Functional categories, determiners, prosody and early child grammar

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Abstract

This chapter concerns infants' initial language acquisition. Based on findings of studies with infants from birth to 2.5 years of age, I advance the idea that functional categories and prosody conjointly bootstrap early acquisition (Christophe, Guasti, & Nespor, 1997; Christophe, Millotte, Bernal, & Lidz, 2008; Morgan, Shi, & Allopenna, 1996; Shi, Morgan, & Allopenna, 1998; Shi, 2014). Shortly after birth infants use acoustic-phonetic and prosodic cues as well as frequency cues to find specific functional morphemes in their native language input. They then use these items to learn lexical words and interpret phrasal structures. The experimental results on determiners are particularly illuminating. These words are among the first that infants track from continuous speech input. By age one, infants treat them as an abstract functional category and use it to activate larger syntactic structures. They rely on determiners to perform grammatical categorization and feature assignment for lexical words, and these processes operate within the constraint of the activated phrasal structure. I show with empirical evidence that infants do not construct phrase structures by linear/serial statistics. Rather, their syntactic analyses, including certain statistical computations, are guided by the hierarchical structures of the grammar.

Functional categories such as determiners, auxiliaries and complementizers are essential components of the grammar. Relative to lexical categories (e.g., nouns, verbs, adjectives), functional categories are more subtle and complex in word meaning. They are, however, important for signalling relations among lexical categories. They are the skeletons of grammatical structures and are crucial for all syntactic theories. How young children learn functional categories is the center of syntactic acquisition research.

One classical observation in child language research is that functional categories are absent in early speech production up to about two years of age. Speech production starts with one-word utterances shortly before age one, followed by short word combinations from about 1.5 years of age. These early utterances consist nearly exclusively of words of lexical categories. This observation led to the view that early child language contains no or little syntax, and that functional categories must be gradually acquired after significant knowledge of lexical categories has been established.

In this chapter I argue for a developmental story that is different drastically from the conventional view. I will discuss the experimental findings showing that the acquisition of functional elements[1] starts from the first year of life, even before the onset of speech production, and that the processing of these elements becomes sophisticated during the second year of life. In Sections 1 and 2, I present an overview of experimental findings supporting the prosody-functor bootstrapping model of language acquisition. Section 3 gives an in-depth discussion of a series of perceptual studies that specifically examined the processing of determiners and the related syntactic acquisition during the initial 2.5 years of life.

1. Functional categories and early language acquisition: The prosody-functor bootstrapping model

How infants break into early language has long intrigued acquisition researchers. The idea of the prosody-functor bootstrapping model is that functional morphemes, together with prosody, can guide babies in their initial grammatical and lexical analyses. This model might appear counter-intuitive, given that it is well known from early corpus studies that speech by children under two years of age is telegraphic, containing primarily lexical words and lacking functional morphemes (e.g., Brown, 1973). However, there were clues in later studies suggesting that young children have knowledge of functional morphemes, and that the omissions are because of certain factors. Two-year-olds omit functional items in their production due to phonological constraints (e.g., Dye, 2011; Demuth & Tremblay, 2008) or processing limitations such as sentence complexity and memory (e.g., Valian & Aubry, 2005). For example, French-learning children drop determiners more often when these words precede bisyllabic nouns than when they precede monosyllabic nouns (Demuth & Tremblay, 2008). They omit the determiner in *le ballon* but not in *la balle* so that the utterances conformed to the prosodic foot.

[1] Functional elements here refer to words or bound morphemes of functional categories. The terms functional morphemes, functors, functional elements and functional items are often used interchangeably in the field to mean either grammatical affixes (e.g., tense endings) or function words (free morphemes).

Knowledge of functional morphemes was also observed in controlled production experiments. Using an imitation task, Gerken, Landau, and Remez (1990) found that toddlers tended to omit functional morphemes, but not nonsense functors that were prosodically comparable. They repeated *Pete bounce the ball* upon hearing *Pete bounces the ball*, omitting the functor *–es*, whereas their repetition of *Pete pusha ko truck*, which included a prosodically matched nonsense functor *–a*, was intact. Children seemed to deliberately drop *–es* based on their knowledge about the suffix and the morphological relationship between uninflected and inflected variants of words. These studies thus suggest that the lack of functional elements in productions does not necessarily imply a lack of representations. Rather, knowledge of functional categories might be much richer early in acquisition than is commonly assumed.

This reasoning is expressed in the prosody-functor bootstrapping model (Shi, 2014) and in earlier versions of this theory, including prosodic bootstrapping and function word stripping (Christophe, Guasti, & Nespor, 1997; Morgan, Shi, & Allopenna, 1996; Shi, Morgan, & Allopenna, 1998). The theory proposes that functional morphemes, together with prosody, serve as the first available information in the input for guiding infants to break into grammar and to learn about lexical words. The prosody part of the model concerns the idea that certain grammatical structures have prosodic correlates in the spoken input, which may enable infants to start the initial syntactic analysis. For instance, infants can find certain clauses and phrases based on the prosodic groupings and assign words to different grammatical categories by their distinct prosodic properties. In this chapter I discuss the idea that at the initial stage of acquisition, infants use functional categories to project higher syntactic structures, and that phrasal prosody serves to limit the constituent scopes of this analysis. I will argue further that the way that infants represent functional categories and use them to bootstrap syntax agrees with the predictions of the generative grammar. As discussed in the next sections, these proposals of the prosody-functor bootstrapping model are supported by experimental studies with newborns and infants.

2. From a broad binary distinction to detailed functional categories

Methodological advances in speech perception procedures and ERP measures have made it possible to more directly test certain hypotheses about representations of functional categories in early infancy. In such experiments carefully manipulated speech materials including those that infants do not yet produce can be presented, and infants' brain responses (ERP) or behavioural responses can indicate their knowledge about the speech stimuli. The ERP technique, which can be used to study infants' detection of phonetic, lexical or grammatical distinctions, measures brain responses without requiring any behaviour from the infant. Behavioural techniques, on the other hand, are more commonly used and have yielded robust data across labs. For babies from birth to a few months of age, the high-amplitude sucking paradigm can be used to present speech stimuli contingent upon the baby's sucking on a pacifier, which is connected by a tube to a computer. The baby's sucks are automatically recorded and calculated by the procedure. Sucking rate (per minute) towards different stimuli can reveal infants' discrimination ability.

The most widely used methods for studying language processing and acquisition are preferential looking and eye-tracker procedures, suitable for many ages (starting from two months). Visual responses require minimal motor activities on the child and are thus less demanding than responses in other tasks (such as pointing or production). A display on a TV (for example, a checkerboard, a talking puppet, one or more objects, an event, etc.) and speech stimuli are simultaneously presented during each trial, and the child's listening responses (measured in terms of eye fixations towards the visual stimuli) are recorded by a computer program. Linguistic knowledge can be interpreted from looking patterns (i.e., listening patterns) for different types of stimuli. For example, an experiment may present a cartoon character speaking grammatical versus ungrammatical sentences as distinct trials. If infants do not differ statistically in their looking durations in grammatical trials and ungrammatical trials, there is then no evidence that the knowledge is present. On the other hand, a statistically significant looking time difference for the two types of trials indicates that infants as a group represent the knowledge. The looking time difference can either be longer looking for grammatical trial (i.e., familiarity preference), or longer looking for the ungrammatical trials (i.e., a novelty effect, suggesting surprise to incorrect stimuli). It has been shown in the literature that infants tend to show a novelty preference for easier stimuli and robust knowledge, and they likely show a familiarity preference for complex stimuli and emerging knowledge (e.g., Cyr & Shi, 2013; Hunter & Ames, 1988; Thiessen & Saffran, 2003). The direction of looking preference cannot always be predicted in such experiments. What is important is that it is justified to interpret either direction as a demonstration of a capacity since a group effect in either direction of preference is unlikely to occur by statistical chance. Note that the direction of preference can be predicted in certain task manipulations. For instance, in habituation experiments, where one type of stimuli is presented repeatedly until the child becomes bored, a looking increase (i.e., a novelty preference) is expected for a new type of stimuli in the test phase if the child can discriminate the test stimuli from the habituation stimuli.

Infant studies using such experimental methods have shown that functional categories begin to be acquired from birth and subsequently bootstrap various language acquisition tasks (such as the segmentation, grammatical categorization and interpretation of the meanings of adjacent lexical words, as well as the analysis of phrase structures), consistent with the prosody-functor bootstrapping model.

