Priming syntactic ambiguity resolution in children and adults

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Abstract

Adults use their recent experience to disambiguate ambiguous sentences: Structures that have recently been primed are favored in the resolution of ambiguity. Using a forced-choice task with a tablet, we asked whether 5-6-year-old French speaking children could also be primed in the resolution of attachment ambiguities, as well as two additional questions relating to the mechanism behind this effect: are they affected by the proportion of prime structures in the input, and are they affected by how surprising a prime is in context. We found that both children and adults can be primed to choose different interpretations for the same ambiguous sentence, and are sensitive to the proportion of structures in the input. We did not find an effect of surprisal of the prime on participants' selection of response or reaction times. This is the first study showing priming of ambiguous sentences at 5-6 years, suggesting that children, like adults, use recent experience as a source of disambiguating information.

Highlights

- 5-6-year-old children and adults showed priming of phrase attachment ambiguities
- The interpretation of the target also depended on the proportion of primes of each type in the input
- The choice of interpretation did not depend on how surprising a prime was in context

Keywords

Adaptation, Priming, Ambiguity, Language, Children

INTRODUCTION

Language contains ambiguities at multiple levels. To name a few, a sentence can be ambiguous *lexically*, such as in the case of homophones (e.g., "look at the *watch*" vs. "*watch* your child"); or *syntactically*, such as in cases where two different parsings of the same sentence are possible (e.g., "Someone saw the servant of the actress who was on the balcony" – who was on the balcony: the actress or the servant?). Adults are able to process these and other types of ambiguities by rapidly utilizing and integrating multiple sources of information, such as verb bias, contextual constraints, and prosody (Gibson & Pearlmutter, 1998). Learning to process a language thus entails learning to utilize these sources of information to converge on one of several possible meanings or interpretations, preferably the one intended by the interlocutor (MacDonald, Pearlmutter, & Seidenberg, 1994).

Children begin to use different sources of disambiguating information at different ages. For example, unlike adults, 8-12-year-old children do not yet seem to use semantic plausibility to disambiguate temporary ambiguous sentences (Traxler, 2002). *Verb bias* - the probability that a verb will appear with one construction relative to others - can be used by both 4-5-year-old children and adults to disambiguate locally ambiguous sentences such as "put the frog on the napkin in the box". In the same experiment, and unlike adults, 4-5-year-old children could not use extra-linguistic context (e.g., whether there are two frogs in the scene, only one of which on a napkin) to interpret such ambiguous sentences (Snedeker & Trueswell, 2004). This suggests that the ability to use extra-linguistic context has a longer developmental time-course than the ability to use verb-bias. In contrast, the ability to use other sources of disambiguating information may develop quite early. Children as young as 3 years old can already use gestures to disambiguate lexical ambiguities (e.g., "bat", Kidd & Holler, 2009), and prosody has been found to allow ambiguity resolution in the case of noun-verb homophones by infants as young as 18 months (Carvalho, Dautriche, Lin, & Christophe, 2017). In other words, the ability to use some sources of disambiguating information has a longer developmental time-course than the ability to use others, with children learning to utilize and combine different sources of information as they grow older.

Here, we focus on one important source of information for ambiguity resolution - recent experience: whether a specific structure was recently used or not. Recent experience has been found to affect adults' processing of ambiguities, such that structures that have recently been encountered are favored in the resolution of ambiguity (Boudewyn, Zirnstein, Swaab, & Traxler, 2014; Branigan, Pickering, & McLean, 2005). The effect of recent experience on the processing of ambiguous sentences has not been systematically studied in children, and it is therefore an open question whether children can and do use this source of information to resolve ambiguities.

There is abundant evidence that children do tend to reuse syntactic structures that were recently used by their interlocutor, a phenomenon known as *syntactic priming*. However, almost all studies focused on production and not on comprehension (e.g., Messenger, Branigan, McLean, & Sorace, 2012; Peter, Chang, Pine, Blything, & Rowland, 2015; Rowland, Chang, Ambridge, Pine, & Lieven, 2012; Shimpi, Gámez, Huttenlocher, & Vasilyeva, 2007). In production priming studies, a child is typically found to be more likely to use a specific construction (e.g., the passive voice) if it was recently used by an experimenter. Priming in children's comprehension was notably tested in one series of studies (Snedeker & Thothathiri, 2008a,b). Snedeker and Thothathiri showed that it is possible to prime 3-4 year-old children's comprehension by manipulating their expectation to encounter either a double-object or a prepositional object construction. Children heard sentences such as "Give the bird the dog bone" or "Give the birdhouse to the sheep", while watching a display which included both the bird, the dog bone, the birdhouse and a distractor. Snedeker and Thothathiri measured the proportion of looks to the bird and the birdhouse before the disambiguating information was heard, and found that children who were primed with a double-object construction were more likely than children who were primed with a prepositional-object construction to look at the bird rather than the birdhouse; in other words, children were primed to interpret the noun phrase following the verb as the recipient rather than as the direct object.

There is evidence, then, that priming affects children's syntactic processing in both production and comprehension; however, it has not been shown that priming in children can also affect ambiguity resolution (we discuss below one study that found an effect only in 9, but not 6-year-old children). In other words, it is possible that priming can create an expectation for one structure over another when the sentences have similar meaning but differ in their structure (as in the dative alternation), but that children cannot be primed to give one of two different interpretations to the exact same sentence. In the current study we thus ask whether children and adults are affected by their recent linguistic experience in interpreting sentences that contain prepositional-phrase attachment ambiguities.

We focus on prepositional-phrase attachment ambiguities, which arise when a prepositional phrase can modify either the verb or the object noun in a sentence. An example for one such ambiguous sentence is: "the girl is tickling the baby with the brush." On one interpretation of this sentence, the girl is using a brush to tickle the baby. Here, the prepositional phrase "with the brush" modifies "tickling", and therefore attaches to the verb phrase. We will refer to this interpretation as a verb-attachment interpretation. On the other interpretation, the baby being tickled is the one holding the brush. Here, "with the brush" modifies the noun phrase "the baby". We will refer to this as a noun-attachment interpretation. Recent experience of a resolution of this ambiguity towards one of these interpretations has been shown to affect interpretation of these ambiguities in adults (Boudewyn et al., 2014; Branigan et al., 2005) – but this has never been shown in children.

