1. Introduction

Learning word meanings can be a very complex task for toddlers during their daily life. Toddlers need to extract word forms from the speech stream and associate them with possible meanings in their environment. But what kind of information can children use when they need to identify the meaning of a novel word? The syntactic bootstrapping hypothesis (Gleitman, 1990; Landau & Gleitman, 1985; see also Fisher, Hall, Rakowitz, & Gleitman, 1994; Fisher, 1996) proposes that having access to the syntactic structure of sentences can help children to discover the meaning of novel words. According to this hypothesis, syntax can serve as a “zoom lens” to help learners figure out which part of the world is being talked about, and hence to identify candidate meanings for novel words. In other words, the range of syntactic environments in which a given word occurs can be informative about its meaning (see Gillette, Gleitman, & Lederer, 1999).

In the simplest case to illustrate this idea, it has been shown that around the age of two, children are able to learn that a novel word such as “larp” refers to an action, when listening to sentences in which it appears as a verb, as in “He is larping that”; but when exposed to sentences like “This is a larp” in which “larp” appears in a noun position, they learn that “larp” refers to an object (e.g., a baby). This suggests that children exploit the syntactic frames in which novel words occur to infer their possible referent. Going further, it has been shown that toddlers can also learn that a novel verb such as “blicking” refers to a causal action between two participants when listening to transitive sentences such as “She is blicking the baby”, but they do not make the same inference when listening to intransitive sentences such as “She is blicking” (Yuan & Fisher, 2009; Yuan, Fisher, & Snedeker, 2012). In Ferguson, Graf, and Waxman (2014), 19-month-olds exposed to sentences like
“The dax is crying” were able to infer that “dax” referred to an animate entity (i.e., a novel animal), because it appeared in the subject position of a verb that requires an animate agent; but when exposed to sentences like “The dax is right here”, they did not show any preference for the animate entity at test. Taken together, these studies show the important role played by syntactic structure to assist language acquisition: at an age when toddlers do not have an extensive vocabulary yet, the syntactic structure of sentences helps them to discover the meaning of novel words. The question that arises is how toddlers manage to access the syntactic structure of sentences before acquiring an extensive vocabulary.

A potential cue that has triggered a great deal of interest is phrasal prosody: the rhythm and melody of speech. Across the world’s languages, the prosodic organization of speech is such that every prosodic phrase boundary is always aligned with a syntactic constituent boundary (Nespor & Vogel, 1986; Shattuck-Hufnagel & Turk, 1996), although the reverse is not true, since many syntactic boundaries are not marked prosodically. Crucially, however, prosodic information such as phrase-final lengthening, pitch contour variations and pauses between prosodic units may allow young listeners to find the boundaries between some of the syntactic constituents of a sentence, even in the absence of a very extensive vocabulary (Christophe, Millotte, Bernal, & Lidz, 2008; Morgan & Demuth, 1996; Morgan, 1986). This ability to exploit phrasal prosody to identify syntactic constituent boundaries, in addition to the perception of function words (Halle, Durand, & de Boysson-Bardies, 2008; Höhle, Weissenborn, Kiefer, Schulz, & Schmitz, 2004; Höhle & Weissenborn, 2003; Shafer, Shucard, Shucard, & Gerken, 1998; Shi, Werker, & Cutler, 2006; Shi & Melaçon, 2010), has been proposed to be potentially important for infants to bootstrap their way into syntactic acquisition, because phrasal prosody would allow them to identify some of the syntactic constituents in a sentence, while function words would allow them to determine the syntactic nature of these constituents (Christophe et al., 2008; Shi, 2014).

Supporting this hypothesis, several studies have shown that the perception of prosodic boundaries can indeed help adults and preschoolers to constrain their syntactic analysis and resolve syntactic ambiguities (in English: de Carvalho, Lidz, Tieu, Bleam, & Christophe, 2016; Kjellgaard & Speer, 1999; Snedeker & Yuan, 2004; Höhle & Weissenborn, 2003; Shafer, Shucard, Shucard, & Gerken, 1998; Shi, Werker, & Cutler, 2006; Shi & Melaçon, 2010), has been proposed to be potentially important for infants to bootstrap their way into syntactic acquisition, because phrasal prosody would allow them to identify some of the syntactic constituents in a sentence, while function words would allow them to determine the syntactic nature of these constituents (Christophe et al., 2008; Shi, 2014).

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experiment resulting in more than 50% (4 out of 8) unusable test trials with missing eye-tracking data. All participants were monolingual native French speakers. Parents signed an informed consent form. This research was approved by the local ethics committee.

