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Toddlers track hierarchical structure dependence

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ABSTRACT

Previous research suggests that toddlers can rely on distributional cues in the input to track adjacent and nonadjacent grammatical dependencies. It remains unclear whether toddlers understand the hierarchical phrase structures that determine the corresponding grammatical dependencies. We addressed this question by testing toddlers on two different phrase structures in French that govern distinct patterns of grammatical gender feature agreement. We first show that the two structures are in fact extremely infrequent in children's input. Then we report on a preferential looking experiment in which French-learning 30-month-olds were presented with French sentences in the two structures, and the grammaticality of the feature agreement was manipulated. Crucially, the contrasting structures contained the same sequentially ordered feature-bearing words in our design (e.g., correct agreement: *La banane*$_{\text{FEMININE}}$ *dans le chapeau*$_{\text{MASCLINE}}$, *elle*$_{\text{FEMININE}}$ … 'The banana in the hat, it …'; incorrect agreement: **La banane*$_{\text{FEMININE}}$ *et le chapeau*$_{\text{MASCLINE}}$, *elles*$_{\text{FEMININE}}$ … 'The banana and the hat, they …'). Thus, children must go beyond those words and distinguish the structures hierarchically in order to determine the grammaticality of the different agreement patterns. We predicted that if toddlers rely solely on input support to acquire the structures and the agreement, they should show no discrimination of feature grammaticality. If, however, they can rely on mechanisms beyond linear input, such as the principle of structure dependence in the universal grammar (UG), they should show a grammaticality effect. The results confirmed the latter prediction, demonstrating the possible influence of the learner's internal system, suggesting that UG knowledge might guide early language development.

1. Introduction

During language acquisition children hear speech in linear sequences. The sequences are more than specific words strung together. Rather, they are organized in terms of abstract categories in dependent relations. For example, the English utterance *a dog* consists of a determiner followed by a noun, and in *a dog runs* the verb must agree with the preceding subject phrase in number. Children need to go beyond specific words in their input and track the dependency relations among categories in phrase structures, a task that is crucial for achieving the abstract knowledge necessary for infinite grammatical productivity in language use. Notably, input speech does not contain explicit grammar instructions. Occasional feedback from caregivers such as repetitions or recasts seems to be too noisy or too rare to be a significant factor in acquisition (e.g., Marcus 1993). Much of language acquisition research has been devoted to the question of how children acquire abstract structural knowledge from linear input.

In this article we consider the processing of grammatical dependencies among functional and lexical categories, as well as the phrase structures that determine the dependencies. Infants' early speech consists of one-word utterances and simple word combinations (e.g., *ball; doggie run*), lacking grammatical markings. However, listening experiments suggest that infants perceive nuanced

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grammatical elements long before producing them (Hallé, Durand & de Boysson-Bardies 2008; Marquis & Shi 2012; Mintz 2013; Shi et al. 2006; Shi & Lepage 2008; Shi, Werker & Cutler 2006). Studies on infants' acquisition of dependencies focused on co-occurring elements in the surface sequences of input. American toddlers perceive the dependency between *-is* and *-ing*, detecting violations such as **everyone can baking* … (Santelmann & Jusczyk 1998). Similarly, German toddlers track dependencies such as in *Das … Kind hat den Ball geholt* '… child has the ball fetched,' discriminating them from violations such as * … *kann … geholt* '… can … fetched' (Höhle et al. 2006). Toddlers also perceive subject-verb feature dependencies and detect violations such as **Mommy book a reads* (Soderstrom et al. 2007). French-hearing infants track subject-verb number agreement (e.g., Le_{SG} NOUN va_{SG} … 'The$_{SG}$ NOUN will$_{SG}$ …'), distinguishing them from agreement violations (*Les_{PL} NOUN va_{SG} … 'The$_{PL}$ NOUN will$_{SG}$ …') (Culbertson et al. 2016; van Heugten & Shi 2010). In a recent study toddlers perceived number agreement involving conjoined subjects (Koulaguina et al. 2019) and demonstrated impressive abstract knowledge.

Grammatical gender is a type of dependency. In French every noun has a gender, masculine or feminine, e.g., *téléphone*$_{MAS}$ 'telephone.' Gender for most nouns is semantically arbitrary, with no clear marking in spoken forms. Children must rote-learn the gender of nouns individually. Certain other classes of words (e.g., articles, pronouns, adjectives) have both masculine and feminine versions (e.g., *le*$_{MAS}$/*la*$_{FEM}$ 'the'; *petit*$_{MAS}$/*petite*$_{FEM}$ 'small'). Agreement is determined by the noun gender, e.g., *la*$_{FEM}$ *table*$_{FEM}$; *le*$_{MAS}$ *téléphone*$_{MAS}$. French-hearing infants start learning the gender of specific nouns from about 18 months of age (Cyr & Shi 2013; van Heugten & Christophe 2015). Around age 2, they start tracking gender agreement across multiple word classes, for example, distinguishing correct agreement in subject-dislocation sentences such as *La*$_{FEM}$ NOUN$_{FEM}$ *elle*$_{FEM}$ … 'The$_{FEM}$ NOUN$_{FEM}$ it$_{FEM}$ …' from incorrect agreement in **La*$_{FEM}$ NOUN$_{FEM}$ *il*$_{MAS}$ … (Melançon & Shi 2015).

