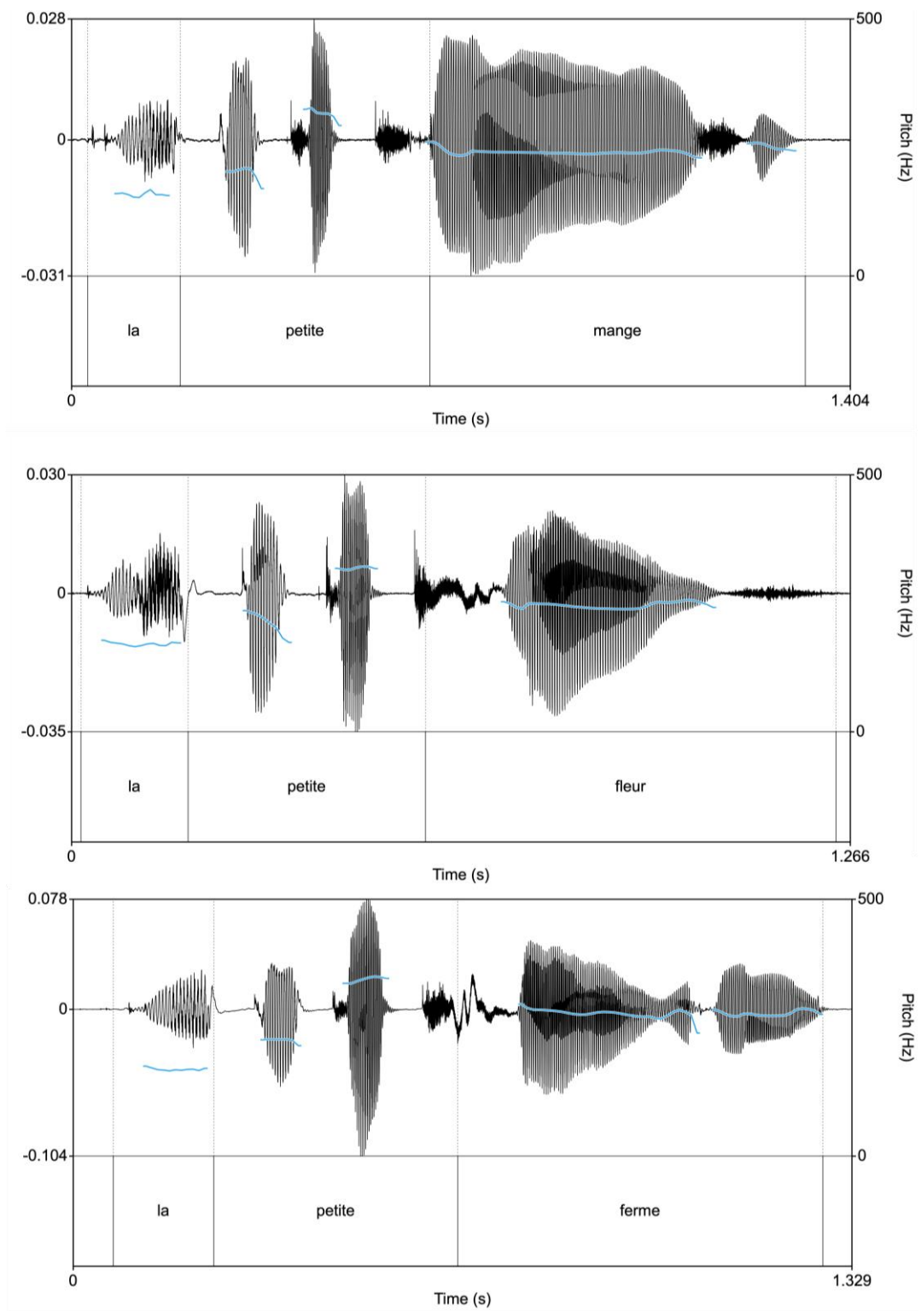


Figure 1. Soundwave and pitch for one verb phrase (*la petite mange*, top), one noun phrase (*la petite fleur*, middle), and one test phrase with a homophone (*la petite ferme*, bottom).