2.1.2. Materials

Eight pairs of French noun-verb homophones likely to be known to young children (Kern, 2007; Veneziano & Parisse, 2010, 2011) were selected to create eight pairs of experimental sentences. For each pair of homophones, two sentences were created: one using the ambiguous word as a noun (the noun prosody condition, e.g., [le bébé souris, noun] [a bien mangé] – [The baby mouse, noun] [ate well]) and a second one using the ambiguous word as a verb (the verb prosody condition, e.g., [le bébé, noun] [sourit, verb à sa maman] – [The baby, noun] [smiles, verb to his mom]); see Appendix A for a complete list of test sentences). Sentences uttered in the noun prosody condition had a prosodic boundary after the ambiguous target word and sentences uttered in the verb prosody condition had a prosodic boundary before the target word, consistent with theoretical descriptions of the relationship between prosodic and syntactic boundaries (e.g., Jun, 2005; Nespor & Vogel, 1986). A female French native speaker (the last author) recorded all the sentences in a child-friendly register. Note that the prosodic boundaries associated with each prosodic condition were found to be naturally produced by naïve adult native speakers, even when they were not aware of the syntactic ambiguity (Millotte et al., 2007). To estimate toddlers’ knowledge of the ambiguous words, the parents of the participants in this experiment filled a short questionnaire. Overall, most toddlers understood most of the words used in this study (mean number of words comprehended: 13.8 out of 16; range: 10–16).

In addition to the experimental sentences, six filler sentences were created using target words that were unambiguously either a noun or a verb (e.g., noun: chat ‘cat’ in the sentence: [Le petit chat] [est très mignon] The little cat is very cute. vs. verb: lave ‘to wash’ in the sentence: [La vieille] [lave sa jupe] The old lady washes her skirt). To ensure that prosodic cues would be the only information available to participants to determine whether the ambiguous word was a noun or a verb,2 each test and each filler sentence was cut at the offset of the target word, and its end replaced by 1000 ms of babbles noise obtained by superimposing the end of all filler sentences. Thus, there was no lexical disambiguating information following the ambiguous word.3

There were 16 test sentences, 8 in the verb prosody condition and 8 in the noun prosody condition. Each participant was presented with only one member of each pair. Two counterbalanced lists of stimuli were used, each list containing four sentences in the noun prosody condition and four sentences in the verb prosody condition, plus four filler sentences (two of them having an unambiguous noun as a target and the other two having an unambiguous verb as a target). The order of sentences within each list was randomized, with the constraint that there were no more than two test sentences in a row and no more than two items from the same syntactic category in a row. To create the intermodal preferential looking task, for each sentence beginning (e.g., le bébé-/suwi/), two images were created, one depicting the noun interpretation of the ambiguous word (e.g., a mouse) and another one depicting its verbal interpretation (e.g., a baby smiling). For filler sentences, one image corresponded to the target word and the other was unrelated but represented a word from the opposite syntactic category. For instance, if a given filler target was a noun then the other image depicted an action. In total, 28 images (16 for the test sentences and 12 for the filler sentences) were created. An artist (the third author) provided line drawings of approximately equal size and complexity depicting each of these images. The experimental materials, both sentences and images, were the same as those used in de Carvalho et al. (2016) with preschoolers.

2.1.3. Acoustic analyses

In order to assess prosodic differences between the two conditions, acoustic measurements (duration and pitch) were conducted on the sentence beginnings (see Fig. 1).

The analysis of duration revealed a significant pre-boundary lengthening, as expected from the literature (Cooper & Paciá-Cooper, 1980; Delais-Roussarie, 1995; Jun & Fougeron, 2002; Millotte et al., 2008, 2007; Nespor & Vogel, 1986; Shattuck-Hufnagel & Turk, 1996; Soderstrom, Blossom, Foygel, & Morgan, 2008): the rhyme of the word placed just before the prosodic phrase boundary (marked in Fig. 1 by thick black lines) in the verb condition (e.g., last vowel -e/ from bebe) was lengthened by 98% compared to this same rhyme in the noun condition (403 vs 204 ms, see Table 1), and the rhyme of the word placed just before the prosodic phrase boundary in the noun condition (e.g., -if from /sui/) was lengthened by 35% compared to this same rhyme in the verb condition (427 vs 317 ms). Additionally, we also observed a phrase-initial consonant strengthening (see Fougeron & Keating, 1997): the onset of the target word in the verb condition (205 ms, phrase-initial position) was lengthened by 70% compared to the noun condition (121 ms, phrase-medial position).

The analysis of pitch contours also revealed significant differences between conditions, consistent with the literature describing French as having a tendency for a rising pitch contour towards the end of prosodic units (Di Cristo, 2000; Welby, 2003; Welby, 2006). A greater pitch rise was observed on the target word in the noun prosody condition (+127 Hz) compared to the verb prosody condition (+69 Hz). This difference is due to the fact that in the noun prosody condition the target word was in a phrase-final position, while in the verb prosody condition it was placed at the beginning of a phrase. For the same reasons, the word preceding the target word (e.g., “bébé”) had a greater pitch rise in the verb in the verb prosody condition (+184 Hz) than in the noun prosody condition (+21 Hz). All of these differences were significant (see Table 1).

