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Two-year-olds compute syntactic structure on-line

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Abstract

Syntax allows us human beings to build an infinite number of new sentences from a finite stock of words. Since toddlers typically utter only one or two words at a time, they have been thought to have no syntax yet. Using Event-Related Potentials (ERPs), we demonstrated that 2-year-olds do compute syntactic structure when listening to spoken sentences. We observed an early left-lateralized brain response when an expected verb was incorrectly replaced by a noun (or vice-versa). Thus, toddlers build on-line expectations as to the syntactic category of the next word in a sentence. In addition, the response topography was different for nouns and verbs, suggesting that different neural networks already underlie noun and verb processing in toddlers, as they do in adults.

Human language is unique because it is generative. From a finite repertoire of words, humans can build an infinite number of new sentences. The way children come to master the set of syntactic computations that underlies spoken language remains debated. On the one hand, these syntactic computations have been argued to be too complex and too idiosyncratic to be acquired by infants on the sole basis of the sentences they hear (the ‘poverty of the stimulus’ argument, Chomsky, 1986). In that view, language acquisition would rely on innate constraints (Fisher, 2002a; Fisher, Hall, Rakovitz, & Gleitman, 1994; Gleitman, 1990; Lidz, Waxman, & Freedman, 2003; Naigles, 1990; Naigles, 2002). The child’s early syntactic representations would be similar in kind to the adult’s, and become functional as he/she learns words to fill the abstract syntactic categories. On the other hand, constructivists argue that children start without syntax. Their first utterances are limited to specific word strings, produced by rote. Infants construct syntactic categories such as ‘noun’ and ‘verb’, and learn the specific syntactic computations of their mother tongue, by generalizing on these fixed utterances, using their general learning capacities and social skills (Lieven, Behrens, Speares, & Tomasello, 2003; Tomasello, 2000; Tomasello & Abbot-Smith, 2002). This can only happen once a “critical mass of exemplars” has been reached, around 3 years of age.

The main reason why this debate remains unsolved is the difficulty to gather relevant evidence. When children start to produce more than one word at a time, around 1.5 to 2 years of age, their utterances are typically incomplete, and often lack grammatical markers such as articles, auxiliaries, or verb endings. As a result, it is difficult to decide unambiguously whether toddlers simply parrot parts of sentences, or actively exploit syntactic computations to create their own novel sentences but are limited by their poor planning and motor control (Fisher, 2002a;

Naigles, 2002; Tomasello & Abbot-Smith, 2002). Comprehension may thus be a better measure of infants' linguistic competence. However, at this age behavioral studies depend on indirect measures of linguistic comprehension, such as looking times to visual scenes, while children are listening to spoken sentences that are either congruent or incongruent with the visual input. Even though many of these studies show that children between one and three years of age do extract meaning from spoken sentences (Bernal, Lidz, Millotte, & Christophe, 2007; Fisher, 2002b; Fisher, Klingler, & Song, 2006; Naigles, 1990), their interpretation in terms of syntactic competence per se remains controversial (Tomasello & Abbot-Smith, 2002; Tomasello & Akhtar, 2003). Indeed, syntax is not always strictly necessary for meaning extraction (e.g. telegraphic speech can be understood). Event-related potentials (ERPs) by-pass these methodological difficulties, by allowing experimenters to measure cerebral activity while children are passively listening to sentences. Here, we investigated whether 24-month-old toddlers, who are just beginning to produce multi-word utterances, already show different brain responses to grammatical and agrammatical sentences.

High-density ERPs were recorded in two-year-old French children, who watched short video stories featuring a female speaker playing with small toys. Agrammatical sentences were constructed by inserting a verb in a noun position, or a noun in a verb position (see Table 1). Crucially, grammatical and agrammatical sentences were perfectly matched, in that the critical noun or verb was always preceded by the same function word, "la" (meaning *the* or *it* depending on the preceding context). For instance, for the verb "mange"/*eat*, the word string "la mange", is grammatical in "alors je <u>**la** mange</u>" /*Then I <u>eat **it**</u>,* but agrammatical in "je prends <u>**la** mange</u>"/*I take <u>**the** eat</u>* (where a noun is expected after the article "la"). Conversely, for the noun "balle"/*ball,* the word string "la balle" is grammatical in "je prends **la** balle"/ *I take **the** ball* but agrammatical in "alors je **la** balle"/ *then I ball **it*** (where a verb is expected after the object clitic "la"). Two-words chunks are thus always correct, the agrammaticality can only be detected by children if they compute the syntactic tree of the sentence on-line. Indeed, the legality of the word string "la X" crucially depends on the category (noun or verb) attached to the word and whether this category fits with the preceding context or not (see Table 1 for the full experimental design).