These findings invite further interesting questions. How did children in those studies represent the dependencies? Did they track the structures that governed the dependencies? In all the studies so far, a child was presented with grammatical versus ungrammatical utterances in one single syntactic structure. A discrimination finding can be explained either by the successful tracking of linear co-occurring items/categories or by the processing of that structure at a more abstract level.

In the present study we further investigated the knowledge of agreement in toddlers. We asked whether toddlers represent and process structural differences when tracking feature agreement. To address this question, we designed an experiment in which each child was tested on two contrasting grammatical structures that appear similar in their linear sequence. Using the French subject-dislocation construction, in which the subject pronoun clitic of the main verb must agree with the preceding dislocated subject phrase in feature, we created sentences differing in the internal structures of the subject phrase, one containing a noun phrase with a post-noun modifying prepositional phrase (Structure 1) and the other containing two conjoined subjects (Structure 2), e.g.,

Structure 1: *La banane dans le chapeau, elle*-V … 'The banana in the hat, it-V …'
Structure 2: *La banane et le chapeau, ils*-V … 'The banana and the hat, they-V …'

The subject phrase of the two structures contained identical gender-bearing words in the same linear order (*la, banana, le, chapeau*). The subject pronoun clitic must agree with the first noun in Structure 1. In Structure 2, however, both nouns were relevant in a complex way for the agreement operation with the following subject pronoun (see following details). The third word in the subject phrase distinguished the two structures.

The distinction of the two structures is elegantly captured in generative grammar (see the structural representations in Figure 1). For both structures, gender agreement operates in a principled way between the upper units of subject phrase and the pronoun clitic. In Structure 1 the subject phrase ([*La banane dans le chapeau*]$_{FEM}$) inherits the feminine gender of the head-noun *banane*$_{FEM}$. It is the gender of this higher subject phrase unit with which the following NP above the subject pronoun (*elle*$_{FEM}$) must agree. The gender of the noun *chapeau*$_{MAS}$ below the prepositional phrase (PP: *dans le*

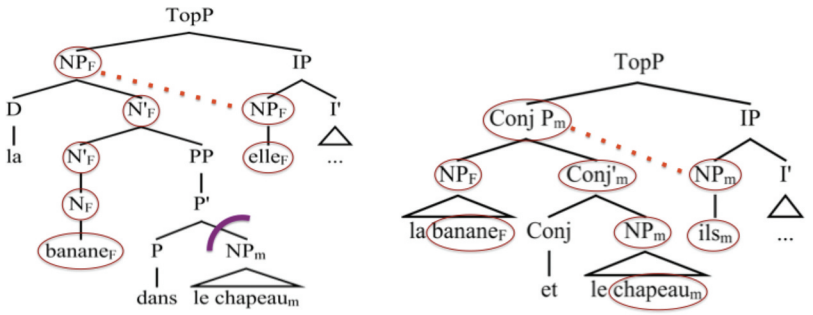

Figure 1. Tree representation of Structure-1 (left) and Structure-2 (right) sentences. In both structures, a prosodic break was produced between the end of the complex subject phrase and the subject pronoun clitic in our stimuli. Thus, the subject phrase is in the left-dislocated position, and the pronoun clitic is in the subject NP position under IP (see Culbertson 2010). The circles show feature percolation from a noun up to higher phrasal units. The dotted line in each tree shows the gender feature agreement at the upper phrasal level (between the unit above the subject pronoun clitic and the preceding dislocated subject phrase unit).

chapeau) is blocked from percolating up to higher phrase units, as shown in Figure 1. These characteristics of gender percolation and PP blockage are language general and apply to different types of features such as number, gender, and person.

In Structure 2, the higher subject phrase dominates two conjoined noun phrases (NPs). Both nouns of the conjoined NPs are relevant for the gender of the higher subject phrase. If the nouns have the same gender, the higher unit inherits that feature ([*le* NOUN_{MAS} *et le* $\text{NOUN}_{\text{MAS}}]_{\text{MAS}}$; [*la* NOUN_{FEM} *et la* $\text{NOUN}_{\text{FEM}}]_{\text{FEM}}$). If the nouns have different genders (regardless of orders), the higher subject phrase resorts to the default masculine feature ([*le* NOUN_{MAS} *et la* $\text{NOUN}_{\text{FEM}}]_{\text{MAS}}$; [*la* NOUN_{FEM} *et le* $\text{NOUN}_{\text{MAS}}]_{\text{MAS}}$). The two nouns in our experiment differed in gender. Thus, the higher subject phrase resorted to the default masculine feature, with which the NP above the subject pronoun (*ils*$_{\text{MAS}}$) must agree, [[*La banane*$_{\text{FEM}}$ *et le chapeau*$_{\text{MAS}}]_{\text{MAS}}$ [*ils*$_{\text{MAS}}$-VERB . . .]]. In fact, regardless of the number of nouns in a conjoined NP, they all affect feature percolation in this fashion.