2.1.4. Apparatus and procedure

Toddlers were tested individually in a sound-attenuated double-walled booth. They were sitting on their parent’s lap, facing a 42-in. screen positioned 70 cm away from them. Toddlers’ eye movements during the experiment were recorded by an eye-tracker (Eyelink-1000) placed below the screen (operating in remote mode). Parents wore opaque glasses and were asked not to interact with their children during the experiment. The experimenter remained outside the booth during the test and used a 5-point calibration procedure to calibrate the eye-tracker.

In order to introduce toddlers to the task, the experiment started by a practice block in which they were presented with two filler sentences (one having an unambiguous noun as a target and the other an unambiguous verb). Right after that, toddlers
started the test block, composed of eight ambiguous test sentences and four filler sentences.

Each trial started with an inspection period to provide toddlers enough time to inspect each of the images individually on each side of the screen. For instance, one image was presented on the left (or right) side of the screen for three seconds, accompanied by a neutral audio prompt (e.g. ‘Hey look!’), then the other image was presented on the opposite side of the screen for another 3 s (with another neutral audio prompt). Five hundred milliseconds later, both images were presented side-by-side on the screen for 3 s, without any acoustic stimulus. Then these images disappeared and a colorful fixation target appeared in the middle of the screen. Once participants looked at this fixation point for at least 500 ms, the two images reappeared on the screen at the same time as the auditory test sentence was played. The time course of each trial is illustrated in Fig. 2.

2.1.5. Data processing and analysis

Toddlers’ eye-gaze towards the images was recorded by an Eyelink-1000 while they listened to the test sentences, with a time-sample collected every 2 ms. Before statistical analysis, the data was down-sampled by a factor of 10, by averaging the data from 10 adjacent samples, so that the final sampling rate was one sample every 20 ms. Thirty-nine trials out of 320 were removed from the statistical analysis (17 in the noun condition and 22 in the verb condition), because more than 25% of the data frames were missing between the onset of the test sentences and the end of the ambiguous word. The eye-gaze analysis uses the proportion of fixations toward the noun image as a dependent variable, because fixations to noun vs. verb image in this task are complementary (apart from the time spent looking away). To find the time-window(s) which exhibited a significant difference between conditions, a cluster-based permutation analysis was conducted (as in Dautriche, Swingley, & Christophe, 2015; de Carvalho et al., 2016; Hahn, Snedeker, & Rabagliati, 2015; Von Holzen & Mani, 2012; see Maris & Oostenveld, 2007, for a formal presentation of the analysis itself). This analysis allows us to test for the effect of Condition without inflating the rate of Type I error. It proceeds in two phases. First, for each time point, a paired two-tailed t-test testing for the effect of Condition (noun prosody vs. verb prosody) is conducted (on the proportion of looks toward the noun picture). Adjacent time points with a t-value greater than some predefined threshold (here, t = 1.5) are grouped together into a cluster. The size of the cluster is defined as the sum of the t values at each time point within the cluster. Second, to obtain the probability of observing a cluster of that size by chance, we conducted 1000 simulations where we randomly shuffled the conditions (noun prosody, verb prosody) for each trial. For each simulation, we calculated the size of the biggest cluster identified with the same procedure that was applied to the real data. A cluster of adjacent time points from the real data shows a significant

The same threshold was used in de Carvalho, Dautriche and Christophe (2016). Note that the value of the threshold does not affect the rate of false alarms of the test, since the significance of the cluster is estimated through the permutation procedure.
effect of condition if its size is greater than the size of the largest cluster found in 95% of the simulations (ensuring a p-value of .05). This analysis was conducted on a time-window extending from −700 ms before the onset of the ambiguous word until 2000 ms after the onset of the ambiguous word. Plots of eye-gaze data were performed with the ggplot2 package (Wickham, 2009).

2.2. Results

Fig. 3 shows the average proportion of looks toward the noun image in the noun prosody condition (red curve) and in the verb prosody condition (blue curve), time-locked to the beginning of the ambiguous word onset. This reflects toddlers’ online interpretation of sentences as the linguistic input unfolds (e.g., Trueswell, ...
that prosodic phrase boundaries are perceived and exploited by infants from six months onwards (Gerken et al., 1994; Gout et al., 2004; Shukla et al., 2011; Soderstrom et al., 2003), it is possible that even younger toddlers might be able to use phrasal prosody as cue to recover the syntactic structure of sentences.

In order to investigate this question, Experiment 2 aims to directly test whether 20-month-old infants are able to use prosodic structure to access the syntactic structure of sentences and constrain their syntactic analysis. A pre-test of Experiment 1 with a small group of 18-month-olds (n = 20) revealed that this task was not appropriate for testing this age group, for the following reasons: (a) The task seemed to be too long for them, they became fussy before the end of the experiment, and tended not to finish the task; (b) some toddlers were afraid of the babble noise masking the end of sentences and started crying during the experiment; (c) the duration of each trial seemed to be too short for 18-month-olds, not leaving them enough time to choose the correct image. In the current experiment, trials ended around one second after the offset of the target words (i.e., the duration of the babble noise mask), while younger infants may have needed more time to process the sentences and to switch their eye-gaze toward the correct image. Supporting this idea, previous eye-tracking studies with 19- and 21-month-olds have shown that it can take them between 1 and 4 seconds after target word offset to look toward a noun or a verb referent (Arunachalam, Escovar, Hansen, & Waxman, 2013; Ferguson et al., 2014). Thus, in Experiment 2 we adapted the experimental procedure to test younger toddler’s ability to use phrasal prosody to constrain syntactic analysis.