There is evidence that infants at birth are already equipped with the perceptual capacities to process the prosodic, frequency and distributional patterns of functional items. The initial perception of grammatical categorization seems to involve a broad binary division, functional versus lexical categories, based on distinct acoustic-phonetic and phonological cues that are language-general. As shown in analyses of input speech across typologically distinct languages (Monaghan, Christiansen, & Chater, 2007; Shi, Morgan & Allopenna, 1998), functional items are generally reduced in their spoken forms relative to lexical words. Functional items are mostly little words (e.g., with few phonemes and minimized duration/amplitude), whereas lexical words tend to have fuller forms (with more phonemes/syllables and prominent acoustic properties). This pattern is probabilistic, but the constellations of multiple cues support the binary distinction (Monaghan, Christiansen, & Chater, 2007; Shi, Morgan & Allopenna, 1998). For example, although there are some small lexical words, the large majority of them are

fuller than functional items. In a study using the high-amplitude sucking paradigm, Shi, Werker & Morgan (1999) found that one- to three-day-old newborns perceived the cues and categorically discriminated function words and lexical words. Specifically, babies were habituated with words from one class (e.g., lexical words) and were tested either with exemplars of the other class (e.g., function words) or with new exemplars of the same class. The results revealed that sucking rate increased significantly more for the new class than for new exemplars of the same class. The newborns also showed language-general responses: both the group that heard English prenatally and the group exposed prenatally to a different language (mostly Asian languages) discriminated the two kinds of words in English in the same fashion. The categorical discrimination shown by the newborns was similar to the successful category learning by unsupervised neural networks (Shi, Morgan & Allopenna, 1998). Subsequent cross-language perceptual experiments (looking tasks) with six-month-old English-learning and Chinese-learning infants (Shi & Werker, 2001, 2003) further confirmed that infants can rely on language-general acoustic-phonetic cues to categorically discriminate the two broad classes of words.

Starting language acquisition with this broad binary categorical division is optimal, as these two basic categories are distinct in their linguistic functions. The initial bifurcation can prepare infants to treat the two global classes differently in subsequent learning, for example, using functional morphemes to project grammatical structures and focusing more on meaning for lexical words. Although languages vary in the exact kinds of refined grammatical categories that are included, the broad binary division of functional and lexical categories is language universal, and their basic acoustic-phonetic and phonological distinction (i.e., functional morphemes being reduced in form relative to lexical categories) is also universal (Monaghan, Christiansen, & Chater, 2007; Shi, Morgan & Allopenna, 1998). Humans apparently have evolved to have innate perceptual mechanisms to process this fundamental binary categorical distinction from birth, as shown in Shi, Werker and Morgan (1999).

The two categories are also distinct in their frequency and distribution. In contrast to lexical words, which are vast in total number but relatively infrequent in occurrence, functional morphemes are a tiny set with each item occurring highly frequently. Distributionally, functional categories occupy particular positions relative to lexical words in the phrasal structure. For example, function words tend to occur phrase-initially in head-initial languages such as English and Italian, but phrase-finally in head-final languages such as Japanese and Turkish. In an artificial language experiment (Gervain, Nespor, Mazuka, Horie, & Mehler, 2008) eight-month-old infants were familiarized with nonsense syllables that were strung together continuously, a few appearing frequently and many others infrequently, simulating function words versus lexical words. Infants were tested with two types of short sequences taken from the training string: frequent-infrequent versus infrequent-frequent. Italian infants preferred frequent-infrequent sequences, and Japanese infants preferred infrequent-frequent ones, consistent with the opposite head directions of the two languages. Functor-like frequent syllables seemed to serve as anchors for parsing continuous speech into phrase-like units.

Following the initial broad binary categorization of functional versus lexical categories, infants must learn detailed functional categories (such as determiner and auxiliary categories) as well as individual functional items of their native language.

Perceptual studies revealed that the learning of native-language functional items begins at about six months of age, long before infants produce their first words. In preferential looking tasks (Hallé, Durand, & de Boysson-Bardies, 2008; Höhle & Weissenborn, 2003; Shi & Lepage, 2008; Shi, Cutler, Werker, & Cruickshank, 2006; Shi, Marquis & Gauthier, 2006; Shi, Werker & Cutler, 2006) and in an ERP experiment (Shafer, Shucard, Shucard, & Gerken, 1998), English-, French- and German-learning infants aged 8 to 11 months showed evidence of segmenting and storing function words in their respective languages, distinguishing them from mispronounced nonsense functors. In addition to free function words, French-learning 11-month-olds and English-learning 15-month-olds have been shown to recognize and store bound functional inflectional suffixes, and generalize the processing to the context of novel lexical stems (Marquis & Shi, 2012; Mintz, 2013). It is striking that although functional items are reduced in the spoken form, infants represent them in phonetic detail and are acutely sensitive to mispronunciations before one year of age.

As soon as infants store some functors in memory, they immediately put them into use, even though their early semantic and syntactic knowledge of these items per se might still be impoverished. French- and English-learning 8- to 11-month-olds not only encode the word forms of determiners in their language, but also use them to segment adjacent words (Shi & Lepage, 2008; Shi, Cutler, Werker, & Cruickshank, 2006). For example, in Shi, Cutler, et al. (2006), infants perceived *the breek* as two separate words, i.e., they used the determiner *the* to segment the adjacent *breek.* In contrast, they treated *ke* (a mispronunciation of the onset consonant of *the*) distinctly, perceiving *ke tink* as one bisyllabic form.

Shortly after their first birthday, infants show knowledge of refined functional categories. They begin to group the appropriate individual words into the determiner class (Shi & Melançon, 2010) and pay attention to their category relationship with adjacent familiar and novel nouns (Babineau, Shi, & Christophe, 2020; Höhle, Weissenborn, Kiefer, Schulz, & Schmitz, 2004; Kedar, Casasola, & Lust, 2006; Kedar, Casasola, Lust, & Parmet, 2017; Shi & Melançon, 2010). Around 1.5 years of age, infants exposed to grammatical gender languages further divide determiners to sub-gender classes and use them to assign novel nouns to corresponding gender classes (Cyr & Shi, 2013; Van Heugten & Christophe, 2015). Around this age, infants also track the structural dependencies between non-adjacent functional items (e.g., Höhle, Schmitz, Santelmann, & Weissenborn, 2006; Santelmann & Jusczyk, 1998; Van Heugten & Shi, 2010). For example, English-learning infants perceive sentences containing the '*is* V-*ing*' dependency as grammatical, and '*can* V-*ing*' as ungrammatical (Santelmann & Jusczyk, 1998). They detect the ungrammaticality of functional morphemes in utterances containing real and nonsense lexical words such as *he book this reads* and *meep are good* (*meep* is a nonsense noun in English) (Soderstrom, White, Conwell, & Morgan, 2007). The use of function words for categorizing novel lexical words has been shown in English-learning infants (Mintz, 2006) and Mandarin-Chinese-learning infants (Zhang, Shi, & Li, 2015) as young as 12 months of age. Many of these studies used nonsense lexical words, which were unknown to infants. Thus, the findings were not a reflection of memorized sequences from infants' prior natural input; rather, they reflect grammatical productivity during early acquisition. Infants even used function words to do grammatical categorization in an artificial language (Gomez & Lakusta, 2004) and in a natural foreign

language (Gerken, Wilson, & Lewis, 2005) after being briefly familiarized with utterances of the languages containing distributional cues typical of lexical and functional items.

Functional items also assist the learning of word meaning from an early age. Infants understand that lexical items are more important for conveying meaning and functional items are more crucial for syntax. When exposed to continuous utterances of a foreign language or an artificial language in a perceptual learning task (Hochmann, 2013; Hochmann, Endress, & Mehler, 2010), 17-month-olds quickly distinguished function words and lexical words based on their distributions and/or sound properties, and preferred to map novel objects to the lexical words rather than to the function words. A number of studies found that infants' interpretation of the meaning of lexical words is constrained by syntactic structures, which typically involved functional categories. For example, while watching a novel object engaging in a novel action and hearing a sentence containing a novel word, infants would interpret the word as a noun referring to the novel object (e.g., *It's a gorp*) or a verb referring to the action (e.g., *he is gorping*), depending on the contextual functional items. This processing has been shown in studies with toddlers from 18 months of age in several languages such as English, French, Japanese and Turkish (e.g., Bernal, Lidz, Millotte, & Christophe, 2007; Göksun, Küntay, & Naigles, 2008; He & Lidz, 2017; Oshima-Takane, Ariyama, Kobayashi, Katerelos, & Poulin-Dubois, 2011; Waxman, Lidz, Braun, & Lavin, 2009). The effect of functional items shown in these studies is consistent with the theory of syntactic bootstrapping (Gleitman, 1990), which proposed that early syntactic knowledge guides infants' learning of word meaning.

Overall, the evidence is clear that infants begin to process functional categories from birth, that during the initial two years of acquisition they progress from a broad binary category division (functional versus lexical) to detailed categories, with functional categories emerging early, and that they show sophisticated knowledge of phrase structures related to functional categories.

3. Determiners and syntactic knowledge in early child language

The focus of Section 3 is on the acquisition of determiners (for example, *the* in English, *le* in French) and the related syntactic structures during the first few years of life. I will discuss in detail a series of experiments, with the aim to demonstrate that infants' early knowledge contains abstract syntax consistent with generative grammar, and that the learner's structural analysis is constrained by the grammar.

3.1. Determiners, nouns and noun phrases

During the second half of the first year of life infants begin to build a receptive vocabulary of their native language (Bergelson, & Swingley, 2012; Fenson, Dale, Reznick, Bates, Thal, & Pethick, 1994). As discussed above, determiners are among the first stored word forms (Hallé, Durand, & de Boysson-Bardies, 2008; Shi & Lepage, 2008; Shafer, Shucard, Shucard, & Gerken, 1998; Shi, Werker & Cutler, 2006), starting

with the most frequent ones, e.g., *the* in English (Shi, Cutler, Werker, & Cruickshank, 2006).

