Bootstrapping the Syntactic Bootstrapper

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In 1985, Laudau & Gleitman first outlined the *syntactic bootstrapping* hypothesis, in their book *Language and Experience – Evidence from a blind child*, followed in 1990 by Lila Gleitman's article "The structural sources of verb meanings" (in *Language Acquisition*). They proposed that young children might learn the meaning of words (and in particular, verbs), by paying attention to the syntactic structures in which these words occur. This highly counter-intuitive hypothesis earned Lila a lot of flak from the community, and paved the way for the broader research framework that is now known as 'synergies in language acquisition': the general idea that even impoverished knowledge in one area of language might help children refine their representations in another (e.g., even a very crude proto-lexicon will help you learn your phonological system, see for instance Martin, Peperkamp, & Dupoux, 2013). Thirty years later, syntactic bootstrapping is widely accepted and has been supported by many experimental results – even though a lot remains to be discovered. In this paper, we will examine the ways in which very young children may start gathering the relevant syntactic facts on which to base their acquisition of word meanings – or, in other words, how to 'bootstrap the syntactic bootstrapper'.

In order to exploit syntactic structure to figure out the meaning of unknown words, very young children have to be able to recover at least some elements of the syntactic structure of the sentences they hear, even when they do not know all their content words. Two sources of information have been proposed to be particularly useful to infants, because they are available early and they provide useful information about syntactic structure: phrasal prosody and function words (Christophe, Millotte, Bernal, & Lidz, 2008; Morgan & Demuth, 1996; Shi, 2014).

Phrasal prosody, the rhythm and the melody of utterances, is spontaneously produced by speakers and exploited by infants soon after birth (Mampe, Friederici, Christophe, & Wermke, 2009; Mehler et al., 1988). Infants may use the prosodic characteristics of sentences to extract critical information about their native language, such as aspects of its syntax, a proposal known as

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prosodic bootstrapping (Christophe, Nespor, Guasti, & van Ooyen, 2003; Morgan, 1986). In particular, intermediate prosodic units, called phonological phrases (following the terminology of Nespor & Vogel, 1986) give information about the syntactic structure of a sentence, since their boundaries are aligned with syntactic constituent boundaries (Nespor & Vogel, 1986; Selkirk, 1984). Phonological phrases usually contain one or two content words along with the function words associated with them. They are typically marked by final lengthening and strengthening of the initial phoneme, and they tend to have a single intonation contour with a possible discontinuity of the F0 contour at the boundary between two prosodic units (cf. Shattuck-Hufnagel & Turk, 1996, for a detailed review). Phonological phrase boundaries are detected from 6 months of age (see e.g. Gerken, Jusczyk, & Mandel, 1994; Soderstrom, Seidl, Kemler Nelson, & Jusczyk, 2003) and used to constrain lexical access by 10 months of age (Gout, Christophe, & Morgan, 2004; Johnson, 2008; Millotte et al., 2010).

Function words and morphemes are grammatical elements such as articles, pronouns, auxiliaries, and inflectional affixes (such as conjugation endings). Infants may discover them relatively early because they are extremely frequent syllables generally appearing at the boundaries of prosodic units (Shi, Morgan, & Allopenna, 1998), a position that seems to be specifically salient for the cognitive system (Ferry et al., 2016; Johnson, Seidl, & Tyler, 2014; Shukla, Nespor, & Mehler, 2007). A wealth of experimental work shows not only that infants younger than one year of age notice when the function words of their native language are replaced by nonsense syllables (e.g. Hallé, Durand, & de Boysson-Bardies, 2008; Shi, 2014, for a review; Shi, Cutler, Werker, & Cruickshank, 2006; Shi & Gauthier, 2005), but also that from 14 months on, they expect nouns to be preceded by determiners rather than other types of function words, and by 18 months they expect verbs to be preceded by personal pronouns (e.g. Cauvet et al., 2014; Hohle, Weissenborn, Kiefer, Schulz, & Schmitz, 2004; Kedar, Casasola, & Lust, 2006; Shi & Melançon, 2010).

Taken together, these two sources of information, phrasal prosody and function words, may allow young children to build an approximate syntactic structure of sentences, or *syntactic skeleton* (Christophe et al., 2008). More specifically, upon hearing a sentence such as “the little dog is eating”, the child may extract an initial syntactic representation of the kind “[the XXX]$_{NP}$ [is Xing]$_{VP}$”, where phrasal prosody delimitates units, and function words and morphemes supply the syntactic labels of each constituent (e.g. nouns are typically preceded by articles, verbs by pronouns or auxiliaries). This approximate syntactic representation may be available to young children even without having access to the content words making up the sentence (in our example these words are represented simply as syllables in the form of Xs), and may be sufficient to support the acquisition of word meanings.