3. Experiment 2

To adapt the experimental design to 20-month-olds, several changes were implemented. The experiment was shortened by half by using only four of the previous eight pairs of noun-verb homophones. To avoid using the babble noise mask, only homophones for which the verb could be used in an intransitive structure were used (either intransitive verbs, or verbs that accepted omission of their complement). Finally, to give infants more time to process the sentences, each ambiguous sentence was repeated twice.

These changes led us to create minimal pairs of globally ambiguous sentences, such as ‘Regarde le bébé [suivi], which can be produced either as [Regarde le bébé [suivi]] - Look at the baby mouse 1, where [suivi] is a noun, or as [Regarde, [le bébé [ [suivi]]] - Look! The baby smiles!, where [suivi] is a verb (brackets indicate prosodic boundaries). As in Experiment 1, both sentences are composed of exactly the same words, and can be disambiguated by their prosodic structures, which reflect the different syntactic structures. If 20-month-olds exploit phrasal prosody to constrain their syntactic analysis, we expect them to look more toward the noun picture when listening to sentences in the noun prosody condition, than when listening to sentences in the verb prosody condition. In order to directly compare the performance of the 20-month-olds and the 28-month-olds, we tested two groups of toddlers in this experiment: the younger group of 20-month-olds, and a new group of 28-month-olds, in which we expected to replicate the same effect found in Experiment 1.

3.1. Method

3.1.1. Participants

Sixty-four toddlers participated in this experiment. They were all monolingual native French speakers and were divided into two age groups (with 32 toddlers in each age group): the 20-month-old group, ranging in age from 19.0 (months.days) to 21.3, with a mean age of 19.19 (SD = 0.6; 14 girls) and the 28-month-old group, ranging in age from 26.19 to 28.27, with a mean
pants listened to four sentences in the noun prosody condition and half heard them in the verb prosody condition. An additional twenty-six children completed the experiment (eleven 28-m.o and fifteen 20-m.o) but they were not included in the final sample because of fussiness during the experiment resulting in more than 50% of trials with missing eye-tracking data (n = 19), because they cried (n = 4), or because of technical problems (n = 3). Parents signed an informed consent form. This research was approved by the local ethics committee.

3.1.2. Material

Four pairs of French noun–verb homophones were used to create eight experimental sentences, four using the target word as a noun (e.g., [Regarde le bébé /suivi] NOUN) [Tu vois le bébé /suivi] NOUN?] - Look at the bébé mouse NOUN! Do you see the bébé mouse NOUN? and four using the ambiguous word as a verb (e.g., [Regarde], [le bébé /suivi] VERB) [Tu vois?] [le bébé /suivi] VERB! - Look! The bébé mouse smiles VERB! Do you see? The bébé NOUN smile VERB; see the Appendix B for a complete list of test sentences). In each trial, the target word was repeated twice, to give infants more time to process the sentences. As in Experiment 1, sentences uttered in the verb prosody condition had a prosodic boundary before the target word (i.e., corresponding to the boundary between the noun and the verb phrases), while in sentences uttered in the noun prosody condition all the words were grouped together into one single prosodic unit. The same speaker as in Experiment 1 recorded all the sentences using a child-directed register. An example of each kind of sentence is depicted in Fig. 4. As in Experiment 1, parents' reports suggest that most of the participants understood the majority of the words (mean number of words comprehended: 7.75 out of 8; range: 7–8; for the 28-month-olds; and 6.34 out of 8; range: 3–8; for the 20-month-olds). In addition to experimental sentences, two filler sentences contained a non-ambiguous target word at the end of the sentence (one noun sentence “[Regarde le petit chat?] [Tu vois le petit chat?]” – Look at the little cat! Do you see the little cat?) and one verb sentence “[Regarde! [tu petite] [dort!]] [Tu vois?] [tu petite] [dort!];” – Look! The little girl is sleeping! Do you see? The little girl is sleeping! These two filler sentences were used at the beginning of the experiment to familiarize toddlers with the task.

To make the experiment as simple as possible for young toddlers, each participant was presented either with sentences in the noun prosody condition, or with sentences in the verb prosody condition, in a between-participants design. Half of the participants listened to four sentences in the noun prosody condition and the other half listened to four sentences in the verb prosody condition, for a total of 6 trials (2 filler trials followed by 4 test trials). Test sentences were presented in random order.