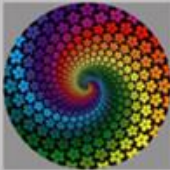





The four filler items used an unambiguous syntactic structure (either *c'est une* + *Noun*, “it’s a Noun” or *Elle* + *Verb*, “she is Verbing”), and directed children to look at the opposite syntactic category. For example, if a participant was in the verb condition, they heard four *la petite* + *familiar Verb* sentences (e.g., *la petite dort*, “the little one is sleeping”) and four *C'est une* + *familiar Noun* sentences (e.g., *C'est une vache*, “this is a cow”). The filler trials assured that participants were asked equally often to look at the action or the object in both conditions. The order of the trials was randomized, with the only constraint that a given syntactic category should not appear more than twice in a row.

In the test phase, consisting of four trials, participants saw two images depicting the noun and verb interpretations of four homophones (e.g., for *la petite ferme* they saw a little farm, and a little girl closing a chest). The ambiguous words were *ferme* [fɛʁm] “closes/farm”, *marche* [makʃ] “walks/stair”, *porte* [pɔʁt] “carries/door”, and *sourit/souris* [suʁi] “smiles/mouse” (in French there is no difference in pronunciation between “*souris*” and “*sourit*” – both words are pronounced as /suʁi/, because the final ‘s’ and ‘t’ are silent). All these ambiguous words are known to children of young ages, as 20-month-old infants were already shown to interpret similar ambiguous sentences as containing either a noun or a verb depending on prosodic cues (de Carvalho, Dautriche, & Christophe, 2016; de Carvalho, et al., 2017). Moreover, in de Carvalho and colleagues (2017), the authors also asked the parents of the participants to fill out a short questionnaire indicating whether their children understood each of the meanings of the ambiguous words used in their task (the same words we used in our current study). These results suggest that most toddlers are able to understand most of the ambiguous words used in our task.

Note that in our task, children and toddlers in both conditions saw the same images and heard the exact same sentences. The prosody of the test sentences was the same as that of the induction sentences—ambiguous as to whether the final word was a noun or a verb and the same audio files were used for both conditions. The order of the test trials was randomized (except for the last trial, which, due to a programming error, was always *la petite sourit/souris* “smiles/mouse”). In all trial types the target side was counterbalanced. Each trial lasted about 30 seconds, with the full experiment lasting about 6 min. There was one difference between the two-year olds and three- to four-year-old groups. For the three- to

four-year-old group only, to make the experiment shorter, we removed the pre-presentation of the two images together (images were presented one by one without naming, then a sentence was played when no images were visible, then the two images together and the sentences twice), we also made the pre-presentation of single images shorter. For a full-length sample trial see figure 2.

Figure 2. Example of the time-course of a test trial (target side was counterbalanced).

			2-year old	3-4 year old
	Oh, c'est quoi ? "oh what is that?"		5 sec	4 sec
	Oh, regarde, qu'est-ce qu'elle fait ? "oh look, what is she doing?"		5 sec	4 sec
	Fixation point 1 second			
	Both images together with no sound		3 sec	0 sec
	Fixation point is displayed until the gaze is on it (at least 0.5 seconds)			
	Oh, regarde, la petite ferme ! tu vois ? la petite ferme ! "Oh look, the little farm / the little one closes! Do you see? The little farm / the little one closes"		10 sec	10 sec

Data analysis

Current experiment.

For each participant in this experiment, we measured the time course of eye-gaze during each test trial. We ran two different analyses on the eye-gaze data. First, we calculated the proportion of looks towards the verb image for each participant (averaged over the entire time window), and conducted a mixed-effects regression (using the lme4 package, Bates, Maechler, Bolker, & Walker, 2015) comparing the overall looking time at the verb image, averaged across the whole trial, between the two conditions, the two age groups, and an interaction between condition and age. The analysis included a random intercept for participant and item. We report p values using the lmerTest package (Kuznetsova, Brockhoff, & Christensen, 2017) and Bayes Factors obtained from the R package BayesFactor (Morey, Rouder, Jamil, & Morey, 2015), by comparing each model to a model lacking the effect of interest (e.g., for the effect of condition we compare a model which includes Age, Condition as fixed effects and participant and item as random effects to a model which includes Age as fixed effect and participant and item as random effects). Our inference criterion was $BF_{10} > 3$.