1. Eighteen-month-olds exploit phrasal prosody and function words to infer word meanings

If children do manage to compute such a representation, then they should be able to infer whether a novel word is a noun or a verb, just by looking at its sentential context. Once they have inferred the syntactic category of this novel word, noun or verb, they should then be able to use it to constrain its potential meaning: nouns are more likely to refer to objects, and verbs, to actions (Bernal, Lidz, Millotte, & Christophe, 2007; Waxman, Lidz, Braun, & Lavin, 2009). We tested this by using a word-learning paradigm recently developed by He & Lidz (2014), who showed that 18-month-olds listening to a sentence such as *Look, it's a doke!* were able to infer that the novel word *doke* referred to an object, while they thought that *pratching* referred to an action after having heard *Look! It's pratching!*. In this case, the critical word, *doke* or *pratch*, was immediately preceded and/or followed by disambiguating function morphemes (*a*, *it's… -ing*), and toddlers did not need to integrate phrasal prosody in order to successfully compute the syntactic category of the novel words.

However, in everyday sentences, neighboring functional morphemes are not always sufficiently informative, and listeners may need to access the syntactic structure of the sentence in order to recover the syntactic category of a given content word. This is best illustrated with sentences featuring noun/verb homophones, such as *bear* which can be either a noun, as in *[The giant bears]$_{NP}$ [are very hungry]*, or a verb, as in *[The giant]$_{NP}$[bears$_{v}$ a heavy load]$_{VP}$* (square brackets mark phonological phrase boundaries). Adults have been shown to rely on phrasal prosody online in order to recover the intended meaning of an across-category homophone (Millotte, René, Wales, & Christophe, 2008; Millotte, Wales, & Christophe, 2007), and so have preschoolers (de Carvalho, Dautriche, & Christophe, 2016; de Carvalho, Lidz, Tieu, Bleam, & Christophe, 2016). Whether toddlers can simultaneously exploit phrasal prosody and function words to infer the syntactic category of a novel word and constrain its possible meaning, however, has not been studied yet.

To investigate this question, we used minimal pairs of sentences that differed only in their prosodic structures, and featured two novel French words (*bamoule* and *doripe*). In a Habituation-Switch paradigm (e.g. Werker, Cohen, Lloyd, Casasola, & Stager, 1998), 18-month-olds were first habituated with two video stimuli showing a penguin doing two different intransitive actions (e.g., spinning, cartwheeling) one in each video. During the presentation of one of the videos (e.g., a penguin spinning), infants heard sentences in the Noun-prosody condition (e.g., *[Regarde la petite bamoule!]* – 'Look at the little bamoule!', where *bamoule* was a noun, naming an object, here the penguin), and during the presentation of the other video (e.g., a penguin cartwheeling), they heard sentences in the Verb-prosody condition (e.g., *[Regarde],[la petite][doripe!]* – 'Look, the little(one) is doriping', where *doripe* was a verb, naming an action, here cartwheeling). Then, to test toddlers' interpretation of these novel words, the audio tracks of the two videos were switched. Half of the children were exposed to the Noun-Switch-condition, hearing the noun sentence with *bamoule* while seeing the cartwheeling video, and half were exposed to the Verb-Switch-condition, hearing the verb sentence with *doripe* while seeing the spinning video. If toddlers have learned, like adults would, that *bamoule* means ‘penguin’ and *doripe* means ‘cartwheeling’, they should be surprised in the Verb-Switch condition (look longer to the video), because they are listening to the *doripe* sentence while the penguin is spinning instead of cartwheeling. However in the Noun-Switch condition, toddlers should not be surprised when listening to the sentence with *bamoule*, since there is still a penguin present in the video, even if it is now doing a different action. The results of this experiment, presented in Fig. 1, showed that in comparison to the habituation phase, toddlers looked longer at the videos in the Verb-Switch condition than in the Noun-Switch condition.

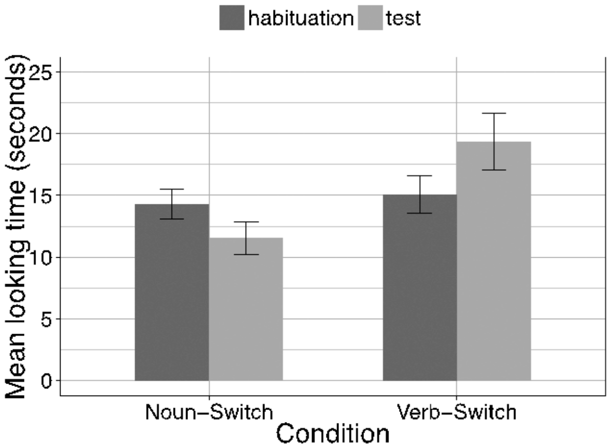

Figure 1: Mean looking time in seconds toward the videos during the last two trials of the habituation phase (in dark gray) and during the two trials of the test phase (in light gray) for children assigned to the Noun-Switch Condition (on the left) and to the Verb-Switch Condition (on the right). There was a significant interaction between Condition and Phase (habituation/test) ($F(1,46)=5.09$, $p < .03$).