	Verb	Noun
Grammatical	Alors elle **la** mange *(Then she eats it)*	Elle prend **la** balle *(She takes the ball)*
Agrammatical	*Elle prend **la** mange *(She takes the eat)*	*Alors elle **la** balle *(Then she balls it)*

Table 1 : Experimental design: Two crossed factors, Grammaticality and Noun/Verb, yielded 4 subconditions as shown here. Agrammatical sentences were constructed by inserting a noun in a verb sentence-frame (in blue) or a verb in a noun sentence-frame (in green). In this design, the comparison between grammatical and agrammatical conditions relies on responses evoked by perfectly similar acoustic strings (e.g. "la mange"), thereby ruling out potential acoustic confounds.

Materials and Method

Participants.

Twenty-seven French monolingual toddlers (13 girls and 14 boys) were tested (mean age 24 months 2 days, range 23;16 to 24;14). An additional 33 infants did not provide useable data:

24 did not accept to wear the recording system, and 9 were either too agitated during the experiment, or they stopped watching before the end of the test. Before beginning the experiment, the experimenter checked with the parents that the eight target words were known by the child. Parents also gave their written informed consent for the protocol. The study was approved by the regional ethical committee for biomedical research.

Stimuli.

Eight target words were used, 4 nouns and 4 verbs, all well-known to 24-month-old French infants. Target words were not noun/verb homonyms (nouns : ‘fraise’/*strawberry*, ‘balle’/*ball*, ‘grenouille’/*frog*, ‘girafe’/*giraffe* ; verbs : ‘mange’/*eat*, ‘donne’/*give*, ‘regarde’/*look*, ‘finis’/*finish*).

Stimuli were audiovisual sequences that were recorded by a French native speaker who spoke in child-directed speech (the last author). The speaker crouched behind a table, so that her head and shoulders were visible behind the table, and she could manipulate small toys placed on the table. The speaker often looked directly into the camera and smiled a lot, to keep the children engaged. Each video sequence featured a short story, consisting of an introduction, two experimental sentences, a filler sentence, and two other experimental sentences (see table 2). During the introduction and filler sentence, both the speaker and the table were visible. All test sentences were pronounced with a close-up on the speaker’s face, so that the visual stimulation was identical across test sentences. Each story thus contained 4 test sentences and lasted approximately 30 seconds. Within these 4 sentences, 2 featured a test noun, and 2 a test verb; 2 were grammatical and 2 agrammatical. The order of the conditions was counterbalanced across stories. There were 16 different stories overall, i.e. 64 different test sentences, half grammatical half agrammatical, half featuring a target noun half featuring a target verb.

Within test sentences, the target nouns and verbs were always preceded by the function word ‘la’ (meaning either *it* or *the* depending on the preceding context). Target sequences were thus identical in grammatical and agrammatical sentences : For instance, ‘la fraise’ was grammatical in ‘Elle veut manger **la fraise**’/*She wants to eat **the strawberry***, but agrammatical in ‘*Mais elle **la fraise**’/*but she **strawberries it***. The duration of the function word ‘la’ did not differ between grammatical and agrammatical sentences (grammatical, 156.2 ms; agrammatical, 162.6 ms, t(63)<1), neither did the duration of the target words (grammatical, 474.7 ms, agrammatical, 501.6 ms, t(63)<1). Test sentences were also counterbalanced across video stories, for the number of syllables before the target word, and the syntactic structures used in each condition.