Second, we ran two cluster-based permutation analyses (one for each age group) to find if there exists a specific time-window(s) where a significant effect of condition is observed. Adjacent time points with a t-value greater than 1.5 were grouped together into a cluster, and the probability of observing a cluster of the same size by chance was estimated by running the same analysis on simulated data in which group was randomly assigned to participants (1000 iterations). The same kind of analysis was used in other eye-tracking studies using a similar preferential-looking paradigm with infants and preschoolers (e.g. de Carvalho, Babineau, Trueswell, Waxman, & Christophe, 2019, de Carvalho et al., 2017; Von Holzen & Mani, 2012; see Maris & Oostenveld, 2007 for a formal presentation of the analysis itself).

Comparison with Havron and colleagues (2019).

To compare the effect of syntactic adaptation in this language-processing experiment with the effect of syntactic priming in language-learning, we directly compared our results with the results of Havron and colleagues (2019). We ran a linear model (in the 2019 dataset there is only one observation per participant so we do not use a mixed-effects model), and used Bayesian factors derived from the BayesFactor package as described above.

Results

Current experiment.

Our first analysis, conducted on the average overall looking time per participant (excluding looks away, which were not significantly different between conditions), found an effect of condition: Collapsing across age groups, children from the verb condition were more likely to look at the image illustrating the verb interpretation ($M = .51$, $SD = .23$) than children from the noun condition ($M = .42$, $SD = .21$, $\beta = .16$, $SE = .047$, $t = 3.25$, $p = .016$, $BF_{10} = 0.17$). This effect suggests that children from the verb condition were more likely to interpret the homophone as a verb than children in the noun condition. We also found a significant effect of age, with two-year olds looking more at the verb interpretation, overall, than three- to four-year olds ($\beta = .11$, $SE = .03$, $t = 3.26$, $p = .002$, $BF_{10} = 0.79$). Last, we found a significant interaction between the two factors, such that only three- to four-year olds (verb: $M = .57$, $SD = .15$; noun: $M = .38$, $SD = .11$; Cohen's $d = 1.45$; 95%CI = 2.1-0.805) but not 2-year-olds (verb: $M = .45$, $SD = .17$; noun: $M = .49$, $SD = .13$; Cohen's $d = -0.237$; 95%CI = -0.822-0.348) showed an effect of condition ($\beta = -.21$, $SE = .05$, $t = -4.25$, $p < .001$, $BF_{10} = 165.18$, see Figure 3). Note that the variance in the verb condition was larger than the variance in the noun condition.