Such a looking pattern during the test phase suggests that the action change was inconsistent with toddlers’ interpretation of the novel verb, while it did not matter for their interpretation of the novel noun (a penguin was present in both videos). Thus, 18-month-old toddlers were able to exploit prosodic structure to group words into constituents, and calculate the syntactic structure of sentences, which then helped them to infer the probable meaning of novel words, mapping nouns to objects and verbs to actions. In such a situation, we observe that toddlers are able to integrate information coming from phrasal prosody (that delimits syntactic constituents), and function words (to label these syntactic constituents), in order to access the syntactic category of unknown words. Remarkably, although 18-month-olds still have a reduced lexicon, they seem to be able to rely on phrasal prosody and function words to access the *syntactic skeleton*, a first-pass syntactic structure of sentences, that may be sufficient to constrain the acquisition of word meanings (Christophe et al. 2008).

Altogether, this experiment shows that 18-month-olds already have a fine-grained knowledge of the contexts in which nouns and verbs are supposed to occur (see also Massicotte-Laforge & Shi, 2015), and that they can rely on this knowledge in order to infer the probable meaning of a novel word, that has not been encountered before. This raises the question of how toddlers managed to learn which contexts go with nouns, and which go with verbs. This is what we address in the next section.

2. How infants manage to learn noun and verb contexts

In an attempt to figure out how young children might have learned in which contexts nouns and verbs occur, we implemented a model that keeps track of the frequency of triplets of adjacent words. This model gets trained on a corpus in which a few words are initially categorized, the *semantic seed*. Specifically, we hypothesize that when children start addressing the categorization problem, they already managed to learn the meaning of a few highly frequent content words, and group them into distinct categories (words referring to objects, words referring to actions). Recent experimental work makes this hypothesis highly plausible. On the one hand, Bergelson and Swingley (2012, 2013) have shown that 6- and 9-month-olds already know some nouns and some verbs. On the other hand, it has been proposed that infants are able to group concepts semantically, and form categories such as agents, artefacts, or actions (Carey, 2009; Saxe & Carey, 2006). Thus, words referring to actions can be grouped together and form the seed of the 'verb' category, while object-referring words may form the seed of the 'noun' category. For instance, let's assume that a given infant managed to learn the meaning of 'book', 'teddy', 'eat', 'baby', 'go', and 'drink', (because they are highly frequent and refer to concrete objects and actions), he may be able to group them into [book, baby, teddy] -- object referents – and [go, eat, drink] -- action referents. By noticing in which contexts the object referents often appear (e.g. after 'and the', or '# a', where # marks the beginning of an utterance), children might be able to decide that an unknown word, such as 'bunny' in 'and the bunny jumped', also belongs to the object-referent category (and similarly for action referents).

Because the model attempts to analyze two-word contexts in order to categorize nouns and verbs, it rests on the prerequisite that infants are able to keep track of bi- and tri-gram frequencies: a number of experiments support this assumption, showing that children as young as 12 months pay attention to this type of distributional information, both when exposed to artificial languages (e.g. Gomez & Gerken, 1999), and when listening to sentences in their mother tongue (Höhle, Schmitz, Santelmann, & Weissenborn, 2006; Santelmann & Jusczyk, 1998; van Heugten & Johnson, 2010).

In practice, the model stores two-word contexts for each word in the training corpus, and uses these contexts to categorize words in an unseen test corpus. In the training corpus, a few words from the *semantic seed* are categorized (into object-referents and action-referents). At test, the model attempts to predict the category of a word by looking at the two words immediately preceding it (its left context): if these two words were part of at least one trigram encountered during training, the model picks as answer the most frequent item occurring after these two words (which could be either the object-referent 'noun' category, the action-referent 'verb' category, or a specific lexical item). The results are presented in Fig. 3, for both precision and recall.