Around one year of age, infants use determiners to categorize the adjacent novel words as nouns (French: Shi & Melançon, 2010; German: Höhle, et al., 2004). In Shi and Melançon (2010), for example, French-learning 14-month-olds were familiarized with phrases each consisting of a French determiner (i.e., *ton* 'your', *des* - indefinite plural article) followed by a novel word, e.g., *ton mige*, *ton crale*, *des miges*, *des crales*. They were then tested with the same novel words preceded by a new determiner (i.e., *le* 'the') versus a subject-pronoun (i.e., *tu* 'you'), e.g., *le mige/crale* versus *tu miges/crales.* Note that the -s ending in the spelling of second person singular verbs in French is silent. That is, *mige* and *miges* were pronounced identically. Auditory stimuli were synchronized with a visual display, and infants controlled the presentation of the two types of test utterances by their looking. Results showed that they discriminated the two types of test utterances. They listened longer to the ungrammatical utterances *tu miges/crales*. Another group of 14-month-olds were familiarized with the same novel words preceded by subject-pronoun (i.e., *je* 'I', *il* 'he'), e.g., *je mige*, *je crale, il mige*, *il crale*. They then heard the same test utterances as did the first group. For this group the ungrammatical test trials were the noun phrases *le mige/crale* whereas *tu miges*/*crales* was grammatical, opposite of the grammaticality for the first group of infants. However, this group did not discriminate the two types of test utterances, producing no difference in listening time. They in fact listened long to both types of test utterances, suggesting that the co-occurrences of the novel words with the non-familiarized subject-pronoun or the determiner were equally new to infants. This response was an indication that the novel words *mige*/*crale* were not categorized as verbs following their co-occurrence with the subject-pronouns *il* and *je* in the familiarization. These results are similar to those found with German-learning infants in a different preferential looking procedure (Höhle, et al., 2004).

These observations reveal that by 14 months of age infants perceive individual determiners as belonging to one common grammatical class and identify the co-occurring novel word as a noun. They generalized the categorical relation to novel phrasal combinations that they had never heard before, indicating grammatical productivity and abstraction. This suggests that infants' knowledge is beyond memorized formulaic exemplars in item-specific constructivist models of syntactic acquisition (e.g., Pine & Lieven, 1997; Tomasello, 2000).

What is the nature of the knowledge in infants' processing of determiners in Shi and Melançon (2010) and Höhle, et al. (2004)? Is the processing guided by syntactic knowledge (as defined in generative grammar), or induced entirely from statistical learning of the input? Child language researchers from the UG perspective (e.g., Valian, 2009; Yang, 2004, 2017) maintain that infants are endowed with abstract syntactic categories and structures, and that acquisition is a process of triggering this knowledge by the ambient input and working out language-specific properties. During this process, frequency- and probability-based learning can occur under the constraints and guidance of UG knowledge. On this view, the following interpretation can be made. The categorization results in Shi and Melançon (2010) and Höhle, et al. (2004) reflect the instantiation of the innately given determiner category and the functional projection of the determiner to an upper phrasal category NP (or DP). The determiner and noun categories are under the same NP, forming a close dependency that is low in the

hierarchical structure. Thus, the relation should be more accessible for infants early in acquisition, and more natural for probability computation. In contrast, the subject-pronoun and verb are not directly adjacent in the structure, as the two categories are dominated by separate phrases: NP above the pronoun and VP above the verb. The NP and VP are conjoined to form the next higher unit in the hierarchy. Consequently, verb categorization in pronoun context should be less natural and more complex to process. In short, infants do not just compute linear probabilities for any co-occurring words. Their analysis must be guided by the grammar. The results of the Shi and Melançon (2010) are consistent with this idea. They showed that at 14 months of age infants can easily use determiners to categorize novel nouns, but have difficulty using subject-pronouns to categorize verbs. Kedar, et al. (2017) found that even at 12 months, infants use the determiner *the* to predict and interpret familiar nouns within an NP; their noun processing was impeded when the noun was preceded by an ungrammatical functor, by a nonsense functor or by no functor. In contrast, verb categorization following a subject-pronoun seems harder. Successes have been observed for familiar verbs in 18-month-olds (Cauvet, et al., 2014), and for novel verbs in 14- and 20-month-olds when extra support of known verbs (Babineau, Shi, & Christophe, 2020) or a prosodic break between the subject-NP and the verb (Massicotte-Laforge & Shi, 2015) was provided in experiments. As discussed in Section 3.2, verb categorization most likely involves relations of higher constituents such as the subject-NP with the main-VP.

Can the 14-month-olds' responses to the determiner - noun and pronoun - verb relations be explained by purely inductive mechanisms? According to the proposal of statistical learning, infants learn phrase structures from serially ordered input by tracking transitional probabilities between categories (Saffran, 2001). The transitional probability, for example, between categories A and B, i.e., P(A B), is defined as the ratio between the number of A-B sequences and the number of A-X sequences, where X can be any category. If this transitional probability is high, the learner can use A to predict (i.e., to categorize) B. In the case of the determiner - noun and pronoun - verb relations, it is necessary to know their respective transitional probabilities, i.e., P(Det N), and P(Pron V), in children's input, that is, the probabilities for a determiner to predict a noun and for a pronoun to predict a verb. It is more plausible to expect functional items to be used to predict lexical items, rather than vice versa. This is because the former is a highly frequent tiny set of items co-occurring often with the latter, a vast infrequent set requiring years of learning, and functional items begin to be stored by infants before one year of age (Hallé, Durand, & de Boysson-Bardies, 2008; Shafer, Shucard, Shucard, & Gerken, 1998; Shi & Lepage, 2008; Shi, Cutler, Werker, & Cruickshank, 2006; Shi, Marquis & Gauthier, 2006; Shi, Werker & Cutler, 2006). In a recent computational analysis of approximately 2.5 million words of French input speech in CHILDES (Charles Yang, University of Pennsylvania, personal communication), the total number of Det - N sequences (tokens) was 105699, with the transitional probability P(Det N) at 0.808, whereas the total number of Pron - V sequences (tokens) was 207018, with the transitional probability P(Pron V) at 0.781. That is, the Pron - V sequences are much more frequent than the Det - N sequences, and more crucially, the two transitional probabilities are similar. These transitional probabilities predict comparable categorization performance for nouns in the determiner context and for verbs in the pronoun context. However, infants in Shi and Melançon (2010) categorized novel words

following determiners as nouns, but failed to show evidence of categorizing novel words following pronouns, which cannot be explained by the idea of transitional probabilities. Furthermore, the Det - N and Pron - V stimuli in Shi and Melançon had equivalent prosody. Specifically, determiners (e.g., *ton, le*) and pronouns (e.g., *je, tu*) were prosodically matched, so were the novel words in different categories (e.g., *mige* as a noun versus as a verb). Both types of utterances formed one prosodic phrase. Hence, prosody of the stimuli should not exert any differential effects. Infants' responses suggest that they were guided by hierarchical phrase structures.

To recap, the results of Shi and Melançon (2010) and Höhle, et al. (2004) are fully consistent with the predictions of the generative grammar, but not with those of the statistical learning model. It should be noted that the two kinds of theories (generative grammar based versus statistical learning) do not have to oppose each other. The Det - N transitional probability may well be useful for infants, but the fact that the Pron - V transitional probability was not used suggests that statistical computation depends on the level of syntactic structures. That is, if infants rely on some statistics to acquire syntax, their computation must be constrained by the grammar. Transitional probability seems to be readily processed for word categories within a phrase such as NP, but blocked for word categories across phrases, as in the case of the subject-pronoun and the verb. Alternatively, it might be that transitional probability alone is not enough, and that the complexity of combing NP and VP delays the acquisition of the latter case.

Therefore, determiners are important for initial acquisition and contribute to the functional projection of the constituent NP. In the next section I will discuss how determiners are used in infants' analysis of more complex NPs in longer utterances. I will also show that the processing of determiners and prosody enables infants to activate higher structures.

3.2. Determiners, prosody, and higher syntactic units

Syntactic structures are far more complex than the Det - N kind of NP. A noun in an NP might be non-adjacent to the determiner (e.g., *the small dog*). A word non-adjacent to the determiner might not be part of the NP (e.g., *the dog ate*). An utterance could be much longer or contain recursive elements. Since many lexical words in the input are novel to one- to two-year-olds, how do infants set the scope of analysis upon hearing a determiner? In particular, how many words downstream from a determiner do they take for finding a noun and for projecting an NP? How do they interpret an utterance ambiguous for multiple syntactic phrases? Do they have adult-like structural representations?

In this section I discuss in detail our recent experimental studies on infants' interpretation of utterances containing determiners and other grammatical categories (Massicotte-Laforge & Shi, 2015, 2018, 2020). To exclusively investigate determiner processing and phrase structure representation without any influence of semantics, we used mostly or all non-words as stimuli, which resembled the typical utterances that one-year-old infants hear (i.e., utterances containing unknown content words mixed with familiar functional morphemes).