Brandt, Nitschke, and Kidd (2017) tested whether children can be primed in their interpretations of ambiguous German object relative clauses - which can be interpreted as agent-first or patient-first (e.g., *Wo ist die Krankenschwester, die die Malerin umarmt*? Can be understood as either "where is the nurse that the painter is hugging?" or "where is the nurse that is hugging the painter?"). However, they only found an effect of priming in nine-year-old, but not six-year-old children. They concluded that children in the younger age group might not have developed a fully abstract representation of object relative clauses yet, or were unwilling to accept priming of the dispreferred interpretation. The current study tries to overcome these challenges by choosing a different construction, which might be easier for young children to process, and by using a tablet device, where children are asked to touch the image that corresponds to the sentence they have heard, which might induce them to be more willing to accept the dispreferred interpretation (by creating more commitment to the prime when a physical response is required).

In addition to an effect of priming on children's interpretation of ambiguous sentences, our design is meant to answer two additional questions relating to the way recent experience affects both children and adults. It has previously been shown that adults quickly converge on the frequency of syntactic structures in the input (Fine, Jaeger, Farmer, & Qian, 2013; Jaeger & Snider, 2013). We ask whether children also adapt their expectations to the proportion of prime sentences of a particular type in their input. We use a design with three different conditions to manipulate the relative proportion of the two possible interpretations (noun-attachment and verb-attachment primes). One group is primed with noun-attachment primes throughout the experiment (100%

noun-attachment); another group is primed with verb-attachment primes throughout the experiment (0% noun-attachment); and the third with alternating verb-attachment and noun-attachment primes (50% noun-attachment). Based on the adult literature, we expect that children and adults will be sensitive to the distribution of structures in their input, and will therefore be more likely to select the noun-attachment interpretation when the proportion of noun-attachment primes is greater.

The second question relates to an even more fine-grained look at how language users converge on the statistics of the input – their treatment of surprisal. The more surprising a linguistic structure is in a given context, the larger the change the language users have to make to their future predictions if they are to accommodate this new information. The amount of surprise a speaker shows upon encountering a syntactic structure x can be quantified using the formula: *Surprisal*(x)=-log(p(x)), where p(x) is the probability of occurrence of the structure x. At the beginning of the experiment, surprisal reflects expectations based on a lifetime of linguistic experience. As participants' exposure to the structures is manipulated over the course of the experiment, their expectation to encounter this structure increases or decreases, and surprisal changes accordingly. For example, Fine et al. (2013) manipulated the proportion of an infrequent structure such that in the context of the experiment it became as frequent as a normally more frequent structure. They found that participants rapidly came to expect the rare structure as much as they expected the more frequent one. They observed a linear relationship between reading times and the surprisal of the structure (-log(p(x)). Therefore, in addition to asking whether children are sensitive to the proportion of each structure in their input overall (between conditions), we also ask whether the effect of experience is logarithmic, as previously found in adults (e.g., Fine et al., 2013) - that is – we examine adults' and children's reaction to surprisal.

Our manipulation of the proportion of primes in the input enables us to calculate the surprisal for each and every trial. If participants' responses are affected by surprisal, then there should be a linear relation between surprisal and the probability of choosing one interpretation over the other. The surprisal at the first trial is -log(p(prime-structure)), in which p(prime-structure) is the probability of encountering that structure in participants' previous experience. We calculated the initial probability of each structure using an online norming study with no priming (see the methods section for details of the norming study). Verb-attachment interpretations were selected 85% of the time when no priming was involved, and noun-attachment 15% of time. To compute surprisal at each trial, we need to take into account both this previous bias, and the number of primes of each type that the participants have seen during the experiment. If we took into account *only* the proportion of primes of each type seen during the experiment, but not the initial bias, the probability of NA would be computed as the proportion of NA primes, and the corresponding surprisal, being -log(p(NA)), would therefore be -log(countNA/(countNA+countVA)). To create a combined measure of the initial surprisal and the one generated by the recent experience, we created the following formula: for NA primes, surprisal= -log ((count NA + 0.15)/ (count NA + count VA + 1)), and for VA primes, surprisal= -log ((count VA+0.85)/ (count NA + count VA + 1))[1]. In the first trial, before any prime has been seen, and both count_NA and count_VA are at 0, surprisal is therefore equal to -log(0.15)=2.503 for a noun-attachment prime, and -log(0.85)=0.234 for a verb-attachment prime. See figure 1 for the amount of surprisal for each trial in each condition, and see OSF link for our analysis scripts.