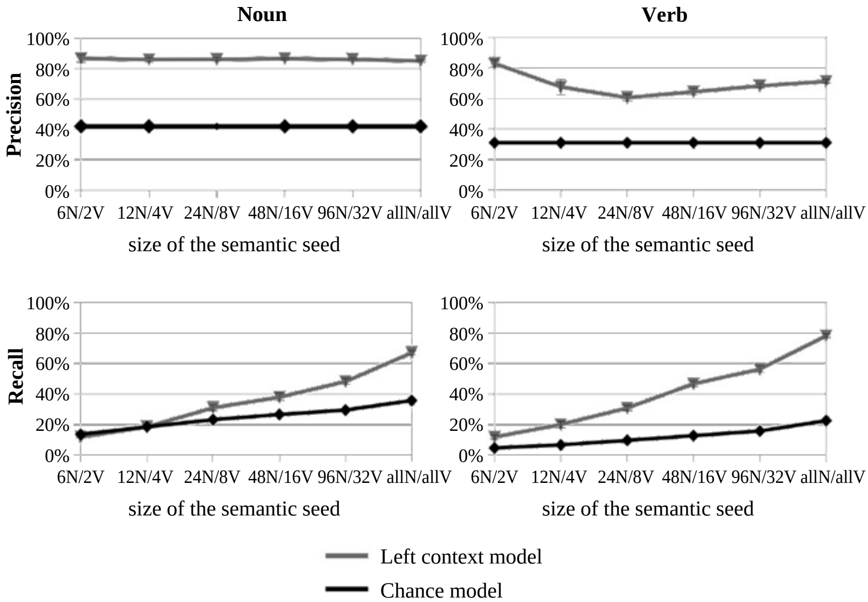

Figure 2: Precision and recall for Nouns (object-referents) and Verbs (action-referents). For each category, precision is computed as the number of hits divided by hits plus false alarms; and recall, as number of hits divided by hits plus misses. The x-axis presents the size of the semantic seed, starting with the smallest one on the left (only 6 nouns and 2 verbs initially known). The rightmost point is a control condition and presents the results when the model is trained on a corpus in which all nouns and verbs are initially categorized (not a plausible learning assumption, this condition gives the upper limit that can be achieved with this categorization method).

For noun and verb categorization, the model achieved a very good precision (between 65% and 85%) that did not depend on the size of the vocabulary initially known (varied parametrically between 2 verbs / 6 nouns to 48 verbs / 96 nouns). In contrast, the recall (the capacity of the model to find all the nouns and verbs), started rather low and improved with the size of the initial vocabulary, suggesting that when more words are known initially, more noun and verb contexts can be learned. Note that from the learner's point of view, a high precision is crucial, while a low recall does not impact learning too much. Indeed, whenever the learner hypothesizes that a given word belongs to the object- or action-category, this information will be used to constrain the potential meaning of that word, leading to wrong inferences if the categorization is incorrect (an undesirable consequence). In contrast, whenever a word is not categorized (low recall), the learner will not attempt to exploit the linguistic context to constrain meaning in that particular instance, and will simply wait until the same word is encountered in a more informative context, or exploit non-linguistic cues, if they are sufficiently informative. Additional analyses showed that even though function words were not encoded in a special way by the model, the contexts most frequently used by the model featured mostly function words (e.g., articles were excellent noun contexts, and personal pronouns made good verb contexts[1]). Thus, the mere frequency of function words made them play a crucial role in this context-based categorization model.

Altogether, this model supports the hypothesis that infants may be able to initially group words together on the basis of their immediate contexts, a result that is congruent with other computational models demonstrating successful categorization with unsupervised learning algorithms (Chemla, Mintz, Bernal, & Christophe, 2009; Mintz, 2003; Redington, Chater, & Finch, 1998; Weisleder & Waxman, 2010).

There are two important features of the model that contribute to its success: First, the model categorizes words only in context. In other words, the model's main aim is not to produce a lexicon in which each word is listed together with its category – or, in the (rather frequent) case of words with more than one category, with its possible categories. Instead, each to-be-categorized word is classified as a function of its immediate context, irrespective of the nature of the word itself. Because of this characteristic, the model can classify words that are

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[1] Note that some function words are ambiguous, and found before more than one category of content words; in French in particular, the definite articles '*la, le, les*' (resp. singular feminine, singular masculine, and plural), which typically precede nouns, are homophonous with object pronouns, which typically precede verbs – a non-trivial chunk of the model's noun-verb confusions came from such contexts. Interestingly, ERP experiments show that from the age of 18 months, French toddlers are not confused by such ambiguous function words, showing that they already perform an analysis which is more complex than the – admittedly extremely simplistic – context analysis performed by the model (Bernal, Dehaene-Lambertz, Millotte, & Christophe, 2010; Brusini, Dehaene-Lambertz, Dutat, Goffinet, & Christophe, 2016; Brusini, Dehaene-Lambertz, Van Heugten, et al., 2016).

encountered for the first time (a useful feature if categorization is going to help word meaning acquisition), and does not suffer when it encounters an ambiguous word. For instance, let's assume that the model first encounters the word *ring* in the sentence *the ring of the lady was really beautiful*, and categorizes it as an object-referent; and that it then encounters the word *ring* a second time, this time in the sentence *they ring the bell*: this word, in this context, will now be categorized as an action-referent. On each occasion, a child using such a strategy would attempt to learn the word's meaning appropriately (looking for an object in the environment in the first case, and for an action in the second one). In fact, recent evidence suggests that toddlers as young as 20 months of age do behave that way, in that they readily learn a novel meaning for a word-form that is already in their lexicon, provided it belongs to a different syntactic category (Dautriche, Fibla, & Christophe, 2015). This also explains why children this young already know the meaning of several pairs of noun-verb homophones, suggesting that their acquisition is not particularly difficult (de Carvalho, Dautriche, Lin, & Christophe, accepted).