We made test sentences that were correct versus incorrect in gender agreement for each structure (see details of stimuli recording and cross-splicing in the Methods section). Participants were French-hearing toddlers aged 30 to 31 months. In a visual-fixation procedure they were tested with two trial types: correct agreement versus incorrect agreement (Table 1). One group heard Structure 1 sentences as the correct type (*La banane*$_{\text{FEM}}$ *dans le chapeau*$_{\text{MAS}}$ *elle*$_{\text{FEM}}$-VERB . . .) and Structure 2 as the incorrect type (**La banane*$_{\text{FEM}}$ et *le chapeau*$_{\text{MAS}}$ *elles*$_{\text{FEM}}$-VERB . . .). Another group heard the reverse arrangement, with Structure 1 sentences as the incorrect type (**La banane*$_{\text{FEM}}$ *dans le chapeau*$_{\text{MAS}}$ *il*$_{\text{MAS}}$-VERB . . .) and Structure 2 as the correct type (*La banane*$_{\text{FEM}}$ *et le chapeau*$_{\text{MAS}}$ *ils*$_{\text{MAS}}$-VERB . . .). Children's listening times toward the two trial types, measured by their looking to the sound source, were analyzed.

The way we nested the distinct structures and agreement grammaticality in the contrasting trial types across two groups of toddlers allowed us to test both structural processing and feature tracking. If toddlers failed to perceive the structural distinction and only relied on the gender-bearing words (determiners, nouns, pronouns) to track agreement, they should not discriminate the two types of test trials. If they correctly processed the grammaticality of the agreement (possibly by using the third word of the subject phrase), they should discriminate the two trial types, and importantly, both groups should also show a uniform preference for one trial type (correct or incorrect). Such a uniform direction of preference would confirm toddlers' ability to distinguish the two structures since the grammaticality of the sentences was structure dependent.

The deeper questions emerging from our experiment concern the nature of children's interpretation of the structures, in case a grammaticality effect (i.e., a uniform preference for correct or incorrect agreement) might be observed. Would the structures be analyzed and represented hierarchically, perhaps with the guidance of UG, as suggested in Chomskyan theory (Chomsky 1965, 1988)? Or

Table 1. Test sentences and design.

Group 1	
Structure 1 (Correct agreement) [*La banane*$_{F}$ *dans le chapeau*$_{M}$]$_{\mathbf{F}}$ *elle*$_{\mathbf{F}}$ … (The banana in the hat, it …)	Structure 2 (Incorrect agreement) *[*La banane*$_{F}$ *et le chapeau*$_{M}$]$_{\mathbf{M}}$ *elles*$_{\mathbf{F}}$ … (The banana and the hat, they …)
La banane dans le chapeau, elle pèse les graminées.	*La banane et le chapeau, elles pèsent les graminées.*
La banane dans le chapeau, elle demeure au fleuve.	*La banane et le chapeau, elles demeurent au fleuve.*
La banane dans le chapeau, elle grasseye ardemment.	*La banane et le chapeau, elles grasseyent ardemment.*
La banane dans le chapeau, elle fuie les tentatives.	*La banane et le chapeau, elles fuient les tentatives.*
La banane dans le chapeau, elle tente leur pécule.	*La banane et le chapeau, elles tentent leur pécule.*
La banane dans le chapeau, elle résonne au couvent.	*La banane et le chapeau, elles résonnent au couvent.*
Group 2	
Structure 2 (Correct agreement) [*La banane*$_{F}$ *et le chapeau*$_{M}$]$_{\mathbf{M}}$ *ils*$_{\mathbf{M}}$ … (The banana and the hat, they …)	Structure 1 (Incorrect agreement) *[*La banane*$_{F}$ *dans le chapeau*$_{M}$]$_{\mathbf{F}}$ *il*$_{\mathbf{M}}$ … (The banana in the hat, it …)
La banane et le chapeau, ils pèsent les graminées.	*La banane dans le chapeau, il pèse les graminées.*
La banane et le chapeau, ils demeurent au fleuve.	*La banane dans le chapeau, il demeure au fleuve.*
La banane et le chapeau, ils grasseyent ardemment.	*La banane dans le chapeau, il grasseye ardemment.*
La banane et le chapeau, ils fuient les tentatives.	*La banane dans le chapeau, il fuie les tentatives.*
La banane et le chapeau, ils tentent leur pécule.	*La banane dans le chapeau, il tente leur pécule.*
La banane et le chapeau, ils résonnent au couvent.	*La banane dans le chapeau, il résonne au couvent.*

Note. The strings in contrasting structures for each group only differ in Word 3 (*dans* in Structure 1; *et* in Structure 2), with the remaining words being homophonous despite some orthographic differences. For example, the subject pronoun clitics (i.e., verb prefixes) *il* and *ils* are pronounced the same, so are the verbs *pèse* and *pèsent*. The content words (verbs, nouns, adverbs) following the subject pronoun are all infrequent words, unlikely known by toddlers.