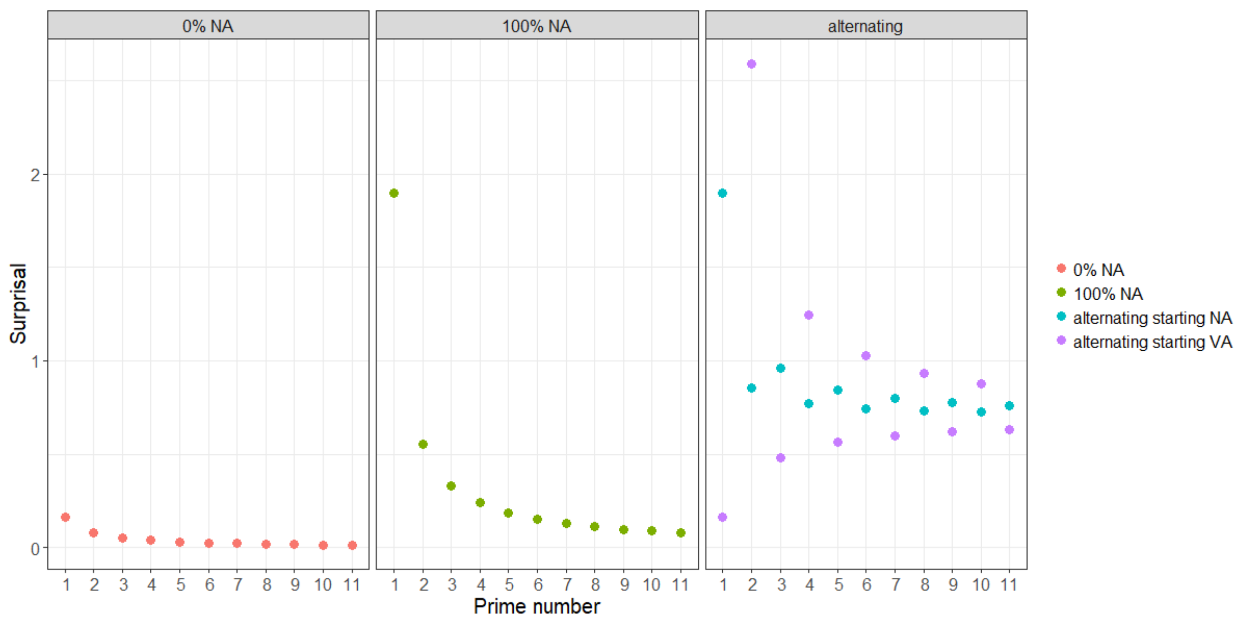

Figure 1: Predicted surprisal plotted against prime number for each of the different conditions. For the 0% noun-attachment condition (left panel), the first prime is a verb-attachment prime, the more frequent structure. Surprisal therefore starts low and continues to decrease. For the 100% noun-attachment condition (middle panel), the first prime is a noun-attachment prime, the less frequent structure. Surprisal therefore

[1] Our initial pre-registered analysis was based on the analysis in Jaeger & Snider 2013, and calculated surprisal slightly differently: -log ((count NA+0.5)/ (count NA + count VA + 1)) instead of our -log ((count NA+0.15)/ (count NA + count VA + 1)). We consider the latter calculation more adequate, given the bias towards verb-attachment interpretations that we measured in our norming study. See the OSF link for more details about the pre-registered analysis and the results it yields.

starts quite high and then decreases. For the alternating condition (right panel), for participants who have started with a verb-attachment prime (purple dots), surprisal is initially low, but then abruptly rises after the second prime, a noun-attachment prime, which is even more surprising in light of the previous prime. For participants who started with a noun-attachment prime (blue dots), surprisal is initially high, but then drops after the second prime, a verb-attachment prime.

We test both children and adults, and expect both groups to show all three hypothesized effects: overall syntactic priming, cumulative priming and a linear relation between proportion of noun-attachment responses to surprisal. Our use of a tablet device enables us to measure not only the final choice of interpretation, but also reaction times. We expect the choice of a verb attachment interpretation to be (1) slower after a noun attachment prime, (2) slower the more noun-attachment primes are in the input, and (3) slower the more surprising the prime is (as manifested by an interaction between surprisal and prime). We have no prediction as to whether children and adults will differ in the size of any of these effects. If children are able to understand the sentence - that is, process the error-signals of the primes - to the same extent as adults, they should show the same priming effects as adults. They might even show a bigger priming effect, as would be predicted by an error-driven learning account, if children's representations are not as robust as adults, and are thus more easily changed in the face of new evidence. Indeed, it was previously found that the effect of mismatch between prime and verb bias is stronger in children than in adults (Peter et al., 2015). If children are less likely than adults to understand the prime sentence or to accept it as a possible interpretation, then they might show smaller effects. An absence of a priming effect in children could be interpreted as an inability to use recent structural information in the interpretation of ambiguous sentences, thus suggesting that this ability takes longer to develop, compared to the use of other sources of information, such as prosody.

METHOD

Participants

81 5-6 year-old French-speaking children (mean age 69 months, 55 girls) from medium to high socio-economic schools in Paris were tested in a quiet room at their preschool. Parental consent was obtained before testing. 80 university students were tested at our lab. They received $2 for their participation.

Exclusion. We excluded bilinguals (2 children), children who chose alternating responses throughout (2 children), and one child who, by her own admission, chose wrong answers on purpose – just to see what happens. Two pairs of items in two of the 100% noun-attachment prime lists were programmed incorrectly (participants saw a prime instead of a target in one target trial); this was fixed mid-testing. These trials were removed only for these first participants. We also removed target trials were participants made the wrong choice on a prime trial (e.g., when the sentence was "the girl is tickling the baby with the brush" they chose a picture of a girl watching a baby paint rather than tickling it with a brush - these trials amounted to 66 trials for children, and 5 trials for adults – 7% of trials for children and 0.6% of trials for adults). We removed six more children's trials for which the experimenter indicated in the log that the child was distracted. We calculated the percentage of correct responses on all non-ambiguous trials (training, filler and prime sentences). No participant had an accuracy of less than 80%; consequently, no participant was removed due to low accuracy.

Materials

11 prime-target pairs were constructed. All prime and target sentences included two characters and an object, using the preposition *avec* ("with"). For example, *la fille chatouille le bébé avec le pinceau*, "the girl is tickling the baby with a brush", is ambiguous in French (as it is in English) as to which character is holding the object. The sentences were ambiguous with respect to whether the prepositional phrase attached to the verb or the noun. We also had six unambiguous filler sentences and three practice items, which did not include the preposition *avec* ("with"). Prime and target sentences shared the same verb, as a recent meta-analysis found overall larger priming effects when lexical overlap exists (Mahowald, James, Futrell, & Gibson, 2015, though lexical overlap might be less important for children, see: Peter, Chang, Pine, Blything, & Rowland, 2015).

We counterbalanced across participants which of the sentences served as the prime and which served as the target. We created 16 pseudo-random lists, four for the 100% noun-attachment primes condition, four for the 0% noun-attachment primes condition, and eight for the alternating condition. While this complicated the interpretation of order effects (since item identity and trial order are partially confounded), the app we used to run the experiment did not permit randomization for each participant, but instead necessitated fixed lists.