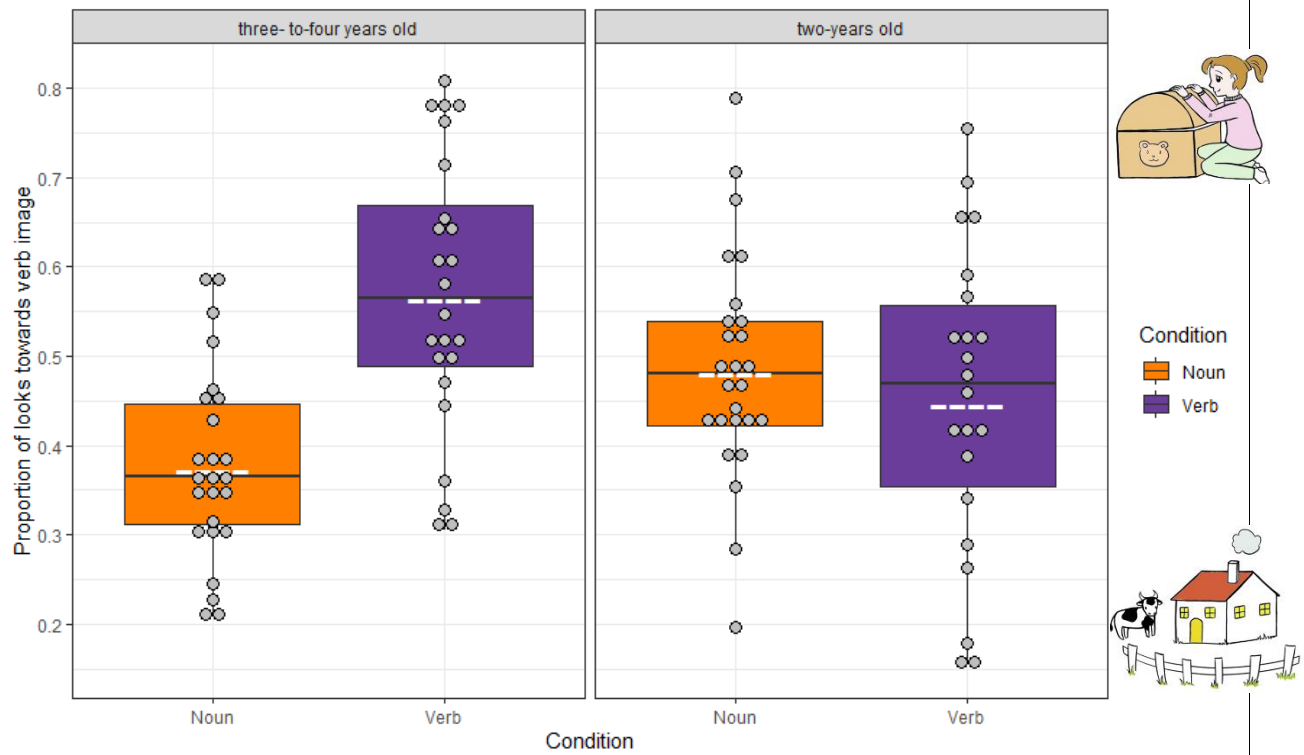


Figure 3. Mean overall proportion of looks toward the verb image at test for the two conditions and two age groups.

Gray dots represent values for each individual participant. The lower and upper hinges correspond to the first and third quartiles, the dotted white lines represent the means, and the black lines within the squares represent the median. The whiskers represent either 1.5 times the inter quartile range, or the minimum/maximum value. Purple marks the verb condition and orange marks the noun condition. Three- to four-year olds from the verb condition looked at the verb image significantly more than three- to four-year olds from the noun condition, but this was not the case for two-year-olds. Asterisks mark the difference from chance level (* < .05, *** < .001).

For three- to four-year olds, the cluster-based analysis revealed two significant time windows with an effect of condition. The first significant cluster ($p = .016$) was found between 2850ms and 4650ms after the beginning of the trial, about 400ms after the beginning of the target word (which starts on average at 2474ms). The second significant window ($p < .001$) was found between 5500ms and 9500ms after the beginning of the trial, which is before the start of the second repetition of the target word (which starts on average at 6729ms, see Figure 4). During these time-windows, three- to four-year olds from the verb

condition looked more at the verb interpretation than three- to four-year olds from the noun condition. For two-year olds no significant time window was identified (see Fig. 4).