would they be learned linearly from the input (e.g., Elman et al. 1996; Pine & Lieven 1997)? Neural network simulations (e.g., see a review in Frank, Bod & Christiansen 2012) and infant experiments using artificial languages (Gómez 2002; Gómez & Lakusta 2004) showed impressive sequential statistical learning of grammatical dependencies as long as the patterns in question were well represented in the training input. Infants can also use linear distributional cues in natural languages to categorize words (for example, classifying novel words as nouns) and learn word order (Cyr & Shi 2013; Koulaguina & Shi 2019; Gerken, Wilson & Lewis 2005; Höhle et al. 2004; Shi & Melançon 2010). Lidz and Gagliardi (2015) proposed an acquisition model in which statistical learning works together with UG. Specifically, statistical learning can work with rich input support, whereas UG-based learning can guide the child to acquire the structures that are rare or too noisy in the input. The child can also rely on UG to choose what analysis to focus on when the input offers cues to multiple kinds of analyses (Babineau & Shi 2014; Lidz, Gleitman & Gleitman 2003).

We therefore examined input characteristics of our two structures—in particular, the frequency of occurrence. A subset of transcripts of input speech to four French-learning children aged 14 to 30 months from several corpora (Pauline corpus: Bassano & Maillochon 1994; Geneva corpus: Hamann et al. 2003; York corpus: Plunkett 2002; Leveille corpus: Suppes, Smith & Leveillé 1973) in CHILDES (MacWhinney 2000) was analyzed. As shown in Table 2, our analysis yielded a total of 3,873 utterance tokens. We then focused on declarative sentences that contained a subject in the main clause. *Wh*-in-situ sentences and *yes*/*no* questions that occurred with the declarative word orders were also included in the analysis, e.g., *Il est où?* 'He is where?'; *Elle va faire dodo?* 'She will take a nap?'. Of these, sentences with a pronoun subject alone (i.e., without any full noun or proper noun as a doubled subject) were the most frequent (1,073), e.g., *Il pleure*. 'He is crying.' The next most frequent were sentences with a left- or/and right-dislocated simple subject plus a subject pronoun clitic (left: 218; right: 81, left and right in the same sentence: 10), e.g., *Papa il est à la cuisine*. 'Papa, he is in the kitchen.' Sentences with a nondislocated simple subject directly preceding a verb phrase (VP) (i.e., no doubled subject pronoun) were much less frequent (37), e.g., *Ta poupée est au lit*. 'Your doll is in bed.' These frequency patterns were similar to the French input analysis reported in Legendre et al. (2010), although our simple subject counts did not include subjects

Table 2. Analysis of French input to children aged 14 to 30 months (from CHILDES); total number of child-directed utterances: 3873.

Types of subjects in declarative sentences		
Sentences with Complex Subject Phrases	Left-dislocated subject with a PP-modifier, + subj. pron. clitic	1
	Right-dislocated subject with a PP-modifier, + subj. pron. clitic	1
	Conjoined subjects (dislocated or non-dislocated), with/without subj. pron. clitic	0
Sentences with Simple Subject Phrases (with one noun or proper noun, no post-noun modifier)	Left-dislocated simple subject, + subj. pron. clitic	218
	Right-dislocated simple subject, + subj. pron. clitic	81
	Left- & right-dislocated simple subject, + subj. pron. clitic (the dislocated phrases were repetitions of the same subject)	10
	Simple subject followed by VP (no subj. pron. clitic)	37
Sentences with Pronoun Subject (without doubled/dislocated subject phrase)		1073

with any kind of postnoun modifiers (e.g., PP-modifier, relative clause, adjective) or conjoined subjects. We specially counted sentences containing complex subject phrases (including those containing any postnoun modifier, as well as conjoint subject NPs) in declarative sentences (in main clauses or subclauses). We found that these structures were rare: Only 2 cases of complex subject phrases occurred, one left-dislocated containing a PP-modifier (i.e., our Structure 1) and the other right-dislocated containing a PP-modifier. In both cases the subject pronoun clitic in the sentence agreed in gender with the head noun of the dislocated phrase. No conjoined subjects (i.e., Structure 2) occurred in declarative sentences. In a corpus study of a much larger sample of child-directed speech in French, Koulaguina et al. (2019) found that only 0.02% of all the utterances contained conjoined subjects (Structure 2). Overall, it seems that a dominant number of declarative sentences contained only a pronoun subject. When subject nouns or proper nouns occurred, they were mostly simple noun phrases.

These results suggest that although our small-scale analysis might have underestimated the frequency of the two structures, we can still expect that the proportion of the two structures in children's natural experience is low. Overall, dislocated simple subject phrases with a subject pronoun clitic occur often, but complex dislocated subject phrases are rare in the input.

Given the infrequent occurrences of the two structures in children's input, we reasoned that a failure in discriminating the agreement-correct versus agreement-incorrect sentences in our experiment would be coherent with sequential statistical learning, whereas a success in discriminating the sentences can be better explained by the guidance of hierarchical structures in UG.