On each trial, two images were presented side by side, and then a cartoon girl ("Mandy") appeared in the space between them. When the participant touched Mandy, she would say the sentence, and the participant was asked to touch the image that corresponded to it. The sentences Mandy said were recorded by a native speaker of French (the last author), who used a prosodic contour meant to be consistent with both the noun-attachment and verb-attachment interpretations. To ensure that this was indeed the case, and to compute the overall bias of our items in French, we ran an online survey with 77 native French speakers. The respondents received only target pairs, that is, they were never primed. Each participant heard only one instance of the same verb – that is, 11 possible sentences rather than the full set of 22. They were asked, for each pair of images, which of the images fit the sentence they had heard. The bias data was used to calculate surprisal and control for the bias of the target. See appendix 1 for a full table of the target sentences, including bias information. See OSF link for the recorded sentences and images.

In the actual experiment, on prime trials, only one of the images corresponded to the sentence, while the other image (the foil) displayed the same characters and the same object but not the same action, and thus clearly did not match the sentence. In target sentences, both images matched the sentence (see Figure 2 for a sample prime-target pair).

a)

b)

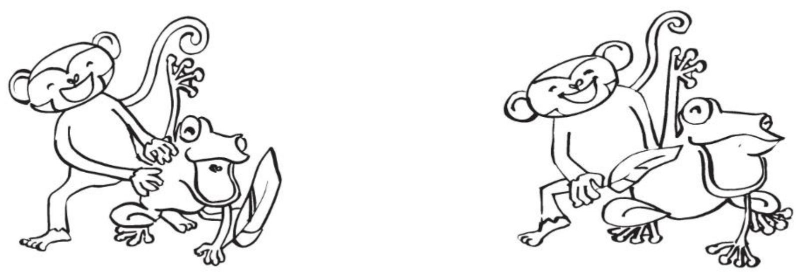

Figure 2: example of a prime-target pair

a) A prime trial: *La fille chatouille le bébé avec le pinceau* (“the girl is tickling the baby with the brush”). Since the image on the left does not match the sentence, the participant will be forced to select the image on the right, which is the noun-attachment interpretation (the girl is tickling a baby who is holding a brush). b) A target trial: *Le singe chatouille la grenouille avec la plume* ("the monkey is tickling the frog with the feather"). On the left, the noun-interpretation (the monkey is tickling a frog who is holding a feather), and on the right a verb-attachment interpretation (the monkey is using a feather to tickle the frog). Both images match the sentence.

Design

Participants were randomly assigned to one of three input conditions: 100% noun-attachment primes (no verb-attachment primes), 0% noun-attachment primes (all verb-attachment primes), and a 50% noun-attachment primes condition (alternating, every two noun-attachment prime trials were separated by exactly one verb-attachment prime trial, and possibly a filler trial). There were 19 children and 20 adults in the 100% noun-attachment condition; 22 children and 20 adults in the 0% noun-attachment condition; and 40 children and 40 adults in the alternating primes condition. Running twice as many subjects in this condition was necessary for counterbalancing (i.e., 20 children began with a verb attachment and 20 with a noun attachment).

Procedure

Children were tested individually in a quiet room in their school, wearing headphones, with an experimenter who could not see the display on the tablet (except in the training phase). They were asked to look at the two images, then touch Mandy, then touch the image she was talking about. They had three practice trials where these was only one correct answer. For these trials only, they were also asked to describe the images before touching Mandy. In these trials, if a child made an error, the experimenter explained why the response was incorrect. After the training phase, the children were told that they would now start the real game. Adults followed the same procedure in our lab. The entire task lasted about 20-25 minutes.

RESULTS

Overall priming

We first examined whether there was an overall priming effect for all participants. We ran a logistic mixed effect model using the software R (R core team, 2017) and the packages lme4 (Bates, Maechler, Bolker, & Walker, 2015) and lmerTest (Kuznetsova, Brockhoff, & Christensen, 2017). We used prime type (contrast coded, verb was the base) and age group (contrast coded, adults were the base), as well as an interaction between the two, as independent variables - to predict the likelihood of selecting a noun-attachment interpretation. Following Bates, Kliegl, Vasishth, and Baayen (2015), we first fit a maximal model including all possible random intercepts and slopes, and then ran a principal component analysis of the random effects structure to determine the number of variance components and correlation parameters supported by the data (using function rePCA from the package RePsychLing, Baayen, Bates, Kliegl, & Vasishth, 2015). This function identifies the most complex model supported by the data, and then, to simplify the model, it relies on comparisons of goodness of fit of nested models with likelihood ratio tests (LRTs). This allows for a robust random effect structure without including unnecessary random effects thereby losing power. Results are presented in table 1.

Table 1: Generalized linear mixed effect model for overall priming

variable	β	Std. Error	z	p
Intercept	-2.99	0.36	-8.25	<.001
Prime type (noun)	1.27	0.31	4.02	<.001
Age group (children)	0.50	0.36	1.37	.169
Interaction	-0.23	0.42	-0.55	.585

Across the three conditions and two age groups, we found an overall priming effect ($\beta = -1.27$, $SE = .31$, $p < .001$; see table 2 for means, SDs and Cohen's ds). Trials that were primed with a noun attachment prime were more likely to be followed by a noun-attachment choice on target trials, with no effect for age group and no interaction between prime type and age group. We ran two additional models for children and adults separately. The effect of priming was significant in both (children: $\beta = 1.05$, $SE = .32$, $p = .001$; adults: $\beta = 1.13$, $SE = .37$, $p = .002$). See table 2 for the effect size for the different groups, and fig. 2 for the distribution of results.