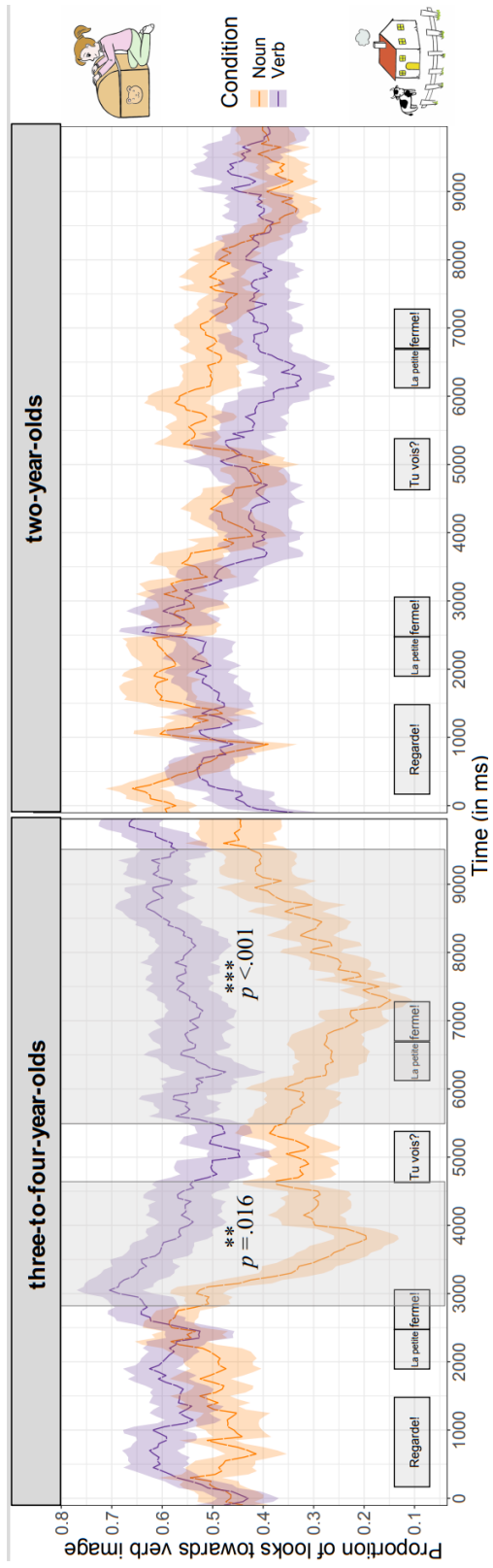


Figure 4. Proportion of looks toward the verb image in the test phase for the two conditions and two age groups, as a function of time, plotted for the entire duration of the trial. Purple marks the verb condition and orange marks the noun condition. Significant time clusters are marked by a grey box.

Exploratory analysis – induction phase.

To examine whether the lack of effect in two-year olds was due to the fact that they were not able to perform the task correctly or were inattentive during the induction phase, we ran the same mixed effects regression on looking time on the results of the induction phase. That is, we compared the overall looking time at the verb image, averaged across the whole trial, between the two conditions, the two age groups, and an interaction between condition and age. The analysis includes a random intercept for participant and item. We found an effect of condition: Collapsing across age groups, children from the verb condition were more likely to look at the image illustrating the verb interpretation than children from the noun condition ($\beta = .19$, $SE = .02$, $t = 10.53$, $p < .001$). We also found a significant effect of age, two-year olds looked at the noun interpretation longer than three- to four-year olds ($\beta = -.04$, $SE = .02$, $t = -2.12$, $p = .03$). Last, we found no interaction between the two ($\beta = .002$, $SE = .027$, $t = 0.08$, $p = .94$). There was thus no evidence that the two age groups differed in their performance in the induction phase.

Comparison with Havron and colleagues (2019).

Last, we compared our results from three-to-four-year olds with the results of Havron and colleagues (2019), whose participants were of the same age. We ran this analysis to test the hypothesis that language learning and language processing act in the same way (since, as explained in the introduction, according to the error-driven learning model, they are one and the same).

We ran a mixed effect model predicting overall looking time per participant as a function of Condition, Experiment and an interaction between the two. The analysis included a random intercept for participant and item. We found a significant effect of Condition ($\beta = 0.19$, $SE = 0.04$, $t = 5.16$, $p < .001$; $BF_{10} = 159918.1$), showing that three- to four-year olds are adapting to recent input, over the two

experiments. We also found a main effect of Experiment ($\beta = 0.1$, $SE = 0.04$, $t = 2.72$, $p = .008$, $BF_{10} = 3.23$), indicating that three- to four-year olds were overall looking more at the verb interpretation in Havron et al. (2019) than in the current experiment. We discuss this finding below. We found no significant interaction, and, in the Bayesian model, anecdotal evidence against an interaction ($\beta = -0.07$, $SE = 0.05$, $t = -1.34$, $p = .18$; $BF_{10} = 0.56$, see fig. 5), leaving it an open question whether the effect of condition is similar in size to Havron et al. (2019) with novel words, or even stronger with familiar words.

Regarding the main effect of experiment, three- to four-year olds in Havron and colleagues (2019) had a slight bias towards the verb interpretation, while three- to four-year olds in the current experiment had a slight bias towards the noun interpretation. The verb bias in Havron and colleagues can be explained by the fact that the experiment used videos to illustrate the meaning of novel actions, and since there were more motion in the action videos than in the object videos, it makes sense that participants tended to look more at the videos with more motion. One possible reason for the noun bias in the current experiment, which used familiar words depicted by still images, might be the linguistic biases in French: *la petite* is indeed much more likely to be followed by a noun than by a verb in French.