For each homophone used in the experiment, two images were created, one depicting the noun interpretation of the homophone and the other depicting the verb interpretation. For the two filler items used, one image corresponded to the target word and the other was unrelated but represented a word from the opposite syntactic category. In total, 12 images were created: 8 for the test sentences and 4 for the filler sentences. These images were drawn by the same person as in Experiment 1, and were colored in order to make the experiment more interesting for young children.

3.1.3. Acoustic analyses

In order to assess prosodic differences between the two prosodic conditions, acoustic measurements (duration and pitch) were conducted on the test sentences. The analysis of duration revealed a significant pre-boundary lengthening, as expected from the literature: the rhyme of the word preceding the target word (e.g., last vowel -/e/ from bébé) in the verb condition (where it was placed just before the prosodic phrase boundary) was lengthened by 211% compared this same segment in the noun condition (where it was placed in the middle of a prosodic unit: 395 vs 127 ms, see Table 2). A silent pause of 232 ms preceding the target word (i.e., between “bébé” and /suivi/) was observed in the verb condition, while there was no pause between these words in the noun condition. Additionally, a phrase-initial strengthening was observed: the onset of the target word in the verb condition (205 ms, phrase-initial position) was lengthened by 88% compared to the noun condition (109 ms, phrase-medial position). The rhyme of the target words (e.g., -/i/ from /suivi/) were utterance-final in both conditions (contrary to Experiment 1); it was lengthened by 49% in the verb condition relative to the noun condition (480 vs 383 ms), possibly because the verb was alone in its prosodic unit.

The analysis of pitch contours in both prosodic conditions revealed a significant difference between conditions (see Table 2), consistent with the literature describing French as having a tendency for a rising pitch contour towards the end of prosodic units. The word preceding the target word (e.g., bébé) exhibited a greater rising pitch pattern in the verb prosody condition (+185 Hz; because of its position at the end of a prosodic unit), than in the noun prosody condition (+53 Hz; when it was placed in the middle of a prosodic unit). Given that in both conditions, the target word was placed in the end of a prosodic unit, no particular hypothesis was made regarding their differences in pitch. The target word in the noun prosody condition (e.g., /suivi/) seemed to exhibit a greater rising pitch pattern in the noun prosody condition (+118 Hz) than in the verb prosody condition (+29 Hz), but this difference was not significant.

Table 2

**Acoustic analyses of the stimuli of Experiment 2.** Mean duration (in ms) and pitch (in Hz) for the segments around the prosodic boundaries for both noun and verb prosody conditions. (Standard error of the mean).

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Noun prosody [le bébé /suivi]</th>
<th>Verb prosody [le bébé] /suivi</th>
<th>Analysis (2-tailed t-tests)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rhyme - word preceding Target (e.g., e from “bébé”)</td>
<td>127 (14.3)</td>
<td>395 (69.2)</td>
<td>t (7) = -4.58, p &lt; .01</td>
</tr>
<tr>
<td>Pause - before Target (e.g., between “bébé” and “/suivi”)</td>
<td>0 (0)</td>
<td>232 (52.2)</td>
<td>t (7) = -4.44, p &lt; .01</td>
</tr>
<tr>
<td>Onset - Target word (e.g., t from “/suivi”)</td>
<td>109 (11.7)</td>
<td>205 (16.1)</td>
<td>t (7) = -6.44, p &lt; .01</td>
</tr>
<tr>
<td>Rhyme - Target word (e.g., i from “/suivi”)</td>
<td>323 (61.8)</td>
<td>480 (116)</td>
<td>t (7) = -2.76, p = .03</td>
</tr>
</tbody>
</table>

| Pitch analyses – Mean pitch change, in Hz, from the beginning to the end of the target words (standard error of the mean). |
|-----------------|-----------------|-----------------|-----------------|
| Word preceding Target (e.g., last pitch value at the last vowel from “bébé” minus first pitch value of “/u/” from “/suivi”) | -53 (16.4) | 185 (28.1) | t (7) = -14.32, p < .01 |
| Target word (e.g., last pitch value of “/i/” from “souri” minus first pitch value of “/u/” from “/suivi”) | 118 (46.9) | 29 (30.7) | t (7) = 1.94, p = .09 |
3.1.4. Apparatus and procedure

The procedure was similar to that of Experiment 1 (although it took place in a different sound-attenuated booth, from IAC Acoustics). Toddlers sat on their parent's lap about 70 cm away from a 27-in television screen and as before, their movements were recorded by an eye-tracker (Eyelink-1000) placed below the screen. The caregivers wore headphones and listened to masking music during the experiment.

As in Experiment 1, the experiment began by presenting toddlers with two filler trials (one asking them to look toward a familiar noun (i.e., chat - 'cat') and another one asking them to look toward a familiar action (i.e., dormir – 'to sleep'). The test block was composed of four ambiguous test sentences (repeated twice for each item). No filler sentences were used into the test block.