Second, the *semantic seed* is highly efficient (even when it is very small), in that it allows this otherwise unsupervised algorithm to build two categories of content words (object-referents and action-referents) each of which achieved a high precision, even at the smallest size of the semantic seed (a mere 6 nouns and 2 verbs initially supposed to be known). In particular, this feature of the model neatly solves one of the problems encountered by other fully unsupervised clustering algorithms, which tend to build many different classes for each category (e.g. Gutman, Dautriche, Crabbé, & Christophe, 2015; Mintz, 2003). Seeding an unsupervised learning algorithm with semantic information has been successfully used in another model of syntactic boostrapping, by Christodoulopoulos, Roth & Fisher (2016) which relies on Hidden Markov Models to categorize predicates (verbs and adjectives) in terms of the number of arguments that they typically take – an information that is particularly useful to guess the possible meaning of predicates (Fisher, Gertner, Scott, & Yuan, 2010), and uses a few dozen nouns as semantic seed.

As efficient as this model is, it works from transcribed input, and does not include prosody. We saw in the first section however that phrasal prosody may help infants to recover the syntactic structure of sentences. To estimate whether it is possible to learn to categorize prosodic phrases, we built a Naïve Bayes model that takes as input a corpus of child-directed speech, in which prosodic boundaries are marked (the corpus was parsed syntactically, then the prosodic structure was derived from the syntactic structure by relying on the definitions provided by Nespor & Vogel, 1986). Just like the word-categorization model presented above, this model rests on the *semantic seed* assumption: a handful of nouns and verbs are assumed to be known by the infant and constitute a seed for creating prototypical noun and verb grammatical categories (Gutman, Dautriche, Crabbé, & Christophe, 2015). It initially assigns a label to the few prosodic units that contain one of these known words (Noun Phrase, Verb Phrase), then attributes probabilistically a label to all the prosodic phrases of the corpus (Noun

Phrase, Verb Phrase, and Unknown) based on some observed features for each prosodic unit: its two first words, and its last word (edge words are especially salient for listeners, including infants, e.g. Johnson et al., 2014). Results show an excellent precision of this model (between 75 and 85%), that does not depend on the size of the vocabulary initially known, i.e. the semantic seed. As in the previous model, although the initial categories are based on a few known words, the categorization process relies ultimately on function words. These results show that it is possible to categorize prosodic units with very little initial knowledge: If children can segment the speech stream into prosodic phrases, they can learn to categorize them simply by paying attention to edge-words (first and last words of a phrase) and by knowing the labels of a few objects and actions (two highly plausible assumptions).

3. Conclusion

To sum up the data presented in this paper, we suggest that children might be able to construct a first-pass syntactic structure of the sentences they hear by relying on two sources of information available early during their development: phrasal prosody and function words. We saw that from 20 months onwards, toddlers exploit the presence of phonological phrase boundaries to constrain their on-line syntactic analysis of sentences (de Carvalho, Dautriche, et al., 2016; de Carvalho, Lidz, et al., 2016), and that 18-month-old toddlers can use this structure to infer the syntactic category of novel words and deduce their probable meaning (as illustrated in section 1). As to the mechanisms through which toddlers may have managed to learn which function words go with which word categories, or more generally what syntactic contexts signal nouns and verbs, we presented modeling work suggesting that they might succeed by relying on a very small number of known object and action labels, a *semantic seed*.

One may wonder how universal such a process would be, given that most of the experimental data was obtained on a handful of languages. Since phrasal prosody is found in all the world's languages (e.g. Shattuck-Hufnagel & Turk, 1996, for a review), and since the links between syntactic structure and prosodic structure are described in a universal way (Nespor & Vogel, 1986; Selkirk, 1984), we would expect learners of all languages to be able to rely on phrasal prosody to help recover the syntactic structure of sentences. In fact, recent studies suggest that infants can even use non-native phrasal prosody for the purposes of finding syntactic constituents, in an artificial language (Hawthorne & Gerken, 2014; Hawthorne, Mazuka, & Gerken, 2015). Regarding function words, not all languages have free function words, like French and English; for instance, agglutinative languages such as Turkish use mostly bound functional morphemes. Other languages, such as Mandarin Chinese, are sometimes said to lack function words entirely; however a closer examination of these languages shows that even though they may lack some categories of function words (for instance, Mandarin Chinese does not use determiners), they possess other categories of function words which may play a similar role (for instance, Mandarin Chinese uses noun classifiers, which will not only give children the information that a given word is a noun and probably refers to an object, but also more precise information as to the kind of object that is referred to). In fact, Shi, Morgan & Allopenna (1998) conducted a cross-linguistic study of the cues which may allow infants to discover functional morphemes in the speech signal, comparing English, Turkish and Mandarin Chinese (three extremely well-chosen languages, as shown by the discussion above), and found that function morphemes in all of these languages possessed similar properties that may allow young children to identify them (high frequency, position with respect to utterance and prosodic edges, and a tendency to be reduced, both phonologically and acoustically). In addition, experimental work suggests that toddlers tend to selectively attribute meaning to items that are not-too-frequent, therefore treating highly frequent items as functional (Hochmann, 2013; Hochmann, Endress, & Mehler, 2010). Overall, we would expect a strategy relying on phrasal prosody and function words/morphemes to be efficient universally across the world's languages, although, of course, direct experimental evidence should be obtained.