Table 2: Means (SDs) and Cohen's ds for the proportion of noun-attachment interpretation choices after different primes

	noun-attachment prime	verb-attachment prime	Cohen's d and CI
adults	0.187 (0.195)	0.114 (0.158)	0.41 [0.044, 0.774]
children	0.248 (0.148)	0.114 (0.143)	0.921 [0.542, 1.299]

Proportion of structures in the input

Next, we examined our second hypothesis, that is, that participants will be sensitive to the proportion of primes of each type in the input. We expected participants to choose more noun-attachment interpretations in the 100% noun-attachment primes condition than in the alternating condition. Likewise, we expected participants to choose more noun-attachment interpretations in the 50% condition than in the 0% noun-attachment primes condition. To examine this hypothesis, we ran two generalized linear mixed effect models. In the first model we compared the 50% and 100% noun-attachment primes conditions when taking into account only targets that were preceded by a noun-attachment prime (because the 0% noun-attachment condition does not contain any noun-attachment primes, and it is not possible to use test trials with verb-attachment primes in this comparison). We used condition (contrast coded, alternate condition is base) and age group (contrast coded, adults are base), as well as an interaction between the two, as independent variables to predict the likelihood to select a noun-attachment interpretation. Here too, we ran a principal component analysis on the random effects structure. Results are presented in table 3. The second model was identical, except that it focused on responses following a verb-attachment prime in the 50% condition vs the 0% noun-attachment primes condition (again, the reason for this is that the 100% condition contains no verb-attachment primes; see results in table 4). Note that each of these two models is run on half the number of trials as our first model, which looked at all conditions combined; these models might therefore have less statistical power to detect a true effect.

Table 3: logistic mixed effect model for cumulative priming, comparison between the 100% NA and 50% groups (trials with NA primes only)

variable	β	Std. Error	z	p
Intercept	-2.022	0.298	-6.789	<0.001
Condition (100%)	0.673	0.337	2	0.046
Age group (children)	0.328	0.366	0.898	0.369
Interaction	-0.280	0.480	-0.584	0.559

Table 4: logistic mixed effect model for cumulative priming, comparison between the 0% NA and 50% groups (trials with VA primes only)

variable	β	Std. Error	z	p
Intercept	-2.772	0.498	-5.567	<0.001
Condition (0%)	-0.696	0.613	-1.136	0.256

Age group (children)	0.411	0.506	0.812	0.417
Interaction	0.383	0.765	0.500	0.617

As can be seen in tables 3 and 4, we found a condition effect for noun-attachment primes (β = 0.673, SE = 0.337, p = .045). Target trials that were preceded by a noun-attachment prime were more likely to produce noun-attachment responses in the 100% noun-attachment primes condition than in the 50% condition. The effect of condition was not significant for verb primes (β = -0.696, SE = 0.613, p = .256). There was no effect of age group nor an age group by condition interaction for either model. We ran additional models for the comparison between the 50% condition and the 100% noun-attachment primes condition, separately for children and adults. The effect of condition was not significant in each group separately (children: β = 0.295, SE = .251, p = .239; adults: β = 0.683, SE = .417, p = .102), perhaps because of a lack of power, since each model runs on only half the data (that is, a quarter of all data collected). See table 5 for means, SDs and Cohen's ds, and figure 3 for a visualization of the results for the different conditions and prime types (created using package ggplot2 in R, Wickham, 2016).

Table 5: Means (SDs) and Cohen's ds for the proportion of noun-attachment interpretation choices after different primes in the different conditions

	noun-attachment prime			verb-attachment prime		
	50% condition	100% noun condition	Cohen's d & CI	0% noun condition	50% condition	Cohen's d & CI
adults	0.160 (0.173)	0.242 (0.227)	0.426 [-.127, 0.98]	0.087 (0.178)	0.128 (0.148)	-0.256 [-0.81,0.294]
children	0.233 (0.156)	0.281 (0.128)	0.327 [-.234, 0.888]	0.093 (0.091)	0.125 (0.166)	-0.22 [-0.752, 0.312]