As in Experiment 1, each trial started with an inspection period, to provide infants enough time to inspect each of the images individually, on each side of the TV-screen. However, because younger children may benefit from having more time to inspect the images, the inspection period for each image was increased from 3 s in Experiment 1 to 5 s in the current experiment. Thus, each image was first presented alone for 5 seconds on the left or the right side of the TV-screen and a neutral audio prompt was played at the same time (e.g. ‘Hey look! Do you see that?’). Both images were then presented together on the screen, without any acoustic stimulus, during five seconds. Then the images disappeared and a colorful fixation point appeared in the middle of the screen. Once participants looked at the fixation point for 500 ms, the trial started: the two images were presented side-by-side on the screen at the same time that infants listened to the audio sentences and their eye-gaze was recorded, for a total duration of 9 s.

3.1.5. Data processing and analysis

Data processing and analysis followed the same criteria as in Experiment 1. This analysis was conducted on a time-window extending from –1500 ms before the onset of the ambiguous word until 6000 ms after the onset of the ambiguous word (i.e., the end of the trial). Thirty-four trials out of 256 were removed from the statistical analysis because more than 25% of the data frames in this analyzed time-window were missing (21 in the noun condition and 13 in the verb condition).

3.2. Results

Fig. 5 shows the proportion of looks toward the noun image for toddlers in the noun prosody condition (red curve) and in the verb prosody condition (blue curve), time-locked to the beginning of the first onset of the ambiguous word, for the 20-month-old group (A) and for the 28-month-old group (B).

Just as in Experiment 1, visual inspection of the data shows that both groups of toddlers tended to look more toward the verb image at the beginning of the trials. However, toddlers in the noun prosody condition increased their looks toward the noun image, starting slightly after the offset of the first critical word for 28-month-olds, and around the second repetition of the critical word for 20-month-olds. This suggests that while the 28-month-olds were faster than the 20-month-olds in this task, both groups were
able to exploit prosodic information to guide their interpretation of the ambiguous target word.

The cluster-based analysis found a significant time-window where the proportion of looks toward the noun picture was significantly different from children in the noun prosody condition compared to children in the verb prosody condition, for both age groups: 28-month-olds (from 780 ms after the onset of the first ambiguous target word; \( p < 0.001 \)), and 20-month-olds (from 4060 ms after the onset of the first ambiguous word or about 300 ms after the onset of the second critical word; \( p < 0.01 \)). These results show that, despite their speed difference, both 20- and 28-month-olds looked more towards the noun picture in the noun prosody condition than in the verb prosody condition.

3.3. Discussion

The results obtained here provide direct evidence that from 20 months on, children exploit prosodic information to access the
syntactic structure of sentences, and use this syntactic structure to identify the syntactic category of an ambiguous word (noun/verb homophone). In an intermodal preferential looking task, when listening to minimal pairs of sentences such as Regarde le bébé [suwi], which can be produced either as [Regarde le bébé [suwi]] – ‘Look at the baby mouse!’, where ‘/suwi/’ is a noun, or as [Regarde], [le bébé] [suwi] – ‘Look, the baby smiles!’, where ‘/suwi/’ is a verb, 20- and 28-month-olds correctly interpreted the ambiguous word as either a noun or a verb, depending on the prosodic structure of the sentence they were listening to.

Although both age groups switched their eye-gaze toward the correct image, 20-month-olds appeared to be much slower than 28-month-olds. For 28-month-olds, the two conditions diverged right after the first repetition of the ambiguous word, while for 20-month-olds this happened during the second repetition of the target word. This difference in processing speed across age groups may be due to differences in attentional skills between the two ages, and/or to the fact that the younger children knew the homophones less well. In any case, these results show that 20-month-olds can use phrasal prosody to access the syntactic structure of sentences and that they use this information to recover the intended meaning of a homophone.

4. General discussion

The results reported in this paper show that from 20 months on, toddlers are able to exploit phrasal prosody to access the syntactic structure of sentences, which in turn allows them to identify the syntactic category of an ambiguous word and access its meaning. In a preferential looking task, both 28-month-olds (Experiment 1 and 2) and 20-month-olds (Experiment 2) were able to correctly assign a grammatical category to an ambiguous word (noun vs. verb) depending only on its position within the prosodic structure of sentences. When presented with ambiguous sentences that were phonemically identical but syntactically and prosodically distinct, toddlers were able to exploit the prosodic structure of sentences to infer their syntactic structures, and use this information to decide whether an ambiguous target word was a noun or a verb. They interpreted the ambiguous target word as a noun when it was embedded in a noun sentence and as a verb when it was embedded in a verb sentence, even though the only cue to syntactic structure came from phrasal prosody. This study is the first to report that children under two years old exploit phrasal prosody to recover the syntactic structure of sentences, and use this syntactic structure to compute the syntactic category of an ambiguous word and to access its meaning.