2. Methods

2.1. Participants

Twenty-four monolingual French-exposed toddlers (age range: 30 months, 17 days–31 months, 26 days; mean age: 31 months, 9 days; 13 boys, 11 girls) participated in the experiment. Two other toddlers were tested, but their data were excluded from analysis due to fussiness (1) and parental interference (1). The parents of all the children signed the consent form. The sample size of 24 toddlers was determined on the basis of the following consideration. In Cyr & Shi (2013), an earlier study using the same task as in the present study, 30-month-olds showed a very strong within-subject effect size (Cohen's d = 1.13) in their listening times toward correct gender agreement trials versus incorrect agreement trials; the agreement involved determiners and pseudonouns that had been introduced in a familiarization phase. For the current experiment, we expected that the effect size would be at least half that size. For a bilateral test at the .05 significance level with 80% power, the required sample size could be estimated at 24.6. Given that the experiment consisted of two conditions, which were expected to produce the same effect, an even number of cases was dictated. Furthermore, given that the effect size would likely be more than half of the previously seen 1.13, the total sample size was set at 24 for the present experiment.

2.2. Auditory and visual stimuli

We used subject-dislocation sentences in French with distinct internal structures for the subject phrase (Figure 1). The dislocated subject phrase (*la banane dans le chapeau* 'the banana in the hat') of Structure 1 contained a prepositional phrase (PP): *dans le chapeau*. As described earlier, the subject pronoun clitic *elle*$_{\text{FEM}}$ agreed with the gender of the first noun in the dislocated subject phrase, *La banane*$_{\text{FEM}}$ *dans le chapeau, elle*$_{\text{FEM}}$-VERB … 'The banana in the hat, it-VERB …'. The gender of the noun *chapeau*$_{\text{MAS}}$ 'hat' had no influence on the agreement.

The dislocated subject phrase of Structure 2 consisted of two conjoined noun phrases (*la banane et le chapeau* 'the banana and the hat'), with both nouns affecting gender agreement. Since the nouns differ in gender (*banane*$_{\text{FEM}}$; *chapeau*$_{\text{MAS}}$), the default masculine gender applied at the upper phrasal level, and the subject clitic *ils*$_{\text{MAS}}$ agreed with the default masculine gender (*La banane*$_{\text{FEM}}$ *et le chapeau*$_{\text{MAS}}$, *ils*$_{\text{MAS}}$-VERB … 'The banana and the hat, they-VERB …').

As shown in Table 1, our design included test sentences in correct and incorrect gender agreement for each structure. Incorrect sentences might cause disfluency or unnaturalness during speech recording, which might be perceived by children and thus could interfere with our goal of testing agreement knowledge. We therefore recorded other correct sentences and constructed all test sentences by cross-splicing different parts of the recorded sentences using the Praat software. Recording was made using a Sound Device 702T (44 kHz sampling frequency, 24 bits bitrate) in an acoustic chamber.

Specifically, we asked a female native French speaker to produce two sets of sentences, the first set contributing to the initial part of our test sentences (the subject phrase) and the second set contributing to the remaining part of our test sentences (from the subject pronoun clitic to the end). The first set began with a left-dislocated phrase consisting of the same words as the initial part of our intended test stimuli (see Table 1). The left-dislocated phrases contained either a PP or conjoined NPs:

(a) [*La banane dans le chapeau*]$_{\text{FEM-SG}}$ [*on va toujours la*$_{\text{FEM-SG}}$ *voir*] 'The banana in the hat, we will always see it'
(b) [*la banane et le chapeau*]$_{\text{MAS-PL}}$ [*on va toujours les*$_{\text{PL}}$ *voir*] 'The banana and the hat, we will always see them'

The features of the left-dislocated phrases are inherited in the same way as in Structures 1 and 2 described previously. The object clitics (here *la* and *les*) later in the sentence agreed (and were coindexed) with the left-dislocated phrase in their features. The subject pronoun clitic *on* 'we,' auxiliary *va* 'will,' and adverb *toujours* 'always' were the same for both (a) and (b), ensuring that the dislocated phrases (the part to be sliced out) were from the same coarticulation context. Multiple productions of these two sentences were recorded. Six recording exemplars of the *dans* sentence (i.e., a) with various intonations and six exemplars of the *et* sentence (i.e., b) with the matching intonations were selected. The first part (from the sentence onset to the offset of the word *chapeau*) was then spliced out from each exemplar to be used for the subsequent step of cross-splicing (described later).

We also recorded the second set consisting of 24 subject-dislocation sentences, half in Structure 1 and the other half in Structure 2. The nouns in the dislocated subject phrases were chosen such that all the sentences were correct in gender agreement. Six Structure 1 sentences contained a feminine subject pronoun agreeing with the preceding subject phrase—([*Les tisanes*$_{\text{FEM}}$ *dans les autos*$_{\text{FEM}}$]$_{\text{FEM}}$ [*elles*$_{\text{FEM}}$ -VERB …] 'The tisanes$_{\text{FEM}}$ in the cars, they$_{\text{FEM}}$ …'). Thus, the second part of these six sentences (that is, *Les tisanes dans les autos, elles pèsent les graminés; … elles demeurent au fleuve; … elles grasseillent ardemment; … elles fuient les tentatives; … elles tentent leur pécule; … elles résonnent au couvent*) matched what we needed for our intended stimuli (see Table 1). Another six contained a masculine subject pronoun agreeing with the preceding subject phrase ([*Les domaines*$_{\text{MAS}}$ *dans les autos*$_{\text{FEM}}$]$_{\text{MAS}}$ [*ils*$_{\text{MAS}}$ *pèsent les graminés*]); etc., with the second part of these sentences matching our intended stimuli. Similarly, six sentences in Structure 2 contained a feminine subject pronoun, ([*Les tisanes*$_{\text{FEM}}$