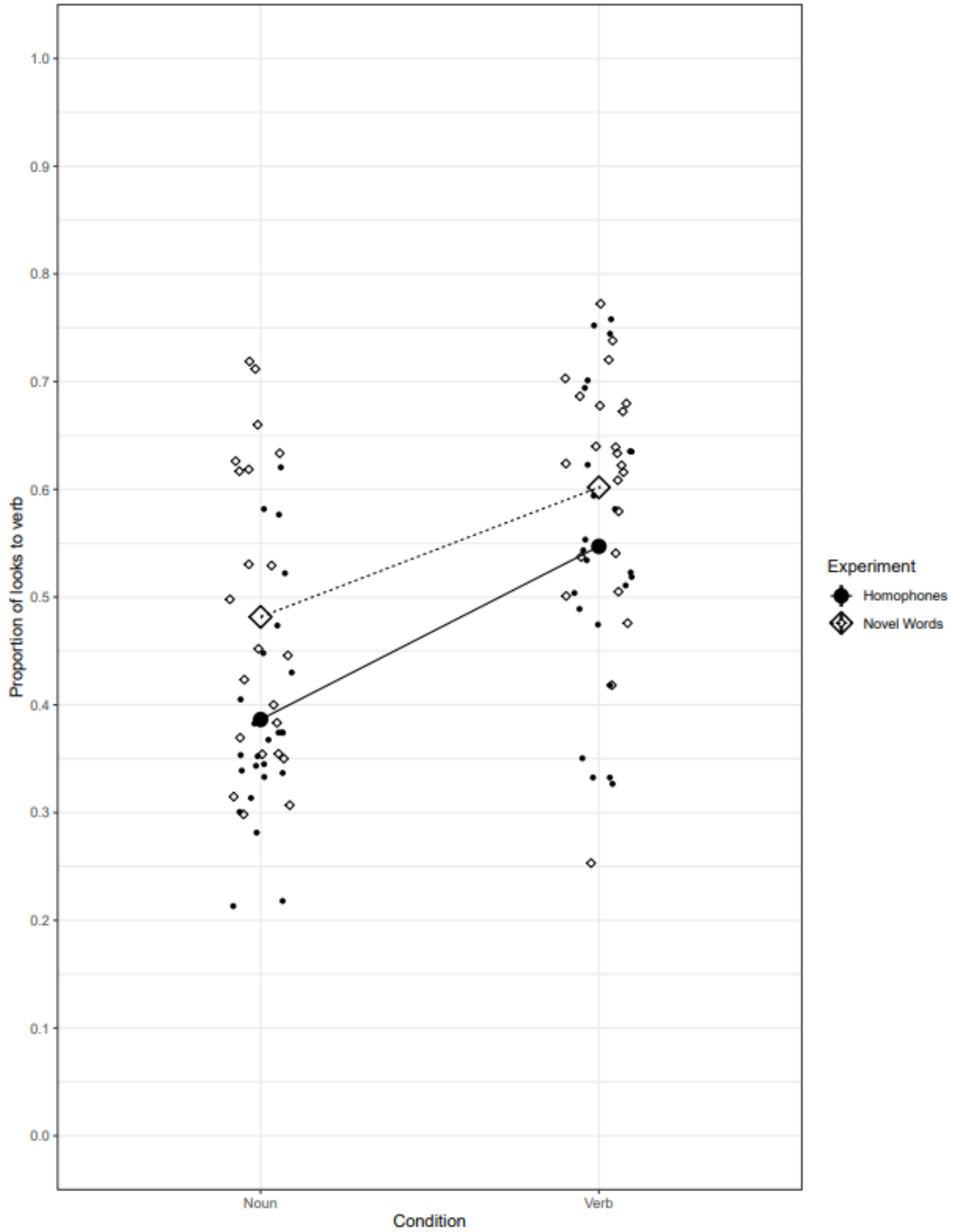


Figure 5. Proportion of looks toward the verb image/video in the test phase for the two conditions, for the two experiments. The novel-words experiment (Havron et al., 2019) is marked with diamonds and a dashed line, the current experiment (Homophones) with full circles and a full line. Each circle or diamond is a participant, and the big circles and diamonds mark the mean for that condition.