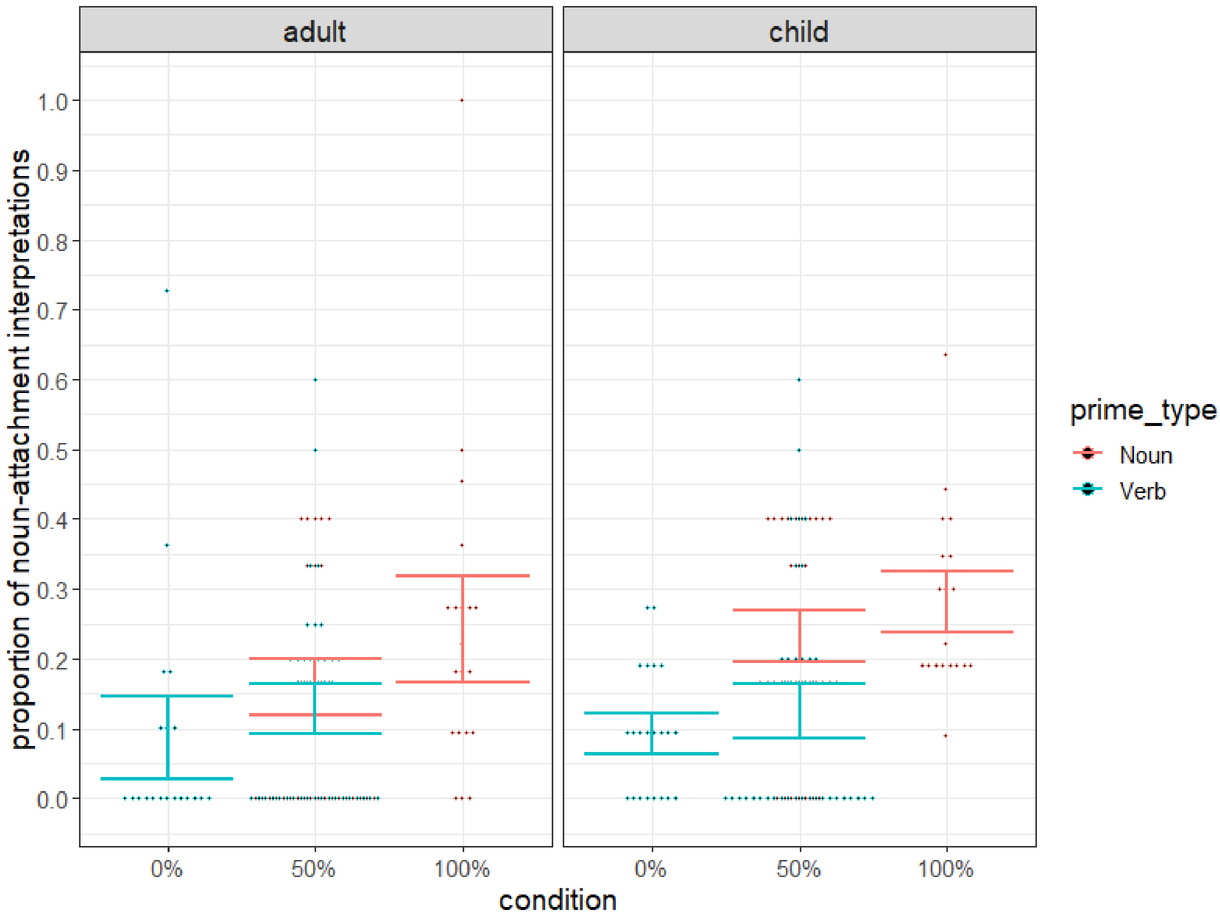

Figure 3: Proportion of noun-attachment interpretation by age, condition and prime type (each dot represents the mean prroportion of noun-attachment per participant and prime type, error bars represent 1.5 standard errors from the mean)

Surprisal

Finally, we tested our third hypothesis, namely, that surprisal would predict the proportion of noun-attachment responses. This hypothesis predicts that more surprising primes will produce larger priming responses. In our case the items were all biased towards the verb interpretation, so noun primes would be more surprising, especially when encountered the first few times (see figure 1 in the introduction for a visualization of the changes in surprisal for both types of primes in the three conditions). Note, however, that there is an unavoidable confound in our experimental design between cumulative primes and surprisal. Since there are exactly two options, noun attachment and verb attachment, high NA prime surprisal logically means that the baseline probability of a VA (before the NA prime was even shown) has to be high. On average, then, participants should be more likely to select the VA interpretation of the target when VA probability is high, as is the case after many VA primes, thus making VA surprisal low. Put in other words, for a participant who has seen many VA primes, VA surprisal would be low, but the effect of cumulative priming should make them more likely to select a VA interpretation in the target than a participant who has seen less VA primes. For this reason, it is important to control for cumulative priming in the analysis. An effect of surprisal over and above an effect of cumulative priming should manifest as an interaction between surprisal and prime type when controlling for cumulative priming - though in our experiment there are not many trials in which surprisal and cumulative priming are not completely confounded, and we might therefore be underpowered to discover such an effect, if it exists. For this analysis, we will look at both choice of interpretation, and reaction times - we describe each below.

Choice of interpretation. To test the effect of surprisal on the choice of interpretation, we ran a mixed effects logistic regression model, which included the following predictors: prime type (contrast coded, noun as base), age group (contrast coded, adults as base), cumulative primes (number of NA primes seen before the current prime), surprisal, and a triple interaction between age group, prime time and surprisal (as well as all first order interactions). We also controlled for target bias, as measured by our online norming study (our preregistered analysis did not include controlling for the bias of the target, as we did not plan to collect this information at the time). As before, we ran a principal component analysis on the random effects structure. See table 6 for the full results.

Table 6: Generalized linear mixed effect model for surprisal

variable	β	Std. Error	z	p
Intercept	-2.68	0.60	-4.48	<.001
Age group (child)	0.33	0.49	0.68	0.499
Prime type (VA)	-1.69	0.77	-2.19	0.028
surprisal	0.13	0.34	0.38	0.706
cumulative number of NA primes	0.03	0.09	0.39	0.694

Target bias	4.34	0.76	5.71	<.001
Age group (child) by prime type (VA)	0.25	0.81	0.31	0.757
Age group (child) by surprisal	-0.34	0.57	-0.59	0.555
Prime type (VA) by surprisal	1.31	1.18	1.11	0.268
Age group by prime type by surprisal	-0.61	1.30	-0.47	0.638

As can be seen in table 6, there was an overall priming effect (β = -1.69, SE = 0.77, p = .028): there were more NA responses after a NA prime than after an VA prime. There was a significant effect of the bias of the target (β = 4.34, SE = 0.76, p < .001). The more biased towards an NA interpretation the targets were, the more likely the participant was to select an NA interpretation in the target. None of the other effects were significant.

Reaction times. We ran the same set of predictors in a second model, in which the dependent variable was not the choice of interpretation, but the logged reaction time of each trial - when considering only trials for which the participant chose the VA response (we chose to only focus on these responses since there was a larger number of them – 80.1% of responses, and they had much lower variance – standard deviation for VA responses was 1895 ms, versus 3368 ms for NA responses). We used participants' average RT from fillers and practice items as a covariate in the analysis of the critical trials (this control factor was not included in the preregistration). As this is a linear rather than a logistic regression, to calculate p values, we used the function mixed() from the package afex (Singmann, Bolker, Westfall, & Aust, 2018). This function estimates a full model and restricted models in which the parameters corresponding to one effect term are withheld. Tests statistics are based on comparing the full model with the restricted models.

Table 7: Linear mixed effects model for surprisal effects on logged RT

variable	β	Std. Error	χ2	p
Intercept	8.346	0.038	22.565	< .001

Age group (grand mean)	-0.087	0.035	6.13	0.01
Prime type (NA)	-0.078	0.032	5.5	0.02
surprisal	0.032	0.019	2.88	0.09
RT on filler and practice trials	0.076	0.013	30	<.001
cumulative number of NA primes	-0.013	0.006	4.22	0.04
Target bias	0.076	0.018	14.45	<.001
Age group (child) by prime type (VA)	0.058	0.041	1.97	0.16
Age group (child) by surprisal	-0.056	0.022	6.22	0.01
Prime type (VA) by surprisal	-0.008	0.049	0.03	0.87
Age group (child) by prime type (VA) by surprisal	-0.021	0.058	0.13	0.72

As can be seen in table 7, there was an overall effect of age group (β = -0.09, SE = 0.04 , p = .01). Children were faster to respond than adults, possibly suggesting that children's responses were less deliberated and more automatic. There was a significant overall priming effect (β = -0.08, SE = 0.03, p = .02): VA responses were faster after a VA prime than after an NA prime. There was a marginally significant effect of surprisal (β =0.03, SE = 0.02, p = .09): responses were slower after surprising primes - with no significant interaction with prime type. We return to this effect in the discussion. There was a significant effect of the bias of the target (β = 0.08, SE = 0. 02, p < .001). The more biased towards an NA interpretation the items were, the slower the participant was to select an VA interpretation. There was a significant interaction between age group and surprisal (β = -0.06, SE = 0.02, p = .01): a simple slopes test revealed that the effect of surprisal was only marginally significant for adults, but not children (adults: β =0.03, SE =0.02, p = .081; children: β =-0.02, SE =105, p = .369). None of the other factors or interactions were significant.