et les autos$_{FEM}$]$_{FEM}$ [*elles*$_{FEM}$ *pèsent les graminés*]); etc., and another six contained the masculine default gender: ([*Les domaines*$_{MAS}$ *et les autos*$_{FEM}$]$_{MAS}$ [*ils*$_{MAS}$ *pèsent les graminés*]; etc).

One recording exemplar of each of these 24 sentences (i.e., the second set) was selected. For a given *dans* sentence pair with the same last words following the subject pronoun (e.g., *Les tisanes dans les autos, elles pèsent les graminés; Les domaines dans les autos, ils pèsent les graminés*), the second parts (starting from the offset of *autos* to the end of the sentence) were spliced out, and each was connected with an exemplar of *la banane dans le chapeau* from the first set, yielding the test stimuli for Structure 1: *La banane dans le chapeau, elles pèsent les graminés*; **La banane dans le chapeau, ils pèsent les graminés* (the star indicates incorrect agreement). Since the singular and plural forms of the main verbs and of the subject pronoun were homophonous despite their spelling differences, the two sentences can be spelled correctly as: *La banane dans le chapeau, elle pèse les graminés*; **La banane dans le chapeau, il pèse les graminés.*

Likewise, an exemplar of *la banane et le chapeau* from the first set with the same intonation (as the aforementioned exemplar of *la banane dans le chapeau*) was connected with the second part of the *et* sentence pair *Les tisanes et les autos, elles pèsent les graminés* and *Les domaines et les autos, ils pèsent les graminés* (from the second set), yielding the test stimuli for Structure 2: **La banane et le chapeau, elles pèsent les graminés; La banane et le chapeau, ils pèsent les graminés.*

The same steps of cross-splicing were done to create the other test sentences. The use of different recording exemplars (varying in intonation) for the first part added acoustic variability, making the stimuli sound more interesting. Since both sets of recorded sentences had a prosodic break (a silence period) after the initial phrase, the cross-splicing was easily applied, and the output sounded natural. The prosodic break was always preserved. The final cross-spliced sentences were put together into four sound files, each containing six sentences corresponding to the test trial types (see Table 1). The content words (verbs, nouns, adverbs) following the subject pronoun clitic were all infrequent words in French, unlikely known by toddlers.

Our speaker also produced the two kinds of subject phrases as independent utterances (i.e., *la banane dans le chapeau; la banane et le chapeau*). Four recording exemplars of each phrase with variable intonations were selected as the final stimuli, forming the two sound files for the familiarization trials (see following details of the experimental design).

Subsequently, we created short visual files of a cartoon puppet, who "spoke" the stimuli of these six sound files, using the Adobe Flash CS3 Professional software. The visual stimuli were exported in a QuickTime format with a 30 fps frame rate and a resolution of 1360 x 768 pixels. The mouth movement of the puppet synchronized with the speech, and his arms and legs also moved. The animation was intended to attract children's interest in the task.

We also used an attention-getter, which was a moving star accompanied by bird songs. In addition, an animation of colorful zooming bubbles with water bubble sounds served as the stimuli for the pre- and post-trials.

2.3. Design and testing procedure

Table 1 displays the final speech stimuli (the cross-spliced sentences) and the design. Participants were randomly assigned to two groups. There were two trial types: correct agreement versus incorrect agreement. One group heard Structure 1 sentences in correct agreement trials and Structure 2 sentences in incorrect agreement trials:

Correct (Structure 1): [*La banane*$_{FEM}$ *dans le chapeau*$_{MAS}$]$_{FEM}$ *elle*$_{FEM}$-VERB …
Incorrect (Structure 2): *[*La banane*$_{FEM}$ *et le chapeau*$_{MAS}$]$_{MAS}$ *elles*$_{FEM}$-VERB …

The other group heard the reverse arrangement, which was important for our design—Structure 2 sentences in correct agreement trials and Structure 1 sentences in incorrect agreement trial:

Correct (Structure 2): [*La banane*$_{FEM}$ *et le chapeau*$_{MAS}$]$_{MAS}$ *ils*$_{MAS}$ -VERB …
Incorrect (Structure 1): *[*La banane*$_{FEM}$ *dans le chapeau*$_{MAS}$]$_{FEM}$ *il*$_{MAS}$ -VERB …

This design ensured that the gender-marked words in correct versus incorrect trials were identical in linear order for each group but different in structures.