Discussion

The current study examined the effect of syntactic adaptation to recent linguistic experience on three- to four-year-olds' and two-year-olds' interpretation of ambiguous sentences containing homophones. It was recently shown that young children can use their experience with current linguistic input to update their syntactic expectations, and that they are able to use their updated expectations to infer the meaning of novel words (Havron et al., 2019). Here we extended these findings by asking first, whether the effects found for language learning would hold for language processing (interpretation of ambiguous sentences), and second, whether this is also true for toddlers who are at an earlier stage in their language acquisition. We found that three- to four-year olds indeed show adaptation of their expectations for a noun or a verb following a syntactic context (*la petite*), as exhibited by a higher likelihood to interpret the homophone as a verb for children in the verb condition than for those in the noun condition. However, two-year-olds did not show an effect of recent linguistic experience on their interpretation of ambiguous sentences.

After finding that three-to-four-year olds were indeed adapting their expectation in language processing, our next step was to compare the magnitude effect of syntactic adaptation in our child group with the effect found in Havron and colleagues (2019) in a language learning task. We found that the effects were of similar magnitude, or even slightly larger in the current experiment. Thus, whether children were tested on their processing of well-known words, or on their ability to infer and learn the meaning of novel words, they exhibited the same behavior, adjusting their expectations based on their recent linguistic experience. Overall, then, manipulating the likelihood to encounter a noun or a verb after *la petite* affects both inference about novel word meaning and the interpretation of familiar homophones. Only one previous study showed that three- to four-year-old children can be syntactically primed in language comprehension (Thothathiri & Snedeker, 2008b; see Havron et al., 2020, for similar results with five- to six-year-old children), and our results therefore add an important finding to the literature on syntactic priming in young children. These findings suggest that young children can be primed not only to

expect a different ending to an unambiguous sentence as in Thothathiri and Snedeker’s study (2008b), but also to interpret a fully ambiguous sentence in a certain way.

The fact that three- to four-year olds from the noun condition show a preference for the noun interpretation, but three- to four-year olds from the verb condition seem to waver between the two possibilities, showing larger variance, should also be discussed. Given the higher frequency of the noun interpretation in children’s input, one would expect children to show some amount of noun preference even without an induction phase. This tendency would only be strengthened by an induction phase. Three- to four-year olds from the verb group, however, have some experience with a verb interpretation, but expect it to be rare. These children do not seem to simply reverse a lifelong bias towards a noun interpretation, but rather to be less certain and more conflicted about their interpretation – wavering between both images. This pattern is the reverse of that found in Havron and colleagues (2019), which showed a verb preference in the verb group, while children in the noun showed greater variance. Havron and colleagues hypothesized that the verb preference stemmed from the greater amount of motion in the action video compared to the object video, attracting even noun-condition children’s gaze toward the verb interpretation, and that if this artifact could be removed, a noun bias would emerge. Our findings support this hypothesis. A more direct support could be obtained in future studies by including a pre-test baseline, and then measuring the change at test. Here, we would expect all children to show a preference for the noun interpretation at pre-test, but after the induction phase the change in looks to the verb interpretation would reflect how their predictions have changed.

A second important finding of the current study is that two-year olds failed to show the effect that was observed with three- to four-year olds. This finding does not support the prediction put forward by error-driven-learning account, that younger children, whose prior knowledge is less robust, will be more likely to change the model they rely on for prediction in the face of prediction error. However, several confounds prevent us from drawing strong conclusions against this hypothesis.

According to error-driven-learning models, children cannot change their predictions without registering an error signal in the face of failed predictions. This is because prediction adaptation can only

happen in response to prediction error. Since error signals depend on performance factors, the same stimulus may not cause the same error signal in the different age groups, making it nearly impossible to experimentally examine whether younger children are more prone to change their predictions than three- to four-year olds in the face of *the same* prediction error (Havron, Babineau, & Christophe, 2020). That is, there is a possibility that two-year-olds were not comprehending or remembering the induction phase to the same degree as three- to four-year olds, but that if we could equate two-year olds' level of integration of the induction phase with that of three- to four-year olds, they would show a larger change than that of three- to four-year olds. This challenge is compounded by the fact that task demands might bear more heavily on toddlers compared to young children, and on children compared to adults, making it hard to find tasks that would be as challenging and engaging across all ages (e.g., Beretti, Havron, & Christophe, 2020; Havron, et al., 2019). One study by Peter and colleagues (2015) managed to create such comparable conditions, and observed larger adaptation in children than adults. In that study, the authors manipulated prime sentences' verb bias to create more or less surprising primes, and thus larger or smaller error signals. They found a larger difference between surprising and unsurprising primes in children than in adults, in line with the expectation for larger prediction adaptation effects in children. However, a recent preregistered study with a similar design did not find a larger effect in children than in adults (Fazekas, et al., 2020). Our study did not create such comparable conditions as these two studies. It is thus a limitation of the current study that we cannot disentangle the following three factors: developmental changes in children's underlying tendency to change their predictions, their lower abilities to process the linguistic context, and task demands.