3.2.1. Using prosody and determiners jointly to activate phrase structures (Massicotte-Laforge & Shi, 2015)

In Massicotte-Laforge and Shi (2015) we created syntactically ambiguous strings containing all pseudo-words except French determiners (*un* 'a', *ton* 'your', *des* 'some', *la* 'the'). For example, in "*un felli mige vure la gosine*." only the determiners *un* and *la* were real words, and the remaining words were all pseudo-words that conformed to French phonology. Each string was ambiguous for multiple sentential structures:

Structure 1: [[Det Adj N][V Det N]], e.g., [[*un felli mige*][*vure la gosine*]]
Structure 2: [[Det N][V Prep Det N]], e.g., [[*un felli*][*mige vure la gosine*]]
Structure 3: [[Det N Adj][V Det N]], e.g., [[*un felli mige*][*vure la gosine*]]

Since French allows prenominal and post-nominal adjectives, the words *felli* and *mige* can be nouns and adjectives. The pseudo-words were phonologically plausible to be the intended grammatical categories, as judged by French-speaking adults during our stimuli design. In particular, for our adult listeners, *felli* sounded like an adjective and a noun, *mige* as a noun, a verb and an adjective, *vure* as a verb and a preposition, and *gosine* as a noun.

In our experiment we focused on testing Structures 1 and 2. In particular, we disambiguated each string by recording two versions with different prosody, such that the prosodic phrases overlapped with the major syntactic phrases in the respective structures. To elicit the prosodic phrases, we asked a native French speaker to produce all-real-word French sentences in the two structures, and then mimicked our novel-word sentences in the same way. For example, for Structure 1, she first produced a model sentence such as *un petit chat mord le ruban* ('a little cat bites the ribbon'), followed by *un felli mige vure la gosine*; for Structure 2, *un cheval dort dans le désert* ('a horse sleeps in the desert.') was recorded before she mimicked the *un felli mige vure la gosine*. With this elicitation method, the speaker produced the prosodic phrases (each marked by brackets {…} below) corresponding to the respective syntactic structures (see the acoustic cues in Massicotte-Laforge & Shi, 2015):

Structure-1 prosody: {*un felli mige*}{*vure la gosine*}
Structure-2 prosody: {*un felli*}{*mige vure la gosine*}

Our general hypothesis was that determiners and prosodic cues work jointly to allow infants to break into syntactic structures. Specifically, we hypothesized that infants use a determiner to find a noun only within the same prosodic phrase, and that verb categorization is guided by the cue of the preceding prosodic phrasing. Recall that in Shi and Melançon (2010) verb categorization was unsuccessful when a novel word was preceded by a subject pronoun, both falling within the same prosodic phrase. Here we hypothesized that the projection of a nominal subject NP (including a determiner and a noun) can assist the categorization of the following verb.

Accordingly, we expected that Word 3 *mige* should be acceptable as a noun for strings with Structure-1 prosody, but not for strings with Structure-2 prosody. For both

kinds of strings, infants were expected to interpret the first prosodic phrase as NP and the second prosodic phrase as VP.

French-learning 20-month-olds participated in a preferential looking (listening) experiment. A puppet animation spoke the speech stimuli during the experiment, and the infant's looking to and away from the puppet on a TV screen controlled the beginning and the end of the puppet's speech. A computer program presented the auditory and visual stimuli while recording automatically the infant's looking to the screen. One group was familiarized with the non-word strings in Structure-1 prosody, and another group with the same strings but in Structure-2 prosody. Both groups were then tested with Word 3 (e.g., *mige*) appearing in two types of utterances in one prosodic phrase, as in Shi and Melançon (2010):

Noun use (determiner context): [Det N], e.g., {*le mige*}
Verb use (subject-pronoun context): [[Pron][V]], e.g., {*tu miges*}

The test stimuli were novel word-combinations since the determiner *le* ('the') and the pronoun *tu* ('you') had not appeared in the familiarization stimuli. For the first group (i.e., familiarization: Structure-1 prosody), the noun-use utterances was grammatical and the verb-use ones ungrammatical. Conversely, for the second group (i.e., familiarization: Structure-2 prosody), the verb-use utterances was grammatical and the noun-use ones ungrammatical. If infants can perceive the distinct structures in the familiarization and categorize Word 3 accordingly, they should show a uniform looking preference according to grammaticality.

The results confirmed our predictions. Infants discriminated the two kinds of test trials. Importantly, infants showed a uniform looking preference: both groups listened longer to ungrammatical trials, i.e., longer listening time to verb-use test trials for the first group and longer listening time to noun-use test trials for the second group. These responses reflected infants' interpretations based on the familiarization prosody: the Structure-1 familiarization group categorized Word 3 *mige* as a noun because it fell within the same prosodic phrase, e.g., {*un felli mige*}; they used the determiner to accept *mige* as a noun even though it was non-adjacent to the determiner. The Structure-2 familiarization group categorized *mige* as a verb since it was in the second prosodic phrase, e.g., {*un felli*}{*mige …*}.

These responses are consistent with those of English-speaking preschoolers to real-word sentences containing the same kind of structural ambiguity (de Carvalho, Lidz, Tieu, Bleam, & Christophe, 2016). Similarly, in de Carvalho, Dautriche, Lin and Christophe (2017) French-learning 20- and 28-month-olds used prosodic phrasing to disambiguate and comprehend French sentences that were ambiguous between the two structures, e.g., [[*le bébé souris*][*…*]] 'the baby mouse …' versus [[*le bébé*][*sourit …*]] 'the baby smiles …' (note that *souris* and *sourit* are homophones in French). Another recent study (de Carvalho, He, Lidz, Christophe, 2019) showed that French-learning 18-month-olds can use phrasal prosody and function words to interpret novel words as denoting noun meaning versus verb meaning in sentences containing a mixture of real and novel content words.

Recall that in Shi and Melançon (2010), presenting a subject-pronoun followed by a novel word (e.g., *il mige* 'he miges') did not enable 14-month-olds to categorize the

latter as a verb. Here in Massicotte-Laforge and Shi (2015) 20-month-olds in a comparable task used the nominal NP and prosodic phrasing to categorize *mige* in {*un felli*}{*mige vure la gosine*} as a verb. Furthermore, the results demonstrate that 20-month-olds can track the category equivalence between full nominal NPs and subject-pronouns, i.e., at a higher constituent level.

In Massicotte-Laforge and Shi (2015) infants used prosody to limit the scope of their analysis of the Det - N relation within the first prosodic phrase. Does this mean that a prosodic phrase starting with a determiner will always be interpreted as an NP? Did the first group of infants (Structure-1 prosody) categorized Word 3 *mige* as a noun simply based on the boundary of the first prosodic phrase, without activating the whole sentential structure (S -> NP VP)? We addressed these questions in subsequent experiments, as discussed below.

3.2.2. Interpreting ambiguous and unambiguous structures (Massicotte-Laforge & Shi, 2018)

In this new set of experiments (Massicotte-Laforge & Shi, 2018), familiarization stimuli were three-word utterances, which were the initial three words of the long sentences of Massicotte-Laforge and Shi (2015), in which the first word was a determiner, i.e., *un* 'a', *ton* 'your', *des* 'some'.

We re-recorded the three-word sequences each as one single utterance-final prosodic phrase, e.g., {*un felli mige*}. The speaker first produced a real-word NP such as *un petit chat* ('a little cat') before producing a non-word utterance. As one prosodic phrase, the utterances were compatible with (i.e., ambiguous among) three syntactic structures, e.g.,

NP1: [Det Adj N], e.g., [*un felli mige*]
NP2: [Det N Adj], e.g., [*un felli mige*]
S: [[Det N][V]], e.g., [[*un felli*][*mige*]]

We familiarized French-learning 20-month-olds (Experiment 1) and 24-month-olds (Experiment 2) with these utterances, e.g., {*un felli mige*}, and then tested them with the same stimuli as in our earlier experiments (Shi & Melançon, 2010; Massicotte-Laforge & Shi, 2015):

Noun use (determiner context): [Det N], e.g., {*le mige*}
Verb use (subject-pronoun context): [[Pron][V]], e.g., {*tu miges*}

We predicted that if infants interpreted Word 3 *mige* in the three-word familiarization utterances only as a noun, they should discriminate the two types of test trials. If all three structures for the familiarization utterances were activated, infants should accept *mige* as a noun and a verb equally during the test trials and show no discrimination.

The results were consistent with the second prediction. Infants of both ages yielded equivalent listening times to noun-use and verb-use test trials, suggesting that multiple ambiguous syntactic structures were triggered during the familiarization phase.