To summarize both analyses, participants were more likely to choose a VA target, and faster when choosing a VA target, after a VA prime than after a NA prime. The bias of the target affected the choice of interpretation and reaction times when selecting an VA response. More NA-biased target sentences produced more NA responses and a slower choice of a VA response. We did not find the expected interaction between prime type and surprisal in either choice of response, or reaction times for VA responses.

DISCUSSION

The current study explored adults' and children's use of the recent distribution of syntactic structures in the input to interpret ambiguous sentences. We examined the effect of recent experience at three grain sizes: First, do children and adults show overall syntactic priming effects in interpreting ambiguous sentences? Second, are they taking into account the proportion of the two syntactic structures in their input? And third, are interpretations affected by how surprising a structure was, when both its prior frequency and its frequency within the experiment are taken into account?

We found an overall priming effect for both children and adults, with no interaction between age group and priming. The results for adults replicate previous studies (Boudewyn et al., 2014; Branigan et al., 2005). For children, this is the first piece of evidence that children as young as 5-year-old can be syntactically primed to select different interpretations for the same sentence. While there was one previous study that primed interpretations of ambiguous sentences, it only found an effect of priming in nine but not six-year-old children (Brandt et al., 2017). The authors explained these results by suggesting that children in the younger age group might not have developed a fully abstract representation of object relative clauses yet, or were unwilling to accept priming of the dispreferred interpretation. One possible reason why we *were* able to prime young children in the current study, might therefore be that 3-5-year-old children can accept both interpretations of the ambiguous structures we used, as had been shown previously (Zimmer, 2017). Therefore, our result is consistent with Brandt and colleagues' suggestion that six-year-old children in their study were not primed because they have not yet fully developed representations of both options for disambiguating the sentences. The difference between our results and theirs could also be explained by methodological differences between the designs. Brandt and colleagues compare primed trials to a baseline with no priming, while we compare priming with one interpretation to priming with the other one - which may give rise to bigger differences. Also, in our study there was always lexical overlap between the verb of the prime and the target sentence (while in Brandt and colleagues there was an overlap of the noun but not the verb). Note however, that while all prime-target pairs had lexical overlap at the verb, our effects cannot be fully explained as a result of a lexical rather than structural priming: the cumulative priming effect we observed can only arise if priming is not only a result of the last prime, but also of previous primes (which did not share a verb with the target).

Our results therefore show that children can be primed not only to choose a specific syntactic structure in production as was previously found (e.g., Peter, Chang, Pine, Blything, & Rowland, 2015; Rowland, Chang, Ambridge, Pine, & Lieven, 2012), but also to interpret a sentence in two different ways. A previous set of studies has already shown that it is possible to syntactically prime children's comprehension - however, that study focused on how children's expectations for a specific structure impacted their lexical access at a point of local ambiguity (Thothathiri & Snedeker, 2008a,b), while we tested children's interpretation of fully ambiguous sentences.

The second grain size we looked at was convergence on the *proportion* of structures in the input. We hypothesized that both children and adults will show sensitivity to the distribution of syntactic structures in the input. Consistent with this hypothesis, we observed that both children and adults were more likely to select a noun-attachment interpretation in the all-noun-attachment primes condition than in the alternating condition. In contrast, in the comparison between the all-verb-attachment primes condition and the alternating condition, participants did not differ in their likelihood to select a verb-attachment interpretation. This finding is in line with previous studies on priming of the dative alternation: The more frequent prime type (double-object, in English) usually shows overall weaker priming (Jaeger & Snider, 2013). In the present study, similarly, the more frequent interpretation (verb-attachment) is less impacted by priming effects. The effect of condition for noun-attachment primes lends support to the idea that adults are able to converge on the actual distribution of structures in their input, as found for adults in previous studies (e.g., Fine & Jaeger, 2016; Fine et al., 2013) - and add to it the finding that children are just as sensitive to this distribution. These results also echo an additional finding from Brandt and colleagues (2017): They found a gradual increase in the proportion of patient-first interpretations of the ambiguous relative clauses from the first half of the prime phase to the second half of the prime phase. Overall, these results show evidence that children, just like adults, are sensitive to recent syntactic structures and capable of adapting their interpretation of ambiguous sentences to the likelihood of encountering these structures.

Our last hypothesis was that adapted prime surprisal will be linearly related to proportion of noun-attachment interpretations. We did not find such an effect on the choice of response - participants were not more likely to choose a NA response after a surprising NA prime than after a non-surprising NA prime. We also did not find this effect in their reaction times: Participants were slowed down by surprising primes when choosing a VA response - whether the surprising prime was a NA or a VA prime. This runs contrary to the hypothesis that they will be faster to select a VA target after a surprising VA prime but slower after a surprising NA prime. We interpret the main effect of prime surprisal with no interaction as being a simple processing cost of surprising events. When the prime was surprising, participants' choice of response was not affected, but they were delayed in choosing this response because they were still processing the previous trial. We also found an interaction between this effect and the age of participants. Adults were penalized more than children by surprising primes. This effect may be due to adults' conscious attempt to make sense of the task and provide the "correct response". This explanation is supported by the fact that children were overall faster in this task, suggesting that their responses were more spontaneous and less planned.