Introductory sentences	La poule **regarde** par terre. Elle voit une **fraise**! *The chicken **looks** down. She sees a **strawberry**!*
Test sentence 1 (Noun Incorrect)	Mais elle **la fraise** sans y faire attention. *But she **strawberries it** without noticing.*
Test sentence 2 (Verb Correct)	Maintenant, elle **la regarde** avec envie. *Now she **looks at it** with envy.*
Linking sentence	Qu’est-ce qu’elle va faire? *What will she do?*
Test sentence 3 (Noun Correct)	Elle veut manger **la fraise**. *She wants to eat **the strawberry.***
Test sentence 4	Alors elle pousse **la regarde** pour l’attraper.

(Verb Incorrect)	*So she pushes **the look** to grasp it.*

Table 2: Example of a full video sequence, featuring four test sentences, one in each condition (Noun Correct, Noun Incorrect, Verb Correct, and Verb Incorrect).

Procedure.

Children were seated on their mother's lap and passively viewed at least two blocks of 16 video stories. Parents were asked not to speak to their children, or distract them, during the experiment. If a child became fussy, a pause could be made during the experiment (in-between two stories).

Apparatus.

Video stimuli were projected on a large screen located about 1 meter away in front of the children. The sound came from a loudspeaker hidden behind the screen. The video stories were presented using the 'xine' program. The sound stimuli were recorded on the left sound channel of the video files; the right sound channel contained a clic at the beginning of each target word. These clics were not heard by children, but used to ensure perfect timing between the audio-video stimuli and the ERP recordings. The EEG was recorded continuously by a Power Mac using a high-density geodesic net with 129 electrodes referenced to the vertex (Netstation, EGI, Eugene, USA). A third computer piloted the experiment, selecting the video-stories to be played (in random order within each block), allowing the experiment to be paused by the experimenter, and sending trial information to the EEG-recording system.

ERP Recording and Data Analysis.

The EEG was digitized continuously at 250 Hz during the video presentations, then segmented into epochs starting 500 ms prior to target word onset and ending 1300 ms after it in grammatical and agrammatical sentences. For each epoch, channels contaminated by eye or motion artifacts (local deviation higher than 150 μv) were automatically excluded and trials with more than 25% contaminated channels were rejected. Channels comprising less than 15 trials in one condition were rejected for the entire recording. The artifact-free epochs were averaged for each participant in each of the four conditions: correct nouns, correct verbs, incorrect nouns, and incorrect verbs (on average 31, 30, 39 and 31 epochs in the four conditions). Averages were baseline-corrected using 200 ms before target word onset, transformed into reference-independent values using the average reference method, and digitally filtered between 0.5 and 20 Hz. Two-dimensional reconstructions of scalp voltage at each time step were computed using a spherical spline interpolation and differences between correct and incorrect sentences were computed.

Since the same word strings were used in both conditions, any significant difference between the waveforms would indicate that children have detected an incongruity in incorrect sentences. Inspecting the two-dimensional reconstructions of the Incorrect-Correct difference, we selected the time-window during which the difference was maximum and the clusters of electrodes at the maxima of the dipole response. Voltage was averaged across the selected time-window and electrodes and entered in ANOVAs with Condition (correct and incorrect), word Category (noun and verb) and Electrode (negative and positive clusters) as within-participant variables. Note that because of the selection of the electrodes at the dipoles maxima, a main effect of Electrodes is not informative, thus only interactions between Electrodes and the other factors were examined.

Source modelling.

Using a fine-grained structural magnetic resonance imaging of a normal two-year-old toddler, we computed a detailed model of a toddler head and cortical folds. Head and brain surface were extracted using the BrainVisa software package (http://brainvisa.info/) in order to obtain a realistic head model, which was warped to the standard geometry of the 129 channels EGI sensor net. This model then allowed us to compute a plausible distribution of the cortical areas at the origin of the surface voltage. To do so, the localization and orientation of 10,000 elementary current dipoles were constrained to the cortical mantle using the BrainStorm Matlab toolkit (http://neuroimage.usc.edu/brainstorm). EEG forward modelling was computed using an overlapping-sphere analytical model with three shells (scalp, skull and cerebrospinal fluid) (Darvas, Ermer, Mosher, & Leahy, 2006; Ermer, Mosher, Baillet, & Leahy, 2001). Cortical current maps were computed from the grand averages of the to-be-modelled effects using a linear inverse estimator (weighted minimum-norm current estimate). This algorithm determines the amplitude of each dipole by minimizing the squared error between the data and the fields computed from the estimated sources using the forward model (Baillet, Mosher, & Leahy, 2001).