In an acoustic chamber (9′8″ x 9′8″) the child sat on the parent's lap in the test room, facing a 42-inch TV screen, which displayed the visual stimuli. Loudspeakers at the location of the screen presented the auditory stimuli. The parent wore headphones that played masking music. A researcher, who was blind to the audiovisual stimuli and to the hypothesis of the study, observed the child through a closed-circuit monitor in an adjacent room and initiated the trials when the child looked at the central screen. The experiment was done in a visual fixation procedure, run by a computer program, which presented audiovisual stimuli and recorded simultaneously the child's looking toward the puppet during each trial. Looking time was thus a measure of children's listening attention to the speech stimuli.

The experiment started with a pre-trial, which served to acquaint the child with the equipment. Two kinds of familiarization trials, each 11.1 seconds, were then presented, one showing the puppet saying the four exemplars of the phrase *la banane dans le chapeau* 'the banana in the hat' and another the four exemplars of the phrase *la banane et le chapeau* 'the banana and the hat.' The between-exemplar pauses within a trial were each 870 ms. The trial order was counterbalanced across participants. These familiarization trials were designed to make the task easier for children since our test trials were quite complex, including multiple sentences with many infrequent words after the subject pronoun.

After the familiarization, test trials began, with the puppet saying correct versus incorrect sentences in alternating trials for a total of 12 trials (six for each type). The children who had heard the *dans* familiarization trial first heard the *dans* sentences as the first test trial, and those who had heard the *et* familiarization trial first heard the *et* sentences as the first test trial. Each trial started contingent upon the child's look toward the central TV screen. A trial would end (and the puppet disappeared) if the child looked away from the screen for at least 2 seconds. A trial would present all six sentences of a type if the child looked to its maximum length (29.3 seconds). The intersentence pause was 1.2 seconds. Between any two trials the attention-getter appeared automatically to attract the child back to the screen. After the test trials, a post-trial was presented to mark the end of the experiment.

2.4. Data analysis and expected results

Each child's looking times (i.e., listening times) in the correct-agreement test trials (six total) and the incorrect-agreement test trials (six total) were compiled separately. Following the standard practice in this testing procedure, we calculated the average looking time per trial for each of the two trial types, excluding the first trial of each type. The data were then analyzed in a 2 x 2 analysis of variance, with Trial Type (correct agreement vs. incorrect agreement) as the within-subject factor, and Group (Group 1 vs. 2) as the between-subject factor. Recall that each child heard test sentences containing dislocated subject phrases with distinct structures, one structure in correct agreement trials and the other in incorrect agreement trials, and the grammaticality status was reversed for the two structures across groups. If toddlers distinguished the structures and correctly processed the agreement, they should show a main effect of Trial Type with a longer looking time consistently for one type of the test trials, either correct or incorrect type, but no Trial Type x Group interaction. If they failed to perceive the structural difference and the agreement patterns, there should be no main effect of Agreement and no Trial Type x Group interaction. If they only processed the lexical difference between *dans* 'in' and *et* 'and' without differentiating the structures nor the agreement patterns, the two groups might both look longer toward sentences containing one of the two words (that is, both groups looking longer toward *dans* sentences or both looking longer towards *et* sentences). In this case, and Trial Type x Group interaction should be significant.

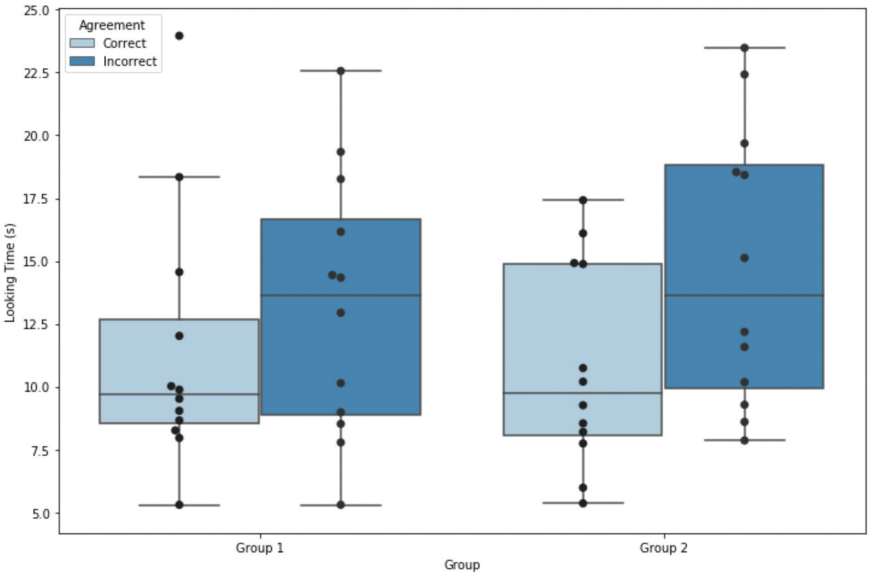

Figure 2. Looking times (listening times) to the two types of test trials by the two toddler groups. The lower and upper boundaries of each box are the first and third quartiles, and the horizontal line inside each box represents the median value. The dots are individual children's data points, with slight jitters applied horizontally to prevent overlapping points in the display. Both groups looked longer while listening to the structure that contained incorrect feature agreement.