This finding contrasts with those of our previous studies that used the same testing stimuli. Specifically, in Shi and Melançon (2010) where the familiarization stimuli were unambiguous NPs with a simple Det - N structure (e.g., *ton mige*), infants interpreted *mige* only as a noun. In Massicotte-Laforge and Shi (2015) where the Structure-1 familiarization sentences contained two prosodic phrases, infants interpreted the first one as an unambiguous NP and accepted *mige* as a noun, but not a verb. It is interesting that the same three-word sequences formed a prosodic phrase in both the present experiment and Massicotte-Laforge and Shi (2015), but infants treated them differently. They interpreted the multiple structures in Massicotte-Laforge and Shi (2018) versus the unique structure in Massicotte-Laforge and Shi (2015), by processing the whole utterances in the respective experiments.

Thus, it is not the case that a prosodic phrase containing a determiner is always interpreted as an NP. Prosody does constrain infants' analysis, as shown in Massicotte-Laforge and Shi (2015). Moreover, infants' interpretation is guided by the grammar, and functional categories play a crucial role in this process. They activated the structure(s) of the whole utterance, rather than just analyzing local statistics. That is, the structures seemed to be already available to infants, ready to be triggered by the input. Prosodic cues can constrain which structure(s) would be triggered, although ambiguities might still remain in certain context, as shown in the present experiment.

In Experiment 3 we inquired how infants categorize Word 2 *felli* upon hearing the same familiarization utterances (e.g., *un felli mige*; *ton felli crale*) in one prosodic phrase. This word was adjacent to the determiner. We assumed that adjacent categorization should be easier than the non-adjacent categorization. Even 14-month-olds can categorize novel words adjacent to determiners as nouns in two-word utterances (e.g., *ton mige* 'your N') (Shi & Melançon, 2010). On the other hand, processing the word adjacent to the determiner in the three-word utterances might be harder since Word 2 is ambiguous between the noun and adjective categories here. That is, it may be more complex for infants to analyze the ambiguous structures of these utterances than those in Shi and Melançon (2010). Therefore, we decided to study infants aged 17 months of age. After being familiarized with the same utterances in one prosodic phrase, e.g., {*un felli mige*}, infants were tested with *felli* in noun use (grammatical) versus in verb use (ungrammatical) trials:

Noun use (determiner context): [Det N], e.g., {*le felli*}
Verb use (subject-pronoun context): [[Pron] [V]], e.g., {*tu fellis*}

Results show that infants discriminated the test trials, showing a longer listening time to the ungrammatical verb use of *felli*. They used the determiner to interpret the adjacent *felli* as a noun, but not a verb. The discrimination here suggests that infants were on task while listening to the three-word utterances, and that the non-discrimination of *le mige* versus *tu miges* after the same familiarization in Experiments 1-2 reflected indeed the activation of multiple structures. That is, the three-word utterances in one prosodic phrase activated ambiguous structures NP1, NP2 and S.

In Experiment 4 we further tested the idea that prosody may constrain infants' syntactic interpretation. The three-word familiarization utterances were re-recorded with a prosodic break before Word 3, same as the location of the prosodic break of the Structure-2 prosody in Massicotte-Laforge and Shi (2015). We used real-word model utterances such as *un cheval dort* ('a horse sleeps') to elicit the corresponding prosody for the stimuli, e.g., {*un felli*} {*mige*}. The familiarization utterances supported one unambiguous syntactic structure with corresponding syntactic phrases:

S: [[Det N][V]], e.g., [[*un felli*][*mige*]]

Following familiarization, 20- and 24-month-old infants were tested with the same noun-use versus verb-use stimuli as in Experiments 1-2:

Noun use (determiner context): [Det N], e.g., {*le mige*}
Verb use (subject-pronoun context): [[Pron][V]], e.g., {*tu miges*}

As expected, infants of both ages discriminated the noun-use versus verb-use of the target non-words (e.g., *mige*) in Experiment 4, listening longer to the ungrammatical noun-use trials, as the Structure-2 prosody group did in Massicotte-Laforge and Shi (2018). The results thus confirmed that infants used the disambiguating prosodic phrases to constrain their interpretation of the utterances to an S(entence).

Taken together, the results demonstrate that input strings can trigger multiple structures in infants (Experiments 1-3), and that when disambiguating prosodic cues are available, infants would use them to activate the unambiguous structure and constrain their interpretation (Experiment 4).

3.2.3. The essential role of determiners (Massicotte-Laforge & Shi, 2020)

Our next goal was to understand the specific role of determiners for activating syntactic structures in infants. In earlier experiments (Shi & Melançon, 2010; Massicotte-Laforge & Shi, 2015, 2018) familiarization utterances contained all non-words except determiners (such as *ton* and *la* in *ton felli mige vure la gosine*). Infants most likely used the determiners conjointly with prosody to interpret syntactic structures. To further assess whether determiners are obligatory and what particular analysis they support, we conducted a subsequent experiment (Massicotte-Laforge & Shi, 2020) in which replaced the determiners with nonsense functors, making the stimuli sentences of our 2015 study consisting entirely of non-words. The determiners in the nominal subject NPs were replaced with *guin*, and the determiner *la* ('the') later in the sentence was replaced with *ti*. These two non-words matched with real function words prosodically and phonologically.

The new familiarization stimuli were recorded with the same eliciting sentences for the two structures (e.g., Structure 1: *un petit chat mord le ruban* 'a little cat bits the ribbon'; Structure 2: *un cheval dort dans le desert* 'a horse sleeps in the desert'), as in Massicotte-Laforge and Shi (2015), yielding distinct prosody for each all-non-word string, e.g.,

Structure-1 prosody: {*guin felli mige*}{*vure ti gosine*}
Structure-2 prosody: {*guin felli*}{*mige vure ti gosine*}

The distinct prosodic phrasing corresponded to the two intended syntactic structures for each string, e.g.,

Structure 1: [[Det Adj N][V Det N]], e.g., [[*guin felli mige*][*vure ti gosine*]]
Structure 2: [[Det N][V Prep Det N]], e.g., [[*guin felli*][*mige vure ti gosine*]]

Infants were 20- and 24-month-olds. Each age group was divided into two sub-groups, one familiarized with Structure-1 prosody, and another with Structure-2 prosody. Both familiarization groups heard the same test trials as in Massicotte-Laforge and Shi (2015):

Noun use (determiner context): [Det N], e.g., {*le mige*}
Verb use (subject-pronoun context): [[Pron][V]], e.g., {*tu miges*}

If prosody alone was sufficient to guide infants to interpret the intended structures and categorize Word 3, both groups should discriminate the test trials in the same way as in Massicotte-Laforge and Shi (2015). If determiners were required for their analysis, there should be no discrimination of the test trials.

The results turned out interesting. For both 20- and 24-month-olds, the infants who were familiarized with Structure-1 prosody did not discriminate the test trials. This contrasts with the successful discrimination when the Structure-1 prosody contained determiners in Massicotte-Laforge & Shi (2015), indicating that infants require a determiner to categorize the noun within the same prosodic phrase. This is consistent with the close relation between the determiner and the noun in the phrase structure.

On the other hand, despite hearing sentences consisting entirely of non-words, the infants familiarized with Structure-2 prosody discriminated the test trials, showing the same pattern of results as the Structure-2 prosody group in Massicotte-Laforge and Shi (2015). This result was again identical for 20- and 24-month-olds. That is, infants in Massicotte-Laforge and Shi (2020) categorized the target words (i.e., Word 3 of the familiarization) as a verb using prosody alone. The absence of real determiners in the sentence did not impede their activation of the verb. This result is reasonable given that determiners and verbs are not closely related in the phrase structure.

Infants in this experiment also seemed to have recognized the equivalence between the first prosodic phrase in the familiarization stimuli and the subject pronoun in the test stimuli. This suggests that infants activated the higher NP based on the first prosodic phrase without necessarily processing the lower categories.

Our results across experiments (Massicotte-Laforge & Shi, 2015, 2018, 2020; Shi & Melançon, 2010) were systematic and robust. This was demonstrated by the fact that whenever there was a discrimination of test trials, infants always listened longer to ungrammatical trials. Their responses revealed strong consistency with the possible syntactic structure(s) of the familiarization stimuli.

Overall, these experiments suggest that infants can use prosodic phrasing to trigger the higher subject-NP constituent, but they need the determiner to categorize its

sister noun under the NP. These results reveal a hierarchical organization of syntactic knowledge in babies aged 20 months or younger. Both functional items (e.g., determiners) and prosody serve as cues to infants' syntactic activation.

3.2.4. On-line processing of syntactic structures

Infants' on-line processing of syntactic structures has also been shown in studies using familiar words (Bernal, Dahaene-Lamberts, Millotte, & Christophe, 2010; Brusini, et al., 2017; Brusini, Dahaene-Lamberts, Dutat, Goffinet, & Christophe, 2016; Kedar, Casasola, & Lust, 2006; Kedar, Casasola, & Lust, 2006; Kedar, Casasola, Lust, & Parmet, 2017). For example, object recognition was impeded when it was named in an ungrammatical sentence such as *can you see and ball?* (Kedar, Casasola, & Lust, 2006) even though the first part *can you see* and the second part *and ball* can occur as parts of grammatical sentences in English (e.g., the first part of *can you see and think …*; the second part of *bat and ball*). This suggests that infants analyze larger structures of the input rather than linear local sequences. Infants also distinguish homophone function words based on the syntactic context where they occur. For example, *le*/*la*/*les* 'the' in French are determiners (e.g., *elle prend la balle* 'she takes the ball') as well as object pronouns (e.g., *elle la mange* 'she eats it'). In ERP experiments 18-to-24-month-olds activated syntactic structures on-line and detected grammatical category violations such as **elle la balle* 'she balls it' and **elle prend la mange* 'she takes the eat' (e.g., Bernal, et al., 2010), although *la balle* and *la mange* were well-formed in their local distributional patterns. French-learning two-year-olds showed similar ERP results when newly taught nouns and verbs were presented in the same kind of sentences (Brusini, et al., 2016).