Results

The inspection of the time-course of the difference between correct and incorrect sentences showed a slow and ample positivity that developed over the left temporal electrodes from 450 to 650 ms (figure 1), synchronous with a weak negativity over the right hemisphere. To assert the significance of the differences observed between correct and incorrect sentences, the voltage was averaged for correct and incorrect sentences across a 200 ms time-window (450 to 650 ms) and across a group of 10 contiguous electrodes over the left anterior temporal lobe (F7, T3 and the channels under this line), and its symmetrical electrodes over the right hemisphere. These values were entered in an analysis of variance (ANOVA) with condition (correct and incorrect), category of words (noun and verb) and hemisphere (left and right temporal clusters) as within-participant factors.

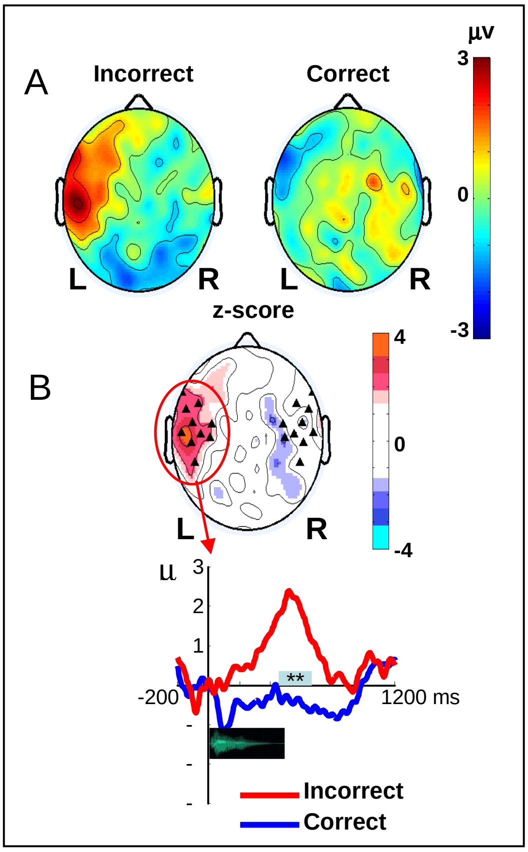

Figure 1: Grammaticality effect: A long lasting positivity, starting 350 ms after the onset of the critical word develops over the left temporal captors. A) Voltage topography between 450 and 650 ms post-onset in correct and incorrect sentences. B) First row: map of statistical significance (z-scores) during the same time-window. Triangles on the topographic map represent the channels used in the statistical analysis. Second row: Grand-averages responses recorded from a left temporal cluster of 10 electrodes showing the positivity induced by the violation of the word category expectation. The length of the speech waveform corresponds to the mean duration of the target word

There was a main effect of condition (F(1,26)=9.18, p=.005) and a significant Condition x Hemisphere interaction (F(1,26)=14.78, p<.001) while there was no significant interaction between word Category and the other factors (Condition x Category: F(1,26)=2.29, p=.31; Hemisphere x Category: F(1,26) < 1; Condition x Category x Hemisphere : F(1,26)=2.19, p=.15). Post-hoc analyses indicated that the difference between correct and incorrect sentences was significant only over the left cluster (condition effect: F(1,26)=23.81, p<.001). The Condition by Category interaction was not significant over the left cluster F(1,26)=2.46, p=.13). For both categories, there was a significant difference between correct and incorrect sentences at this location (Nouns: -0.97 vs 2.67 μv F(1,26)=18.62, p<.001; Verbs: -0.50 vs 1.31 μv F(1,26)=5.51, p=.027).