The finding of an increase in effect with age is thus compatible with two possibilities: (1) That the hypothesis put forward by error-driven-learning models is wrong; (2) that two-year olds are less likely than three- to four-year olds to be able to process the induction phase successfully due to their lower ability to remember the stimuli, comprehend them, or compute regularities in the input. These two options both have the same real-world consequences – that prediction adaptation improves with age, as was found with predictions based on stable linguistic data (e.g., that *an* always precedes a vowel, Gambi et al.,

2018). However, it is theoretically important to disentangle these two options. In an exploratory analysis we found equal success in the induction phase for the two age groups, implying that both three- to four-year olds and two-year olds understood the induction sentences and were as attentive. This finding does not mean that toddlers were as likely to remember the items, integrate them, or abstract from them, but it does offer some support for the first option, that the hypothesis proposed by the error-driven learning model is incorrect.

Additional support that infants should have no problem integrating the induction phase successfully comes from a recent study with 28-months-old toddlers who were able to make use of an induction phase to infer the meaning of a novel word (de Carvalho, Dautriche, Fiévet, & Christophe, 2020, see also Yuan & Fisher, 2009). In the test phase of that study, toddlers were presented with a novel word in an ambiguous context (e.g., ‘he will dase’). When an induction phase dialogue contained this novel verb integrated within right-dislocated and intransitive sentences (“‘Heⁱ will dase, the dadⁱ! Really? He will dase?’”), toddlers interpreted the verb as intransitive in the test phase. However, toddlers who watched a dialog containing this verb in transitive contexts or right-dislocated contexts only, interpreted the novel verb as transitive. While these results support the idea that toddlers are able to remember and integrate an induction phase, they again do not mean that infants were as likely to abstract from the induction phase and deploy their predictions when encountering words that were absent from the induction phase. In addition, these findings are not directly comparable to ours because toddlers in our experiment were required to adapt their life-long syntactic bias to expect a noun following the context *la petite*, while toddlers in their experiment were only required to activate their representation of right-dislocated sentences.

If error-driven accounts of language learning are wrong in hypothesizing that younger children, whose representations of linguistic knowledge are less robust, show larger changes in their representation in response to error-signals, we need an alternative explanation to explain these results. One such possible explanation is that like other cognitive capacities resources (e.g., memory, executive functions, language processing, see Diamond, 2013), the ability to predict improves with age. This could be the case if, for

example, prediction relies on other such resources, or if the improvement in functional connectivity or availability of neural resources leads to improved ability to predict (see Huettig, 2015).

Conclusion

To conclude, we found that three- to four-year olds show adaptation of their expectations for a noun or a verb following the ambiguous syntactic context *la petite*, as exhibited by a higher likelihood to interpret the homophone as a verb for three- to four-year olds in the verb condition compared to three- to four-year olds in the noun condition. This result is comparable to a previous study which found that three- to four-year olds show adaptation of their expectations for a noun or a verb following the syntactic context *la petite* when inferring the meaning of novel words. Thus, whether the next sentence contains an ambiguous word they know (processing) or a novel word (learning) - children rely on their adapted expectations to predict the category to which the word following *la petite* will belong.

Two-year olds did not show the same effect as three- to four-year olds. Thus, our results do not directly support the hypothesis, put forward by error-driven models, that younger children adapt more than older children in response to an error-signal. However, there are alternative explanations that could account for the failure of two-year olds in our task: their limited cognitive skills that would be necessary to integrate the induction phase, task demands, or a difficulty to override overall biases (i.e., expecting a noun after *la petite*). Further studies should find suitable ways to disentangle these possibilities.

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