Taken together, these results suggest that listeners (both adults and children) may construct a first-pass syntactic analysis of sentences, a *syntactic skeleton*, by relying on prosodic boundaries, which generally coincide with syntactic boundaries, and function words which signal the syntactic category of neighboring words. This approximate syntactic structure may help young children to constrain the meaning of novel words – in other words, it may allow learners to 'bootstrap their syntactic bootstrapper'.

References

Bergelson, Elika, & Swingley, Daniel. (2012). At 6-9 months, human infants know the meanings of many common nouns. *Proceedings of the National Academy of Sciences of the United States of America, 109*(9), 3253-3258. doi: 10.1073/pnas.1113380109

Bergelson, Elika, & Swingley, Daniel. (2013). Young Toddlers' Word Comprehension Is Flexible and Efficient. *Plos One, 8*(8). doi: 10.1371/journal.pone.0073359

Bernal, Savita, Dehaene-Lambertz, Ghislaine, Millotte, Séverine, & Christophe, Anne. (2010). Two-year-olds compute syntactic structure on-line. *Developmental Science, 12*, 69-76.

Bernal, Savita, Lidz, Jeffrey, Millotte, Séverine, & Christophe, Anne. (2007). Syntax constrains the acquisition of verb meaning. *Language Learning and Development, 3*, 325-341.

Brusini, Perrine, Dehaene-Lambertz, Ghislaine, Dutat, Michel, Goffinet, François, & Christophe, Anne. (2016). ERP evidence for on-line syntactic computations in 2-year-olds. *Developmental Cognitive Neuroscience, 19*, 164-173.

Brusini, Perrine, Dehaene-Lambertz, Ghislaine, Van Heugten, Marieke, de Carvalho, Alex, Goffinet, François, Fiévet, Anne-Caroline, & Christophe, Anne. (2016).

Ambiguous function words do not prevent 18-month-olds from building accurate syntactic category expectations: an ERP study. *Neuropsychologia*. doi: 10.1016/j.neuropsychologia.2016.08.015

Carey, Susan. (2009). *The origin of concepts*: Oxford University Press.

Cauvet, Elodie, Limissuri, Rita, Millotte, Séverine, Skoruppa, Katrin, Cabrol, Dominique, & Christophe, Anne. (2014). Function words constrain on-line recognition of verbs and nouns in French 18-month-olds. *Language Learning & Development, 10,* 1-18. doi: 10.1080/15475441.2012.757970

Chemla, Emmanuel, Mintz, Toben, Bernal, Savita, & Christophe, Anne. (2009). Categorizing words using "Frequent Frames": What cross-linguistic analyses reveal about distributional acquisition strategies. *Developmental Science, 12,* 396-406.

Christodoulopoulos, Christos, Roth, Dan, & Fisher, Cynthia. (2016). An Incremental Model of Syntactic Bootstrapping *Proceedings of the Seventh Workshop on Cognitive Aspects of Computational Language Learning*.

Christophe, Anne, Millotte, Séverine, Bernal, Savita, & Lidz, Jeffrey. (2008). Bootstrapping lexical and syntactic acquisition. *Language and Speech, 51,* 61-75. doi: 10.1177/00238309080510010501

Christophe, Anne, Nespor, Marina, Guasti, Maria Teresa, & van Ooyen, Brit. (2003). Prosodic structure and syntactic acquisition: the case of the head-direction parameter. *Developmental Science, 6,* 211-220.

Dautriche, Isabelle, Fibla, Laia, & Christophe, Anne. (2015). *Learning homophones: syntactic and semantic context matters*. Paper presented at the Boston University Conference on Language Development, Boston (USA).

de Carvalho, Alex, Dautriche, Isabelle, & Christophe, Anne. (2016). Preschoolers use phrasal prosody online to constrain syntactic analysis. *Developmental Science, 19,* 235-250. doi: 10.1111/desc.12300

de Carvalho, Alex, Dautriche, Isabelle, Lin, Isabelle, & Christophe, Anne. (accepted). Phrasal prosody constrains syntactic analysis in toddlers. *Cognition.*

de Carvalho, Alex, Lidz, Jeffrey, Tieu, Lyn, Bleam, Tonia, & Christophe, Anne. (2016). English-speaking preschoolers can use phrasal prosody for syntactic parsing. *Journal of the Acoustical Sociey of America, 139*(6), EL216-EL222. doi: dx.doi.org/10.1121/1.4954385

Ferry, Alissa, Flo, Ana, Brusini, Perrine, Cattarossi, Luigi, Macagno, Francesco, Nespor, Marina, & Mehler, Jacques. (2016). On the edge of language acquisition: inherent constraints on encoding multisyllabic sequences in the neonate brain. *Developmental Science, 19,* 488-503.

Fisher, Cynthia, Gertner, Yael, Scott, Rose M., & Yuan, Sylvia. (2010). Syntactic bootstrapping. *Wiley Interdisciplinary Reviews: Cognitive Science, 1,* 143–149.