Although for both types of words, a positivity was recorded over the left temporal electrodes, this positivity was more diffuse for nouns, spreading over the frontal areas. Furthermore, the negative pole was clearly different for both categories, more posterior for nouns and more frontal for verbs (figure 2). This topographical difference explains the weak amplitude of the negative pole when both categories were analyzed together. To test whether this difference was statistically significant, we inspected the time-course of the Condition x Category interaction (z-score), and we isolated two clusters of electrodes (figure 2) with significant z-score values (p <0.05) during the time-window of the grammaticality effect. The first one comprised 6 left electrodes, located on the scalp above the common temporal group (between C3 and T3). It corresponds to the more diffuse response of nouns relative to verbs. The second cluster comprised 8 electrodes above the right occipital area (behind a line joining O2 and T6) corresponding to the negative pole of the grammaticality effect for the noun category. To test the significance of this interaction, voltage in each of the four conditions was averaged across the 450-650 time-window for these two clusters, then entered in an ANOVA with Condition (correct and incorrect), word Category (noun and verb) and Electrode (negative and positive clusters) as within-participant factors. A significant Condition x Category x Electrode interaction (F(1,26)=7.36, p=.012) was present, showing that the grammaticality effect (Condition x Electrode) differed for nouns and for verbs. A main effect of word Category (F(1,26)=7.47, p=.011), due to the localisation of the electrodes over the maxima of the effect in the noun Category, was also observed. This yielded a Condition x Electrode interaction (the grammaticality effect) significant only for nouns (-1.77 vs 4.69 µv F(1,26)=8.31, p=.008) and not for verbs (1.723 vs 0.225 µv F(1,26) < 1).

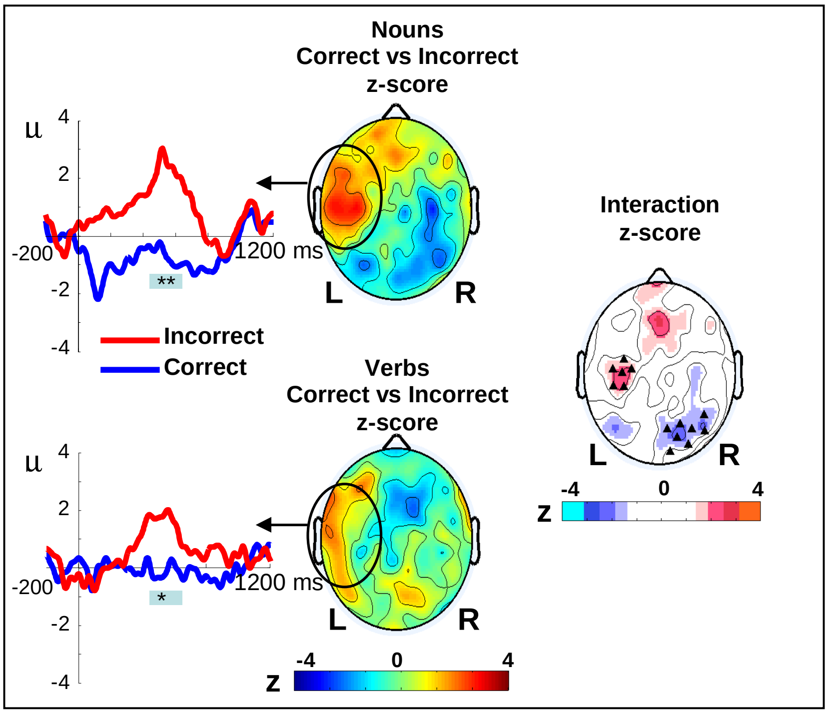

Figure 2 : Grammaticality effect for nouns and verbs. First column: Grand-average response for noun and verb categories recorded from the left temporal cluster. Second column: Topography of the grammaticality effect (z-score) for both word categories between 450 and 650 ms post-onset. The bipolar response is more anterior for verbs than for nouns. Third column: Topography of the significant difference (z-score) between both grammaticality effects during the same time-window.

As pointed out by McCarthy & Wood (1985), a difference between two voltage topographies can be related either to a change in source configuration or in source strength. To resolve this ambiguity, these authors suggested scaling the data by the vector length defined as the square root of the sum of squared voltages over all electrode locations before an ANOVA is performed. Thus, in each subject and for each word category, we normalized the grammaticality effect and performed an ANOVA on these scaled data over the same clusters and the same time-window. The results were similar to the previous analysis (Condition x Category x Electrode F(1,26)=7.59, p=.011) pointing towards a genuine difference in the set of active regions rather than to a weaker response for verbs than for nouns.