These results are consistent with those of our studies (Massicotte-Laforge & Shi, 2015, 2018, 2020; Shi & Melançon, 2010), suggesting that infants have sophisticated grammar early in acquisition, and that they rely on larger syntactic structures, rather than local statistical patterns, to guide their processing. The use of all novel lexical words without any meaning manipulation in our research offered an ideal way to control for possible effect of semantics or previously memorized sequences, allowing us to demonstrate purely syntactic knowledge and its productivity in infants.

3.3. Determiners and grammatical feature agreement

In this section I consider the status of determiners in infants' representation and processing of grammatical features. I will show that infants' acquisition of feature agreement is tightly linked to determiners and hierarchical syntactic structures. The evidence presented here concerns number agreement and gender agreement.

3.3.1. Number

Many languages have number markings and number agreement across grammatical categories. For example, English marks number on multiple categories (e.g., nouns, verbs, demonstratives, auxiliaries, quantifiers, some determiners such as the singular *a*). Kouider, Halberda, Wood, and Carey (2006) found that English-learning 24-month-olds can use the number markings in functional categories to comprehend singular

versus plural objects, e.g., choosing a plural set of a novel object when hearing *there are some blickets*, and a singular novel object upon hearing *there is a blicket.* Determiners in French mark the number feature whereas most nouns do not overtly mark number. In Robertson, Shi, and Melançon (2012) French-learning 24-month-olds used the number marking of determiners to interpret the adjacent noun. They looked more at the named object that matched the determiner in number (e.g., image of two cats while hearing *les chats* 'the-pl cats'), but were confused when there was a mismatch (e.g., image of one cat but hearing *les chats* 'the-pl cats'). At 30 months, infants can distinguish the plural subject - verb agreement in *ils embrassent …* 'they kiss …', which contained the liaison prefix-like /z/ before the verb, from the singular agreement in *il embrasse …* 'he kisses …'; they interpreted the former as denoting the action involving plural agents and the latter denoting a single agent performing the action (Legendre, Barrière, Goyet, & Nazzi, 2010).

Younger infants also demonstrated number agreement processing in pure auditory listening studies. During the first half of the second year of life, infants can already perceive subject - verb number agreement (Culbertson, Koulaguina, Gonzalez-Gomez, & Legendre, 2016; Soderstrom, White, Conwell, & Morgan, 2007; Van Heugten & Shi, 2010), for example, detecting agreement violations such as *meep*$_{sg}$ *are*$_{pl}$ *good* in English and *les*$_{pl}$ *coupiles va*$_{sg}$ *…* 'the coupiles will …" in French.

Theoretically, the acquisition of subject - verb agreement involving full subject-NP in French is particularly interesting. Since nouns are not overtly marked for number in French, number agreement may need to be acquired by the non-adjacent relation between the determiner of the subject-NP and the main verb, e.g., *les*$_{pl}$ N *partent*$_{pl}$ *…,* 'the Ns leave …'; *le*$_{sg}$ N *part*$_{sg}$ *…* 'the N leaves …'. It has been shown that sensitivity to this agreement emerges at a very young age (Culbertson, et al., 2016; Van Heugten & Shi, 2010). In Van Heugten and Shi (2010) French-learning 17-month-olds discriminated correct agreement such as *le*$_{sg}$ N *va*$_{sg}$ *…* 'the N will …' and violations such as *les*$_{pl}$ N *va*$_{sg}$ *…* 'the Ns will …'. This finding contrasts with that of Shi and Melançon (2010) in which infants failed to even track strong adjacent transitional probability between the subject pronoun and main verb. Is it the case that the non-adjacent transitional probability between the determiner and verb (i.e., Det _ Verb) is particularly high and helpful for agreement learning? This is in fact not the case, as shown in a recent analysis of French input speech (Paris database in CHILDES, close to one million words): Of all the Det _ X cases in which X can be any grammatical category, verbs are not among the likely predictable categories that occur one word non-adjacently later from the determiner category, but rather, they are eighth down the rank (Charles Yang, University of Pennsylvania, personal communication). This means that the use of transitional probability between non-adjacent categories (e.g., Det _ Verb) is unlikely the mechanism underlying infants' successful tracking of the number agreement.

The idea that I argue for is that infants' acquisition of agreement is driven by the grammar. As discussed in Section 3.2, our experiments (Massicotte-Laforge & Shi, 2015, 2018, 2020) showed that the break between the two prosodic phrases was crucial for bootstrapping NP and VP, and for verb categorization. In Van Heugten and Shi (2010) there was also a prosodic break between the subject-NP and main VP, e.g., [[Det N][V …]]. Infants must have activated the NP and VP, tracked the number feature at the level of the subject-NP (which inherits the feature from a lower word category), and

perceived its number agreement with the VP (which shares the feature with the lower verb category). That is, the agreement relation that infants perceived was in fact adjacent at a higher phrasal level, rather than non-adjacent between word categories of determiners and verbs. Infants in Van Heugten and Shi processed number agreement hierarchically; they were guided by structural knowledge, consistent with the predictions of the generative grammar.

3.3.2. Grammatical gender

Grammatical gender features are present in certain languages. Depending on specific languages, semantic or phonological cues may exist to indicate gender distinctions (e.g., Corbett, 1991; Mirkovic, MacDonald, & Seidenberg, 2005). For some languages, only a small number of words have obvious conceptual correlates (e.g., the feminine noun *fille* 'girl' and masculine noun *garçon* 'boy' in French), with gender feature assignment to most nouns being semantically arbitrary. For example, the gender of the word *sun* is masculine in French (*soleil*$_{\text{MASC}}$), but feminine in German (*Sonne*$_{\text{FEM}}$). Other categories such as determiners, quantifiers or adjectives can have multiple forms, one for each gender. For instance, the singular definite determiner in French has two forms *le*$_{\text{MASC}}$ and *la*$_{\text{FEM}}$ (both 'the'). When words are combined, gender agreement applies, subject to particular syntactic structures. In *une*$_{\text{FEM}}$ *petite*$_{\text{FEM}}$ *maison*$_{\text{FEM}}$ ('a small house') in French all categories within the NP must agree with the noun gender.

3.3.2.1. Determiners and gender agreement within an NP

Infants in gender languages begin to show evidence of gender representation for their known vocabulary quite early. French-learning 18-month-olds prefer to listen to NPs containing familiar nouns after a gender-agreeing determiner (e.g., *le*$_{\text{MASC}}$ *bébé*$_{\text{MASC}}$ 'the baby') over agreement-violating NPs (*la*$_{\text{FEM}}$ *bébé*$_{\text{MASC}}$) (Van Heugten & Christophe, 2015). By two years of age, Dutch- and French-learning infants use the determiner gender to automatically process the gender of the following familiar noun and to rapidly fixate on the named object among competing objects on a screen (Johnson, 2005; Melançon & Shi, 2015a; Van Heugten & Shi, 2009). Similar on-line gender processing of familiar nouns in NPs was observed in Spanish-learning three-year-olds (Lew-Williams & Saffran, 2007). These responses resemble the automatic processing of gender in adults (Dahan, Swingley, Tanenhaus, & Magnuson, 2000).

How do infants learn gender features of novel nouns? Gender in languages that have regular phonological markings of genders on the nouns (e.g., gender endings of many nouns in Portuguese) should be relatively easy to learn, given that infants have remarkable ability to track morpheme endings and generalize regular patterns to novel stems (Marquis & Shi, 2012; Mintz, 2013). For languages with no reliable phonological or semantic cues to gender such as French nouns, infants need to rote-learn the gender of most nouns individually, which is a major task since nouns are a huge class of words. In a preferential listening study (Cyr & Shi, 2013) we showed that this learning can be accomplished by using determiner gender. We created novel words such as *ravole* and *cagère*, which were judged as equally possible to be masculine or feminine nouns in a pre-test with adults. We then familiarized French-learning 20-month-olds with the novel

nouns in the context of gender-marked determiners, one novel noun with an indefinite masculine determiner (e.g., *un*$_{\text{MASC}}$ *ravole* 'a ravole') and another with an indefinite feminine determiner (e.g., *une*$_{\text{FEM}}$ *cagère* 'a cagère'). Another group of 20-month-olds were familiarized with the opposite gender pairing (*une*$_{\text{FEM}}$ *ravole*, 'a ravole'; *un*$_{\text{MASC}}$ *cagère* 'a cagère'). During the test phase all infants discriminated the novel nouns in the context of non-familiarized definite determiners, i.e., trials presenting *le*$_{\text{MASC}}$ *ravole* and *la*$_{\text{FEM}}$ *cagère* ('the ravole', 'the cagère') versus those presenting *la*$_{\text{FEM}}$ *ravole* and *le*$_{\text{MASC}}$ *cagère*. The two groups yielded opposite looking preferences during the test phrase, contingent upon the opposite gender pairings during the familiarization, indicating that they used the determiners to assign gender to novel nouns abstractly.