Gerken, LouAnn, Jusczyk, Peter W., & Mandel, Denise R. (1994). When prosody fails to cue syntactic structure: 9-month-olds' sensitivity to phonological versus syntactic phrases. *Cognition, 51,* 237-265.

Gleitman, Lila. (1990). The structural sources of verb meanings. *Language Acquisition, 1,* 3-55.

Gomez, Rebecca L., & Gerken, LouAnn. (1999). Artificial grammar learning by 1-year-olds leads to specific and abstract knowledge. *Cognition, 70*(2), 109-135. doi: 10.1016/s0010-0277(99)00003-7

Gout, Ariel, Christophe, Anne, & Morgan, James L. (2004). Phonological phrase boundaries constrain lexical access: II. Infant data. *Journal of Memory and Language, 51,* 548-567.

Gutman, Ariel, Dautriche, Isabelle, Crabbé, Benoît, & Christophe, Anne. (2015). Bootstrapping the syntactic bootstrapper: Probabilistic labelling of prosodic phrases. *Language Acquisition, 22*, 285-309.

Hallé, Pierre, Durand, Catherine, & de Boysson-Bardies, Bénédicte. (2008). Do 11-month-old French infants process articles? *Language and Speech, 51*, 45-66. doi: 10.1177/00238309080510010301

Hawthorne, Kara, & Gerken, LouAnn. (2014). From pauses to clauses: Prosody facilitates learning of syntactic constituency. *Cognition, 133*(2), 420-428. doi: 10.1016/j.cognition.2014.07.013

Hawthorne, Kara, Mazuka, Reiko, & Gerken, LouAnn. (2015). The acoustic salience of prosody trumps infants' acquired knowledge of language-specific prosodic patterns. *Journal of Memory and Language, 82*, 105-117. doi: 10.1016/j.jml.2015.03.005

He, Angela X., & Lidz, Jeffrey. (2014). *Development of the verb-event link between 14 and 18 months*. Paper presented at the Boston University Conference on Language Development.

Hochmann, Jean-Remy. (2013). Word frequency, function words and the second gavagai problem. *Cognition, 128*(1), 13-25. doi: 10.1016/j.cognition.2013.02.014

Hochmann, Jean-Remy, Endress, A. D., & Mehler, J. (2010). Word frequency as a cue for identifying function words in infancy. *Cognition, 115*, 444-457. doi: 10.1016/j.cognition.2010.03.006

Höhle, Barbara, Schmitz, Michaela, Santelmann, Lynn M., & Weissenborn, Jürgen. (2006). The recognition of discontinuous verbal dependencies by German 19-month-olds: Evidence for lexical and structural influences on children’s early processing capacities. *Language Learning and Development, 2*, 277-300.

Hohle, Barbara, Weissenborn, Jürgen, Kiefer, Dorothea, Schulz, Antje, & Schmitz, Michaela. (2004). Functional elements in infants' speech processing: The role of determiners in the syntactic categorization of lexical elements. *Infancy, 5*(3), 341-353. doi: 10.1207/s15327078in0503_5

Johnson, Elizabeth K. (2008). Infants use prosodically conditioned acoustic-phonetic cues to extract words from speech. *Journal of the Acoustical Society of America, 123*, EL144-EL148.

Johnson, Elizabeth K., Seidl, Amanda, & Tyler, Michael D. (2014). The edge factor in early word segmentation: Utterance-level prosody enables word form extraction by 6-Month-Olds. *Plos One, 9*(1). doi: 10.1371/journal.pone.0083546

Kedar, Yarden, Casasola, Marianella, & Lust, Barbara. (2006). Getting there faster: 18- and 24-month-old infants' use of function words to determine reference. *Child Development, 77*(2), 325-338. doi: 10.1111/j.1467-8624.2006.00873.x

Landau, Barbara, & Gleitman, Lila. (1985). *Language and Experience - Evidence from a Blind Child*: Cambridge Mass.: Harvard University Press.

Mampe, Birgit, Friederici, Angela D., Christophe, Anne, & Wermke, Kathleen. (2009). Newborns' cry melody Is shaped by their native language. *Current Biology, 19*(23), 1994-1997. doi: 10.1016/j.cub.2009.09.064

Martin, Andrew, Peperkamp, Sharon, & Dupoux, Emmanuel. (2013). Learning phonemes with a proto-lexicon. *Cognitive Science, 37*(1), 103-124. doi: 10.1111/j.1551-6709.2012.01267.x

Massicotte-Laforge, Sarah, & Shi, Rushen S. (2015). The role of prosody in infants' early syntactic analysis and grammatical categorization. *Journal of the Acoustical Society of America, 138*(4), EL441-EL446. doi: 10.1121/1.4934551

Mehler, Jacques, Jusczyk, Peter W., Lambertz, Ghislaine, Halsted, G., Bertoncini, Josiane, & Amiel-Tison, Christine. (1988). A precursor of language acquisition in young infants. *Cognition, 29*, 143-178.