Brain sources:

Brain sources reconstruction is another way to determine whether a different set of active regions is involved in one case relative to the other. Using the same forward model, the algorithm determines the amplitude of each of 10,000 elementary dipoles constrained to the cortical mantle of a normal two-year-old toddler by minimizing the squared error between the data and the fields computed from the estimated sources (Baillet et al., 2001) for each category. The proposed sources should be rather similar with only an amplitude difference if the surface topographies are only related to a difference of amplitude in the network response. The algorithm revealed a predominantly left-lateralized response for both categories, which is coherent with the prominent response recorded over the left side of the head. In addition, besides activity in the superior temporal regions, the modelisation uncovered a distinct pattern of activity for nouns and verbs (figure 3). For nouns, activity was observed in occipital areas extending toward more anterior temporal areas along the visual ventral pathway, whereas for verbs, activity clustered in frontal regions close to motor regions and in the temporal poles.

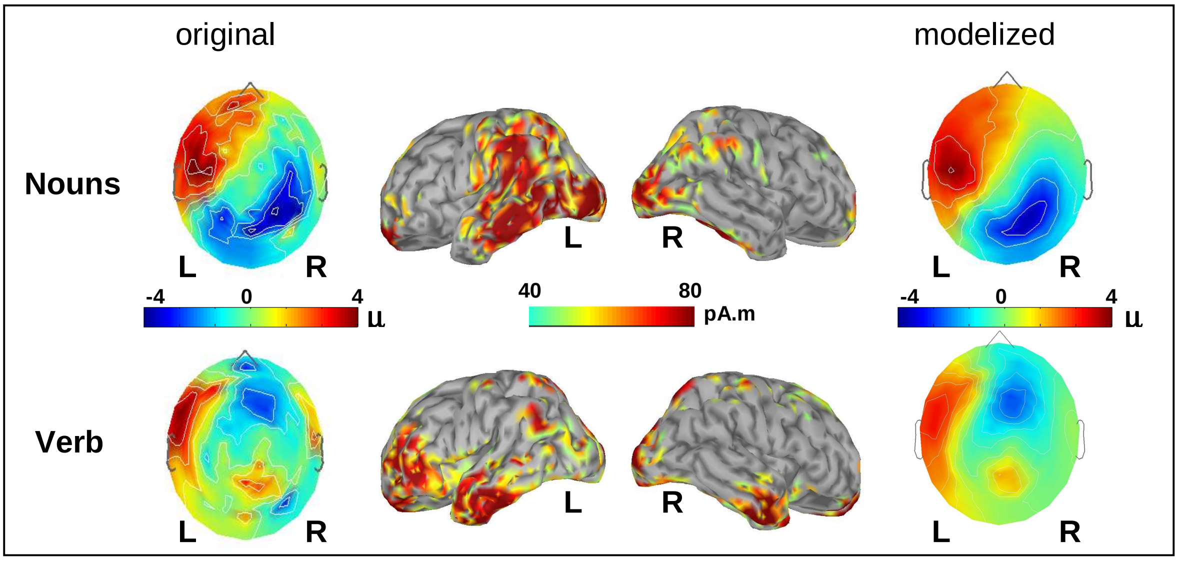

Figure 3: Source reconstructions of the grammaticality effect for nouns (first row) and verbs (second row) at the maximum of the grammaticality effect (532 ms). First Column: voltage topography of the difference Incorrect-Correct. Second and third column: Cortical current maps modelling the observed topography are presented on a smoothed 2-year-old 3-D brain. Activity is expressed in terms of dipole current amplitude (pA.m) with a threshold at 50% of the maximal value (80 pA.m). Last column: scalp topographies generated from the cortical current maps show a good match with the original data presented in the first column.

Discussion

ERPs time-locked to the onset of the critical word uncovered a significant and long lasting positivity (450 to 650 ms post-onset) over the left temporal electrodes for agrammatical sentences as compared to grammatical ones. Since ERPs to the very same words (e.g. “la mange”) are contrasted, potential acoustic confounds are ruled out. The topography of the effect was significantly left-lateralized (Condition x Hemisphere interaction) congruent with several infant studies showing that speech processing is biased to the left side from birth on (Dehaene-Lambertz, Dehaene, & Hertz-Pannier, 2002; Mills, CoffeyCorina, & Neville, 1997; Pena et al., 2003).