To succeed in our experiments, toddlers may have used phrasal prosody and function words together to constrain their syntactic analysis. This hypothesis is based on the fact that while the perception of prosodic boundaries in our experiments allowed toddlers to group words into syntactic constituents, and informed them about the location of syntactic boundaries, the prosodic boundaries per se do not directly provide the syntactic labels of constituents (e.g. noun phrase, verb phrase). To interpret the homophone as a noun or a verb, toddlers may have used the additional information carried by function words5, together with the prosodic structure of sentences. For instance, in Experiment 1, when participants heard a sentence such as [le bébé [suwi] ...], the prosodic boundary before the target word signaled the presence of two prosodic units. Given that the first unit (e.g., [le bébé]) started with an article (e.g., le – the), this unit could be identified as a noun phrase (e.g., [LeDET bébéNOUN]NP - [TheDET babyNOUN]). Having identified the first unit as a full noun phrase, toddlers might expect it to be followed by a verb phrase, which allows them to rapidly identify the ambiguous word (e.g., /suwi/) as a verb. In the noun prosody condition in contrast, given that all three words appeared together into one single prosodic unit starting with an article (e.g., [le bébé /suwi/]), this information led toddlers to interpret the entire constituent as a noun phrase, which entailed that /suwi/ had to be interpreted as a noun. Similarly, in Experiment 2, the presence of a prosodic boundary just before the ambiguous word triggered a verb interpretation, while the ambiguous word was identified as a noun when it belonged to the same prosodic unit as the first three words ([Regarde le bébé souris], ‘look at the baby mouse’). It is important to note that the use of prosodic information to constrain syntactic analysis is not limited to the kind of syntactic ambiguity resolution featured in our experiments. The relationship between prosodic and syntactic structures is present in all sentences, whether or not they contain ambiguous words. For instance, in a sentence such as ‘The little cat jumps really high’, listeners can perceive the prosodic boundary between the subject noun phrase and the verb phrase, as in many sentences that children hear in their everyday lives. In other words, although sentences containing homophones are useful to test listeners’ abilities to rely on phrasal prosody to recover syntactic structure, listeners can learn the relationship between prosodic and syntactic structures from unambiguous everyday sentences.

Overall, the ability to use phrasal prosody and function words together helps infants to generate a first parse of the syntactic structure of sentences, and allows them to calculate the syntactic category of an ambiguous word. Note that toddlers seem not to be bothered by the noun-verb homophony, in these cases, because the critical words occur in disambiguating contexts (contrary to what has been proposed in the literature, e.g. Conwell & Morgan, 2012). We suspect that cross-category homophones such as these will most often appear in disambiguating contexts, and therefore not hinder children’s language acquisition (see Dautriche, Fibla, & Christophe, 2015; Dautriche, 2015; Dautriche et al., 2015, for a fuller discussion of this aspect).

The ability to assign a syntactic category to a word according to its context may be extremely important during language acquisition, especially when children do not yet know the meanings of many words. Indeed, children may exploit the fact that an unknown word occurs in a noun context to infer that it probably refers to an object, while words occurring in verb contexts probably refer to actions (e.g., Gillette et al., 1999; Gleitman, 1990). For instance, He and Lidz (2017) showed that 18-month-olds (but not 14-month-olds) were able to infer that a novel word such as ‘doke’ referred to an object when listening to sentences such as “Look, it’s a doke!”, and that a novel word such as ‘pratch’ referred to an action when listening to sentences such as “Look! It’s pratching!”.

However, not all content words are immediately preceded or followed by a disambiguating function word or morpheme as in “a doke” or “is doking” (e.g., in: “’The giant bears...”, bears can be either a noun or a verb). In such cases, a more sophisticated analysis in terms of syntactic constituents, signaled by prosodic boundaries, might be extremely informative for infants. For example, in a sentence like “[Do you see the baby blicks]?”, infants might be able to infer that “blick” is a noun, referring to an object; but in a sentence such as: “[Do you see? [The baby] [blicks]]!” they might be able to infer that “blick” is a verb, referring to an action. Note that this hypothesis is rather plausible, since to correctly interpret the novel word “blick” as a noun or a verb in this situation, infants would need to exploit exactly the same kind of information they were shown to use in the present experiments.

Other recent findings support the importance of phrasal prosody for syntactic computations in toddlers, showing that prosody
facilitates learning of syntactic constituency in 19-month-olds (Hawthorne & Gerken, 2014; Hawthorne, Rudat, & Gerken, 2016) and that 20-month-old toddlers use phrasal prosody to identify syntactic constituents (Massicotte-Laforge & Shi, 2015). For instance, 20-month-olds familiarized with jabberwocky sentences such as ‘[Tu]ron cralev’ (‘You crale’), but not when the novel word appeared in the expected syntactic context, as a noun ‘Le teron cralev’ (Massicotte-Laforge & Shi, 2015). Taken together, these results show that around 20 months, infants are sensitive to the information provided by phrasal prosody and function words when parsing sentences. Our current findings extend these results and show that infants can exploit prosodic structure to identify possible syntactic constituents; this constituent structure helps them to constrain their syntactic analysis and to access the intended meaning of an ambiguous word.