Millotte, Séverine, Morgan, James L., Margules, Sylvie, Bernal, Savita, Dutat, Michel, & Christophe, Anne. (2010). Phrasal prosody constrains word segmentation in French 16-month-olds. *Journal of Portuguese Linguistics, 9*, 67-86.

Millotte, Séverine, René, Alice, Wales, Roger, & Christophe, Anne. (2008). Phonological phrase boundaries constrain on-line syntactic analysis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34*, 874-885. doi: 10.1037/0278-7393.34.4.874

Millotte, Séverine, Wales, Roger, & Christophe, Anne. (2007). Phrasal prosody disambiguates syntax. *Language and Cognitive Processes, 22*, 898-909. doi: 10.1080/01690960701205286

Mintz, Toben H. (2003). Frequent frames as a cue for grammatical categories in child-directed speech. *Cognition, 90*, 91-117.

Morgan, James L. (1986). *From simple input to complex grammar*. Cambridge Mass: MIT Press.

Morgan, James L., & Demuth, Katherine (1996). *Signal to Syntax: Bootstrapping from speech to grammar in early acquisition*. Mahwah NJ: Lawrence Erlbaum Associates.

Nespor, Marina, & Vogel, Irene. (1986). *Prosodic Phonology*. Dordrecht: Foris.

Redington, Martin, Chater, Nick, & Finch, Steven. (1998). Distributional information: A powerful cue for acquiring syntactic categories. *Cognitive Science, 22*(4), 425-469. doi: 10.1207/s15516709cog2204_2

Santelmann, Lynn M., & Jusczyk, Peter W. (1998). Sensitivity to discontinuous dependencies in language learners: evidence for limitations in processing space. *Cognition, 69*, 105-134.

Saxe, Rebecca, & Carey, Susan. (2006). The perception of causality in infancy. *Acta Psychologica, 123*(1-2), 144-165. doi: 10.1016/j.actpsy.2006.05.005

Selkirk, Elisabeth O. (1984). *Phonology and Syntax: the Relation between Sound and Structure*. Cambridge Mass.: MIT Press.

Shattuck-Hufnagel, Stefanie, & Turk, Alice E. (1996). A prosody tutorial for investigators of auditory sentence processing. *Journal of Psycholinguistic Research, 25*, 193-247.

Shi, Rushen. (2014). Functional morphemes and early language acquisition. *Child Development Perspectives, 8*(1), 6-11. doi: 10.1111/cdep.12052

Shi, Rushen, Cutler, Anne, Werker, Janet F., & Cruickshank, Marisa. (2006). Frequency and form as determinants of functor sensitivity in English-acquiring infants. *Journal of the Acoustical Society of America, 119*, EL61-EL66. doi: 10.1121/1.2198947

Shi, Rushen, & Gauthier, Bruno. (2005). Recognition of function words in 8-month-old French-learning infants. *Journal of the Acoustical Society of America, 117*, 2426-2427. doi: 10.1121/1.4786583

Shi, Rushen, & Melançon, Andréane. (2010). Syntactic categorization in French-learning infants. *Infancy, 15*, 517-533. doi: 10.1111/j.1532-7078.2009.00022.x

Shi, Rushen, Morgan, James L., & Allopenna, Paul. (1998). Phonological and acoustic bases for earliest grammatical category assignment: a cross-linguistic perspective. *Journal of Child Language, 25*(1), 169-201. doi: 10.1017/s0305000997003395

Shukla, Mohinish, Nespor, Marina, & Mehler, Jacques. (2007). An interaction between prosody and statistics in the segmentation of fluent speech. *Cognitive Psychology, 54*, 1-32.

Soderstrom, Melanie, Seidl, Amanda, Kemler Nelson, Deborah G., & Jusczyk, Peter W. (2003). The prosodic bootstrapping of phrases: Evidence from prelinguistic infants. *Journal of Memory and Language, 49*, 249-267.

van Heugten, Marieke, & Johnson, Elizabeth K. (2010). Linking infants' distributional learning abilities to natural language acquisition. *Journal of Memory and Language, 63*(2), 197-209. doi: 10.1016/j.jml.2010.04.001

Waxman, Sandra R., Lidz, Jeffrey L., Braun, Irena E., & Lavin, Tracy. (2009). Twenty four-month-old infants' interpretations of novel verbs and nouns in dynamic scenes. *Cognitive Psychology, 59*(1), 67-95. doi: 10.1016/j.cogpsych.2009.02.001

Weisleder, Adriana, & Waxman, Sandra. (2010). What's in the input? Frequent frames in child-directed speech offer distributional cues to grammatical categories in Spanish and English. *Journal of Child Language, 37*(5), 1089-1108. doi: 10.1017/s0305000909990067

Werker, Janet F., Cohen, Leslie B., Lloyd, Valerie L., Casasola, Marianella, & Stager, Christine L. (1998). Acquisition of word-object associations by 14-month-olds. *Developmental Psychology, 34*, 1289-1309.

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