There are several reasons to think that this response is a specific syntactic response, rather than a general surprise effect. Firstly, the left-lateralized temporal response observed here is very different from typical novelty responses in infants, which are bilateral over the anterior areas (Dehaene-Lambertz & Dehaene, 1994; Reynolds & Richards, 2005). Secondly, specific components are induced by syntactically illegal sentences in adults: the left anterior negativity (LAN) around 200-400 ms reflects an automatic computation of syntactic category, followed by the centro-posterior positive shift (P600) that reflects syntactic reanalysis or repair (Friederici, 2002). The left-lateralization and the early latency of the component we observed here in infants (starting around 350 ms) is compatible with that of the LAN. The opposite polarity of this effect over temporal regions in infants and adults does not preclude a similar cerebral substrate, as several electrical components, such as some auditory mismatch responses (Dehaene-Lambertz & Gliga, 2004), Nc in infants and P300 in adults (Reynolds & Richards, 2005), share similar functional properties at both ages but are of opposite polarities. This might be explained by a different balance between the cortical layers at both ages, concurrently with modification of intra-cortical connections, myelination, ossification of the skull, differential expansion of brain areas, etc.. which affect the topography of the ERPs recorded at the scalp surface. At this early latency, the critical word is only just finished (see figure 1), and the sentence itself continues, therefore it is unlikely that this response reflects a repair process parallel to that indexed by the P600 in adults. Thirdly, the topography of the grammaticality effect differed for nouns and verbs (figures 2), and this was confirmed by brain sources reconstruction (figure 3). This suggests that the grammaticality effect is specific to the task: indeed, a general surprise effect should have surfaced the same for nouns and verbs.

Brain-imaging and neuropsychological data in adults show that different brain regions underlie noun and verb processing (with more frontal involvement for verbs and inferior temporal activity for nouns) (Damasio & Tranel, 1993; Longe, Randall, Stamatakis, & Tyler, 2007; Shapiro, Moo, & Caramazza, 2006; Vigliocco et al., 2006). We thus aimed at tentatively locating the brain sources of the surface voltages. Methods for ERP source reconstruction have greatly improved in recent years, even in infants (Izard, Dehaene-Lambertz & Dehaene, 2008), mostly because of the use of realistic head models derived from high density MRI (Baillet et al., 2001) and of the use of distributed sources instead of unique dipoles. These distributed approaches yield a unique and most probable solution in a Bayesian sense (Mattout, Phillips, Penny, Rugg, & Friston, 2006). Here, we based our source estimate on a realistic head model based on a toddler's MRI, and we distributed sources over each of the tessellation elements of a realistic cortical mantle. Although source reconstructions should be considered as tentative models of brain activity with coarse spatial accuracy, they reveal here that the underlying network of active regions should be different in both conditions in order to correctly explain the surface topographies. In addition, activity clustered toward anterior areas for verbs, whereas for nouns, it clustered in occipital and temporal areas along the visual ventral pathway. This pattern is congruent with adult results and suggests that the adult cerebral organization for language is getting in place during the first years of life.

To sum up, we observed a specific syntactic response to words that were unexpected relative to the on-going syntactic structure. Thus, nouns that occupied a verb position, or verbs that occupied a noun position, both triggered agrammaticality responses. These responses occurred very early, starting at 350ms, before the end of the critical word: They reflect the on-line integration of the word within the syntactic structure, rather than late repair strategies. In previous experiments with toddlers, agrammatical sentences were constructed by using illegal strings of words, e.g. ‘my uncle **will** watch**ing**’ (Silva-Pereyra, Rivera-Gaxiola, & Kuhl, 2005) (see also Oberecker & Friederici, 2006; Oberecker, Friedrich, & Friederici, 2005). Although significant effects were reported, varying in topography and latency[*], constructivists might argue that infants, being good statistical learners (Saffran, Aslin, & Newport, 1996), are surprised by strings they have never heard before. In the present experiment, in contrast, agrammatical sentences were always locally correct: for instance, in “*alors elle la balle” (**then she balls it*), ‘alors’ can be followed by ‘elle’, ‘elle’ can be followed by ‘la’, and ‘la’ can be followed by ‘balle’. Infants could therefore not detect the agrammaticality by noticing the co-occurrence of two words that normally never occur together (i.e. computing transition probabilities between pairs of words, see also Silva-Pereyra, Conboy, Klarman, & Kuhl, 2007). The only way infants could detect the agrammaticality in our sentences was by building a syntactic structure on-line,