This suggest that at an age where their knowledge of content words is limited, but phrasal prosody and function words are available, infants could rely on phrasal prosody and function words to retrieve a partial syntactic representation of spoken sentences and attribute a noun or a verb meaning to words, depending on their position in the syntactic structure of sentences: a mechanism that may be extremely important during the first stages of language acquisition. Recent computational work supports this idea and shows an excellent performance of models relying on a combination of factors including phrasal prosody, function words and a minimal semantic knowledge, to access the syntactic category of unknown words (Brusini, Amsili, Chemla, & Christophe, 2011; Christodouloupolous, Roth, & Fisher, 2016; Fisher, 2015; Gutman, Dautriche, Crabbé, & Christophe, 2015).

To sum up, we provided evidence that from 20 months old, toddlers readily exploit the prosodic structure of an utterance to constrain its syntactic analysis, and access the meaning of an ambiguous target word. We showed that toddlers use phrasal prosody to segment the continuous speech stream into prosodic units, use them to infer the presence of syntactic constituent boundaries, and exploit function words and syntactic boundaries to assign a syntactic category to ambiguous words and recover their meanings. Given that at this age, toddlers are still in the process of learning their lexicon, this ability to assign a syntactic category to words depending on their context may help infants to constrain the acquisition of word meanings. These findings suggest that phrasal prosody plays an important role in language acquisition, since it provides access to a first-pass syntactic structure of sentences which may help infants to bootstrap language acquisition.

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Appendix A. Experimental sentences of Experiment 1

Note that in French several adjectives can be used as nouns. For example, one can say “le grand” (literally: the tall), meaning the tall one, where the pronoun (one) is omitted. The same applies to other adjectives like “le petit, la petite” meaning “the little one”.

<table>
<thead>
<tr>
<th>Pair of ambiguous word</th>
<th>Syntactic category</th>
<th>Target</th>
<th>Full sentence before acoustical mask</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fermer x la ferme</td>
<td>Verb</td>
<td>Ferme</td>
<td>La petite ferme le coffre à jouets</td>
</tr>
<tr>
<td>to close x the farm</td>
<td>Noun</td>
<td></td>
<td>The small one closest the toy box</td>
</tr>
<tr>
<td>Lire x le lit</td>
<td>Verb</td>
<td>Lit</td>
<td>La petite ferme lui plait beaucoup</td>
</tr>
<tr>
<td>to read x the bed</td>
<td>Noun</td>
<td></td>
<td>The small farm pleases him a lot</td>
</tr>
<tr>
<td>Marcher x la marche</td>
<td>Verb</td>
<td>Marche</td>
<td>Le grand lit souvent des histoires à son petit frère</td>
</tr>
<tr>
<td>to walk x the stairs</td>
<td>Noun</td>
<td></td>
<td>The big one often reaad stories to his younger brother</td>
</tr>
<tr>
<td>Moucher x la mouche</td>
<td>Verb</td>
<td>Mouche</td>
<td>Le grand lit sera pour les parents</td>
</tr>
<tr>
<td>to nose x the fly</td>
<td>Noun</td>
<td></td>
<td>The big bed will be for the parents</td>
</tr>
<tr>
<td>Porter x la porte</td>
<td>Verb</td>
<td>Porte</td>
<td>La grande marche lentement toute la journée</td>
</tr>
<tr>
<td>to carry x the door</td>
<td>Noun</td>
<td></td>
<td>The big one walks slowly all day long</td>
</tr>
<tr>
<td>Montrer x la montre</td>
<td>Verb</td>
<td>Montre</td>
<td>La grande marche la fait tomber</td>
</tr>
<tr>
<td>to show x the watch</td>
<td>Noun</td>
<td></td>
<td>The big stair makes her fall</td>
</tr>
</tbody>
</table>

(continued on next page)
Appendix A (continued)

<table>
<thead>
<tr>
<th>Test sentences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair of ambiguous word</td>
</tr>
<tr>
<td>Smiley x le souris</td>
</tr>
<tr>
<td>to smile x the mice</td>
</tr>
<tr>
<td>Pêcher x les pêches</td>
</tr>
<tr>
<td>to fish x the peaches</td>
</tr>
</tbody>
</table>

Appendix B. Experimental sentences of Experiment 2

<table>
<thead>
<tr>
<th>Test sentences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair of ambiguous word</td>
</tr>
<tr>
<td>Lire x le lit</td>
</tr>
<tr>
<td>to read x the bed</td>
</tr>
<tr>
<td>Marcher x la marche</td>
</tr>
<tr>
<td>to walk x the stairs</td>
</tr>
<tr>
<td>Porter x la porte</td>
</tr>
<tr>
<td>to carry x the door</td>
</tr>
<tr>
<td>Sourire x la souris</td>
</tr>
<tr>
<td>to smile x the mice</td>
</tr>
</tbody>
</table>

References