We further examined infants' representation and activation of grammatical gender feature in an on-line comprehension task, with novel nouns and novel objects (Melançon & Shi, 2015a). French-learning 30-month-olds were first trained briefly with two novel objects, each accompanied by a novel word following a gender-marked determiner, e.g., *un*$_{\text{MASC}}$ *ravole*, 'a ravole', *une*$_{\text{FEM}}$ *cagère* 'a cagère'. The NP for each novel object was presented seven times during the training phase. In the test phase, the two objects appeared side by side on the screen, and one was named in an NP containing a definite determiner (either gender-marked *le*$_{\text{MASC}}$ or *la*$_{\text{FEM}}$, or gender-unmarked *les*) with the Det+Adj+N structure. The adjective *joli* ('pretty') was gender-unmarked. There were three types of test trials concerning the agreement status of the gender features between the determiner and non-adjacent noun: 1) gender matched based on training (e.g., *le*$_{\text{MASC}}$ Adj *ravole* 'the Adj ravole' and *la*-fem Adj *cagère* 'the pretty cagère' for the group trained with *un*$_{\text{MASC}}$ *ravole* and *une*$_{\text{FEM}}$ *cagère*), 2) gender-neutral with the gender-unmarked determiner *les* (e.g., *les* Adj *ravoles* and *les* Adj *cagères*, neutral for both groups of infants), and 3) gender-mismatch (e.g., *le*$_{\text{MASC}}$ Adj *cagère* and *la*$_{\text{FEM}}$ Adj *ravole* for the group trained with *un*$_{\text{MASC}}$ *ravole* and *une*$_{\text{FEM}}$ *cagère*). We found that infants not only learned the novel noun-object associations, but also automatically assigned the genders of the indefinite determiners to the specific novel nouns during training.

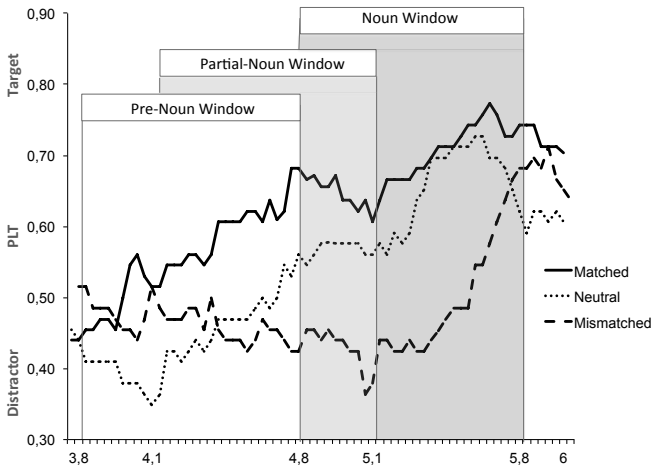

Figure 1. Timecourse of looking (PLT: proportion of looking to target) during three types of test trials (Melançon & Shi, 2015a). On the vertical scale, "target" refers to the object that was named in the auditory stimuli, and "distractor" refers to the non-named object.

Figure 1 shows the progression of infants' eyes fixation while listening to the NPs in the test trials, with looking towards the named object (i.e., the target) being above 0.5. Target recognition was the fastest in gender-matched trials, occurring even before the target noun started to be heard, showing that the determiner led infants to predict the upcoming noun according to the gender agreement. In gender-neutral trials infants waited till they heard part of the noun to look more at the target, as the gender-unmarked determiner could not predict the target. Target recognition was delayed in gender-mismatched trials until the end of the trial, indicating that the agreement violation caused confusion in the processing the NP. These results demonstrate that infants' gender assignment and processing was abstract, generalizing from indefinite determiners during training to definite determiners during testing. The gender status of the determiners influenced their recognition of the following noun on-line during the test trials. This automatic processing was striking given that the training was brief and that infants could have just focused on the word-meaning learning part of the task, which was highlighted by visually salient objects. The rapid processing of gender agreement across non-adjacent Det and N, despite an intervening gender-unmarked adjective, further suggests that the feature knowledge is abstract and robust in two-year-olds.

3.3.2.2. Gender agreement and hierarchical phrasal structures

The studies discussed in Section 3.3.2.1 demonstrate that determiners support infants' noun gender acquisition and the processing of gender agreement within an NP. Gender agreement also occurs in more complex structures. For instance, in the French sentence *La fille, elle marche* 'The girl, she walks', the subject NP *la fille* agrees with the subject pronoun *elle* in gender. In a preferential listening study (Melançon & Shi, 2015b) we familiarized French-learning 24-month-olds with novel nouns following gender marked indefinite and definite determiners, one feminine and another masculine, e.g., *une*$_{\text{FEM}}$/*la*$_{\text{FEM}}$ *gombale, un*$_{\text{MASC}}$/*le*$_{\text{MASC}}$ *mouveille*. Another group heard the opposite gender assignment. We expected that infants should take the gender feature of a determiner and assign it to the novel noun in the NP. After the familiarization, infants were tested with sentences each containing a trained novel noun with a gender-unmarked determiner, followed by a gender-marked subject pronoun. In grammatical sentences (six in total) the subject pronoun agreed with the noun in the preceding subject-NP in gender, and in ungrammatical sentences (six in total) the agreement was violated. For example, for the group familiarized with *une*$_{\text{FEM}}$/*la*$_{\text{FEM}}$ *gombale*, the sentence *Les gombales, elles*$_{\text{FEM}}$ *resonnent au couvent* 'The gombales, they resonated at the convent" was grammatical and *Les gombales, ils*$_{\text{MASC}}$ *resonnent au couvent* was ungrammatical. There was a prosodic break between the subject-NP and the subject pronoun. Infants in the experiment discriminated the gender-agreeing sentences from the agreement-violation sentences, revealing that they used the determiners in the familiarization NPs to assign gender features to the novel nouns, and tracked the gender of the noun and that of the subject pronoun in test sentences for processing agreement.

Syntactically, the agreement in Melançon and Shi (2015b) applies at the higher structural level, rather than at the surface linear level. It is the gender of NP that agrees with the gender of the following subject pronoun. Note that the NP inherits the feature from the head noun category below, which is a mechanism called feature percolation. To

assess if infants indeed track agreement at a higher structural level, we conducted another experiment (Melançon & Shi, 2016), using the same stimuli but adding a prepositional phrase (PP) to modify the subject head noun in the test sentences. The higher NP inherited the gender from the head noun, which was now non-adjacent to the subject pronoun. Grammatical trials presented gender-agreeing sentences such as *Les gombales*$_{FEM}$ *du fond, elles*$_{FEM}$ *resonnent au couvent* 'The gombales at the bottom, they resonated at the convent", and ungrammatical trials presented violations such as *Les gombales*$_{FEM}$ *du fond, ils*$_{MASC}$ *resonnent au couvent*. The nouns in the PPs across the six sentences within each trial type varied in gender such that some shared the gender with the subject pronoun and some did not, and this variable pattern was comparable for all test trials. If infants simply tracked the gender between the noun under the modifier phrase and the adjacent subject pronoun, they should not discriminate the test trials. However, if they understood that it should be the head noun that percolates the gender feature up to the higher NP node, they should ignore the noun under the PP and check the agreement status between the higher NP and the subject pronoun, which were adjacent at the upper phrasal level, but non-adjacent at the linear word level. Results confirmed the latter prediction. Infants in this experiment processed the gender agreement correctly. Their listening times to the grammatical trials versus the ungrammatical ones differed significantly, showing the same looking pattern as in the previous experiment (Melançon & Shi, 2015b) that had no intervening modifier.

Is it possible that infants in Melançon and Shi (2015b, 2016) just linearly compared the gender of the first noun with the gender of the following subject pronoun, without processing the higher phrases? In our latest experiments (Shi, Emond, & Badri, 2020; Shi, Legrand, & Brandenberger, 2020) we considered two types of structures. One type contained a subject-NP with a modifying PP (e.g., *La banana dans le chapeau, elle demeure au fleuve.* 'The banana in the hat, it stays in the river.'):

[[Det N1 [Prep [Det N2]$_{NP1}$]$_{PP}$]$_{NP2}$ [Pron]$_{NP3}$ [V …]$_{VP}$].

In this structure the full subject-NP2 inherits the gender from the head noun N1. The gender of the noun N2 is dominated by NP1 and further up by a PP, so N2 has no impact towards the gender of the higher NP2. The second type of structure contained two conjoined NPs dominated by a higher NP (e.g., *La banana et le chapeau, ils demeurent au fleuve.* 'The banana and the hat, they stay in the river.'):

[[[Det N1]$_{NP1}$ Conj [Det N2]$_{NP2}$]$_{NP3}$ [Pron]$_{NP4}$ [V …]$_{VP}$].