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[*] This variety in the responses observed may be due to the variety of syntactic violations tested. Even though syntactic violations should elicit activity in similar areas of the brain, the actual scalp topography of the response will depend upon a variety of factors, including the acoustic characteristics of the stimuli used, the nature of the syntactic computations involved (e.g. morphosyntax, long-distance relationships, etc…). Similarly the latency of the response should depend upon the time at which relevant information becomes accessible, see discussion in Oberecker, Friedrich & Friederici (2005)

and noticing the conflict between the known syntactic category of the critical word and this structure.

In conclusion, we demonstrate here that toddlers process syntactic structure on-line, at an age when they are still unable to produce syntactically complete multi-word utterances themselves. This experiment thus shows that toddlers' syntactic abilities largely exceed what can be inferred from the sentences they actually produce. This conclusion may seem at odd with some behavioral results, showing for instance that toddlers are reluctant to generalize the use of a newly-learnt verb in syntactic constructions that they have not yet encountered with that specific verb (e.g. Abbot-Smith, Lieven, & Tomasello, 2004). We want to suggest that a possible way out of this paradox lies in considering a complete model of the toddlers' speech production system. Expertise and fluency in production rests on the cooperation and automatization of several subsystems (from syntactic planning to motor control) whose development may follow different time-scales. The present study, using well-known words, demonstrates that infants master not only their meanings, but also their syntactic roles within sentences. Two-year-olds are thus able to construct on-line expectations about the syntactic category of the next word (noun or verb).

These results have broad implications for theories of language acquisition. Firstly, coming back to the issue we raised in the introduction, the present experiment does not in fact advance the debate of whether innate linguistic constraints guide language acquisition. What infants know about the syntax of their language at the age of 2 years, they may very well have acquired during these two years, with or without linguistic constraints. However, our results do suggest that it is non-productive to try to prove that young children do not possess syntactic structures solely by looking at what they produce: There are many reasons why producing syntactically complex sentences is difficult. The two-year-olds in our study demonstrated comprehension of structures that are typically produced at least one year later.

Secondly, this study shows that 2-year-olds are capable of rather subtle syntactic processing, since they distinguish between two homophonous function words in French, ‘la’ article and ‘la’ object clitic. Such an ability to process syntax may help them to acquire the meaning of unknown words, as suggested by Lila Gleitman and her colleagues (Gillette, Gleitman, Gleitman, & Lederer, 1999; Gleitman, 1990). Indeed, in the present experiment we showed that children were able to figure out where verbs and nouns are supposed to occur, even when local transition probabilities were non-informative. This may help them to figure out the syntactic category of new words, and better guess their possible meaning (e.g., nouns = objects, verbs = actions, see Bernal et al., 2007). Future work should aim at developing plausible acquisition mechanisms through which children may manage to acquire such a refined knowledge of the syntax of their native language, even though they do not know many of its content words yet (Chemla, Mintz, Bernal, & Christophe, in press; Fisher, 2002b; Mintz, 2003; Shi & Lepage, 2008). For instance, Christophe, Millotte, Bernal & Lidz (2008) have proposed that function words (very frequent and occuring at prosodic edges) and phrasal prosody (giving syntactic constituent boundaries), may allow children to compute a basic syntactic structure, that may be sufficient to bootstrap lexical acquisition, as well as the acquisition of more complex syntactic structures.

Lastly, we observed that the neural processes involved in noun and verb processing are already different in 2-year-olds, just as has been shown in adults. This suggests that the cerebral network dedicated to language processing is functionally organized early on, and that adult linguistic representations have deep roots going back to the first words stage.

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