Why was a surprisal effect not found? One possibility is that the heavy bias towards a verb-attachment interpretation created experimental noise. When the prime was a verb-attachment prime, participants were likely to process the prime correctly. Noun-attachment primes, however, would have produced more variance. Even when selecting the correct response on a prime trial, participants, and especially child-participants, might still not have been able to accurately process, or accept the primed interpretation (similarly to Brandt et al., 2017). Future studies may attempt to prime a more balanced structure, or ensure that participants do accept the unpreferred interpretation. Another option was discussed in the results section – in our experiment there was an inevitable confound between surprisal and cumulative priming, with trials with lower adapted surprisal appearing after more primes of the same structure – future studies might be able to design an experiment which better dissociates these two factors. The third possibility is that surprisal effects are not as robust as previously believed. A recent study by Harrington and colleagues (Harrington Stack, James & Watson, 2018) explored rapid syntactic adaptation in adults as a function of context with a self-paced reading paradigm. They did not find syntactic adaptation effects, thus failing to replicate the study by Fine et al. (2013) - it is thus possible that we did not find such an effect because adaptation does not happen as quickly and accurately as was previously suggested by Fine et al. (2013). Our failure to find an effect of surprisal as expected, prevents us from concluding anything about developmental differences between children and adults (or lack thereof) in their syntactic adaptation.

In the current study, we focus on recent experience as a source of information for disambiguating sentences. The question of whether children can use recent experience to adapt their interpretations of prepositional phrase attachment is especially interesting in light of Snedeker and Trueswell's (2004) finding that children are only sensitive to linguistic but not extra-linguistic context for disambiguating sentences, while adults are sensitive to both cues. They suggest that children commit to one analysis of the sentence and plan their actions during the early stages of sentence processing, when lexical information is more potent than referential cues, and are then unable to revise these plans in light of late arriving information about referential context. We can think of two (non-mutually-exclusive) reasons why we *did* find priming in children's interpretation despite the fact that children of this age may find it hard to revise their interpretations. First, it might be that the prime sentence induces a change in children's preferences that happens before their selection of response. Chang, Dell, and Bock (2006) suggested that the processing of a prime sentence triggers changes to the underlying model a language user relies on for language processing. The changes induced by the prime sentence will have then taken place before the introduction of the target sentence. Another reason might be related to the implementation of a touch-screen protocol. The tablet interface might encourage children to carefully examine the scene before touching the tablet to make their choice. A recent study compared three techniques (looking, pointing, touching) with comparable materials, and concluded that a tablet-based paradigm compared favorably with an eye-tracking and a story-book paradigm in the context of word-recognition (Frank, Sugarman, Horowitz, Lewis, & Yurovsky, 2016). Additionally, they also found that more children finished the task when it was on a tablet - similarly we had no participant drop out, despite the length of the task (about 25 minutes). This fun and portable low-cost setup can thus be used in further research investigating diverse process of language acquisition.

Recent experience is not the only source of disambiguating information available. Factors like prosody can also affect the preference of one structure over the other. In the current study, prosody was meant to allow for both possible interpretations by using one intonation contour for the entire sentence. It has previously been shown that whereas the presence of acoustic boundary cues in two-phrases-prosody sentences results mostly in a two-phrases grouping (a noun-attachment interpretation), the absence of acoustic boundary cues does not necessarily result in a one-phrase grouping (a verb-attachment interpretation, Meyer, Henry, Gaston, Schmuck, & Friederici, 2016). When there is only one prosodic unit, then, participants may recruit other sources of information to disambiguate (in our case both recent and long-term experience). As has been discussed in Jaeger and Snider (2013), it is possible that speakers also monitor their own choices and self-prime. Therefore, a participant who tended to accept a noun-attachment interpretation early on, either because the first sentence they encountered was more noun-attachment biased or because of recent experience outside the experiment, might have been more likely to perpetuate their choice. The current study did not control for self-priming, nor the specific effect of some constructions, but such effects should be examined in depth in future studies.

This is the first study showing priming of interpretations of ambiguous sentences in both adults and children, using the exact same protocol, thus making the results comparable between age groups. We found that already at 5-6 years of age children can be syntactically primed to choose different interpretations for the same ambiguous sentence, and are sensitive to relative proportions of different structures in the input, just like adults. This suggests that adaptation to the proportion of structures is conversation is not a late emerging phenomenon, the result of a life-long expertise, but also exists in much more impoverished contexts (a tablet game when the speaker is not responding to the participant), and in novice language users – though research on younger children is needed in order to establish the developmental time-course of this ability.

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Appendix 1: stimuli

id	sentence	verb	Bias (% choice of noun attachment image)
1	Le garçon fait un bisou à la fille avec son doudou	fait un bisou	0.429
2	Le prince fait un bisou à la princesse avec la peluche	fait un bisou	0.143
3	Le garçon bouscule la fille avec la trotinette	bouscule	0.15
4	Le prince bouscule la princesse avec le vélo	bouscule	0.472
5	Le singe chatouille la grenouille avec la plume	chatouille	0.074
6	La fille chatouille le bébé avec le pinceau	chatouille	0.037
7	Le chat tape la souris avec le fromage	tape	0
8	Le singe tape la grenouille avec le bâton	tape	0.138
9	La dame envoie la lettre avec le pigeon	envoie	0.222
10	Le garçon envoie le message avec la flèche.	envoie	0.607
11	Le garçon touche la fille avec le parapluie	touche	0.029
12	Le singe touche la grenouille avec un balai	touche	0.143
13	Le garçon regarde la fille avec les jumelles	regarde	0.103
14	Le roi regarde la reine avec la loupe	regarde	0.167
15	Le garçon tire le chat avec la laisse	tire	0
16	La fille tire le cheval avec corde	tire	0.042
17	La fille lave le chien avec une éponge	lave	0.043
18	Le garçon lave le cheval avec une brosse	lave	0
19	Le garçon caresse la fille avec une plume	caresse	0.074
20	La fille caresse le chat avec le pinceau	caresse	0.034
21	Le garçon pousse la fille avec un carton	pousse	0.129
22	Le roi pousse la reine avec le balai	pousse	0.32

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