Here, the first NP1 inherits the gender from N1, and the second NP2 inherits the gender from N2. If the two NPs have the same gender, the higher NP3 will inherit that gender, and the gender of this higher NP3 must agree with the gender of the following pronoun NP4. If the two lower NPs (here NP1 and NP2) have different genders, the higher NP3 resorts to the default feature, which is identical to the masculine feature in form. This default feature then agrees with the default feature of the subject pronoun NP4, which is identical to the masculine pronoun *ils* 'they' in form.

Although the two distinct structures differ in gender agreement operations, they are similar in surface forms, both starting with two Det+N sequences followed by a

subject pronoun. We thus created sentences in these two structures to test whether infants' gender processing is guided by the grammar or by linear statistical computation.

We tested French-learning 17-18-month-olds and 30-31-month-olds in a preferential looking task. Each age was divided into two groups in a yoked design. The first group was tested with two trial types, one (i.e., correct agreement) presenting six sentences in the first structure, i.e., with a PP-modifier, and the other (i.e., incorrect agreement) presenting six sentences in the second structure (i.e., conjoined subject-NPs). In the examples below, the underlined subscripts are relevant features for agreement checking, with MASC0 representing the default feature:

Correct agreement (with a PP-modifier), e.g.,
[*La*$_{\underline{\text{FEM}}}$ *banane*$_{\underline{\text{FEM}}}$ *dans le*$_{\text{MASC}}$ *chapeau*$_{\text{MASC}}$]$_{\underline{\text{FEM}}}$, *elle*$_{\underline{\text{FEM}}}$ *demeure au fleuve.*
'The banana in the hat, it stays in the river.'
Incorrect agreement (conjoined subject NPs), e.g.,
*[*La*$_{\text{FEM}}$ *banane*$_{\text{FEM}}$ *et le*$_{\text{MASC}}$ *chapeau*$_{\text{MASC}}$]$_{\underline{\text{MASC0}}}$, *elles*$_{\underline{\text{FEM}}}$ *demeurent au fleuve.*
'The banana and the hat, they stay in the river.'

The other group of infants in each age were tested with the same two structures, but the agreement status was reversed, and this manipulation was done by a change of the subject pronoun. The trial type "correct agreement" now presented the second structure (i.e., conjoined subject NP) whereas the trial type "incorrect gender agreement" presented the first structure (with a PP-modifier):

Correct agreement (conjoined subject NPs), e.g.,
[*La*$_{\text{FEM}}$ *banane*$_{\text{FEM}}$ *et le*$_{\text{MASC}}$ *chapeau*$_{\text{MASC}}$]$_{\underline{\text{MASC0}}}$, *ils*$_{\underline{\text{MASC0}}}$ ...
Incorrect agreement (with a PP-modifier), e.g.,
*[*La*$_{\underline{\text{FEM}}}$ *banane*$_{\underline{\text{FEM}}}$ *dans le*$_{\text{MASC}}$ *chapeau*$_{\text{MASC}}$]$_{\underline{\text{FEM}}}$, *ils*$_{\underline{\text{MASC}}}$ ...

Except for the difference in Word 3 (i.e., *dans* 'in' versus *et* 'and'), the contrasting sentences in each pair for each group of infants were identical phonemically (the *-s* ending in pronouns and *-nt* ending in verbs are mute and only reflect the French writing conventions). Crucially, the gender-bearing words (determiners, nouns, pronoun) were the same in contrasting sentences.

If infants rely on surface linear statistics to process gender agreement, both groups of infants in our study should yield no discrimination of the two types of test trials. Specifically, for the first group, N2 *chapeau*$_{\text{MASC}}$ and the subject pronoun *elle(s)*$_{\text{FEM}}$ have different genders for both trial types. For the second group, N2 *chapeau*$_{\text{MASC}}$ and the subject pronoun *il(s)*$_{\text{MASC}}$ have the same gender, also for both trial types. Hence, tracking the adjacent dependency should yield no differentiation of the trial types. Likewise, N1 *banane*$_{\text{FEM}}$ and the subject pronoun occurred in both trial types within each group. If infants tracked the linear non-adjacent dependency between these two words, they should also show no discrimination of the two trial types.

However, if gender agreement is processed according to syntactic structures, infants in our study should discriminate correct-agreement and incorrect agreement sentences, and both groups should show the same direction of looking preference according to grammaticality.

Listening times confirmed the latter predictions: Infants showed highly significant discrimination of the test trials, and both groups listened longer to incorrect-agreement sentences. Impressively, infants as young as 17 months of age demonstrated the same pattern of responses as did 30-month-olds.

The results of this work (Shi, Emond, & Badri, 2020; Shi, Legrand, & Brandenberger, 2020) are striking, demonstrating that infants were not performing linear adjacent or non-adjacent statistical computations at the word level. Rather, they showed hierarchical representations of the two distinct syntactic structures and the understanding of feature percolation principles as defined in generative grammar. They used this knowledge to guide their processing of feature agreement.

Overall, the experiments on grammatical gender revealed similar processing as do those on number. Infants' representations of both types of features are tied to the phrase structure knowledge coherent with the generative grammar. The findings demonstrate that infants represent the features in multiple grammatical categories. Their feature checking during speech perception operates along the appropriate hierarchical levels of syntactic trees, rather than by local co-occurrence patterns of specific words or word categories.

4. Concluding remarks

In this chapter I show that although young children's speech before two years of age contains few or no functional items, their internal knowledge about these items can be observed with sensitive experimental measures from an early age. The perceptual studies discussed here reveal that functional categories begin to be acquired from birth, long before the onset of speech production. As soon as infants encode some functional items in their native language, they begin to use them to bootstrap lexical and syntactic acquisition, and this begins at the preverbal stage. From the second year of life they use functional items and phrasal prosody conjointly to interpret syntactic structures. The experimental findings support the predictions of the functor-prosody bootstrapping model.

The asymmetry between perception and production of functional categories during early infancy is remarkable. The early perception of functional categories reveals impressive linguistic knowledge in preverbal and early verbal babies, even though these items are missing in production during the initial two years of life. Multiple reasons can explain the delayed production of functional categories relative to lexical categories. First of all, speech production requires complex motor control, and children appear to need several years to develop adult-like motor skills for articulation and fluency. Functional categories, which are heard as reduced and even as cliticized items, may be particularly challenging for children to produce. Phonological constraints may also play a role. For example, a functional item falling outside of a prosodic foot is likely to be dropped by children (e.g., Demuth & Tremblay, 2008). Furthermore, infants appear to be sensitive to the fact that lexical words are primary for conveying meaning whereas functional morphemes are dominantly syntactic elements with complex meanings, lacking obvious word-to-world mapping. They have a bias to associate an object to a lexical word, rather than to a function word, during word learning (Hochmann, 2013; Hochmann, Endress, & Mehler, 2010). With limited motor abilities, they seem to deliberately avoid functional

items in production (Gerken, Landau, & Remez, 1990). Perceptual studies such as those discussed in this chapter are not affected by production factors and have offered invaluable insights to our understanding of the processing of functional morphemes and linguistic representations in babies, even before they are able to produce their first words.

Determiners are among the earliest functional items observed in young babies. The studies in Section 3 revealed sophisticated knowledge of determiners and the related phrasal structures in one-year-olds and two-year-olds. The findings demonstrate that determiners can play an important role in the learning of the grammatical properties of nouns, including categorization, gender assignment and number/gender agreement processing. The processing of determiners and their relation to other categories is constrained by phrasal prosody and guided by the structures and principles of the grammar. Based on the experiments discussed in Section 3, I argue that infants do not rely on local linear statistical computation; rather, they activate larger phrasal structures and make top-down interpretations. Statistical analysis is possible within the limit of the activated structure. For example, the computation of transitional probability seems to be only operable between word categories within the same phrase (e.g., between Det and N under an NP), but not between word categories across phrases (e.g., Pron and V). The experiments also show that the activated structures by infants are hierarchical. Infants not only perceive the equivalence of words belonging to the same grammatical category (e.g., equivalence of individual determiners), but also process category equivalence at the phrasal level (e.g., between a nominal subject-NP and a pronoun subject-NP). Moreover, they track syntactic dependencies at the phrasal level beyond word categories, for example, tracking gender and number feature agreement between a subject NP and VP.

The debate between theories of constructivism versus innatism is central in language acquisition research. Based on the constructivist theory, syntactic structures are established from induction. Statistical learning and formulaic based exemplar representations both fit the induction assumption of constructivist theories. There is indeed evidence that young children store specific exemplars, and that infants are capable of performing statistical computations. However, as discussed in this chapter, infant experimental studies have yielded results that demonstrate the guiding power of the grammar. Induction based learning does occur, but it is subject to the constraints of the grammar. That is, grammatical structures and principles can guide infants' syntactic analyses, including certain distributional-based computations. Functional items and prosody, the two types of information proposed in the functor-prosody bootstrapping model, can serve the role of activating innate structures and enabling infants to learn language-specific components of the linguistic knowledge.

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