3. Results

Results are depicted in Figure 2. Looking times were analyzed in an ANOVA (see the section "Data Analysis and Expected Results" in the Methods section). The results supported the hierarchical hypothesis. Toddlers discriminated the trial types, $F(1,22) = 9.174$, $p = .006$, listening longer to the incorrect type. The average difference in looking time between correct and incorrect trials across the two groups was 2.885 seconds; using the pooled within-group variance estimate, the 95% confidence interval went from 1.003 to 4.767 seconds, and the Cohen *d* effect size was 0.580. There was no Trial Type x Group interaction, $F(1,22) = 1.370$, $p = .254$, and no effect of Group, $F(1,22) = .056$, $p = .815$.

Furthermore, we performed a Bayesian factor analysis of the looking time difference between correct and incorrect trials across the two groups to compare the null (no effect of agreement, i.e., correct vs. incorrect agreement) and an alternative hypothesis (an agreement effect). These Bayesian *t*-tests were performed in SPSS with diffuse priors for both the mean and variance, indicating minimal prior information. We obtained a Bayesian factor of $BF_{10} = 6.25$ for the alternative versus the null hypothesis, indicating that our data were 6.25 times more likely to occur under the alternate hypothesis than the null hypothesis. Moreover, the inclusion Bayesian factor for Group (Group 1 vs. Group 2) was $BF_{10} = 0.229$, indicating that the data were 3.34 times more likely under models that assumed no Trial Type x Group interaction than those that assumed an interaction. Overall, these results were consistent with those of the ANOVA.

4. Discussion

The results of our experiment showed that toddlers understood the grammaticality of the gender feature agreement. Since the agreement patterns in our sentences depended on the distinct structures, children's responses revealed their understanding of the two structures. They did not show a general lexical preference for one of the two contrasting words (*dans* 'in'; *et* 'and'). Instead, by

recognizing the structural distinction, the two groups of toddlers showed a uniform grammaticality effect.

Then how did the toddlers encode the two structures? Let us first consider sequential processing, as proposed in theories of input based inductive learning (e.g., Frank, Bod & Christiansen 2012; Pine & Lieven 1997; Saffran 2001). Specifically, for Structure 1, toddlers might have learned from their prior input that in Det Noun Prep Det Noun, the first noun in the sequence must be the one to agree with the following subject pronoun in features. This kind of processing was demonstrated in a study in which neural networks learned nonadjacent agreement in English, Italian, Russian, and Hebrew from sequential training input (Gulordava et al. 2019). Structure 2 (Det Noun Conj Det Noun) would be more difficult to track linearly because either the first or the second noun could end up sharing the surface gender with the subject pronoun. Nevertheless, according to input based theories, this structure should be learnable given sufficient distributional support in the training data.

However, our results seem to be incompatible with sequential learning because the necessary input condition seems absent. As shown in our corpus analysis (see Table 2) and in previous research (Koulaguina et al. 2019), these two structures rarely occur in children's input. Given that sequential learning would need enough support of the sequential input (as shown in neural network studies (Gulordava et al. 2019)), toddlers in our experiment should not have discriminated the two structures nor the related feature agreement. Our results were contrary to this prediction.

The grammaticality effect shown in our experiment is more consistent with UG-based hierarchical processing and, in particular, with the principle of structure dependence (Chomsky 1965, 1988), which does not require the frequency of a structure to be high; that is, even occasional occurrences in the input can trigger a representation. Our results suggest that although the structures we tested are rare in the input, our toddlers must have heard them occasionally in their life, sufficient to bootstrap the acquisition. Furthermore, we suggest that the structures that our toddlers processed were hierarchical, perhaps resembling the contrast represented in Figure 1. This interpretation is based on the ideas of the principle of structure dependence, which assumes hierarchical organization to be an essential part of the syntactic representations that children trigger or acquire. Acquisition researchers (e.g., Gleitman 1990; Lidz 2010; Pinker 1984; Valian 2009; Wexler 1990; Yang 2004) who work in the framework of generative grammar assume the presence of hierarchical organization early in acquisition. The gender-marked words in our sentences were identical and had the same serial order, but the structures differed. Our toddlers went beyond those gender-marked words and perceived the distinct structures by tracking the contrasting closed-class words *dans* and *et*. Their structural analysis seems to be deductive. Previous research showed that universal grammar can focus children on structurally important information despite it being statistically weaker than certain other distributional cues (Lidz, Gleitman & Gleitman 2003). Infants process words by processing the larger sentential and phrasal structures rather than local co-occurrence patterns (Bernal et al. 2010; Kedar, Casasola & Lust 2006). Those previous studies as well as our present experiment provide evidence that early grammatical knowledge is quite sophisticated.

To further examine whether children at an earlier stage of acquisition also expect to analyze phrase structures hierarchically, we recently followed up to test the exact same experiment on younger toddlers aged 17 to 18 months (Shi, Emond & Badri 2020). The younger toddlers showed the identical pattern of results as that of the older toddlers in the present experiment, indicating that the principle of structure dependence in UG is available to children from the onset of syntactic acquisition.

It is interesting that toddlers of both ages in our study (30–31 months and 17–18 months) showed a novelty preference for the grammaticality effect, that is, a preference for sentences containing incorrect feature agreement. The direction of preference in preferential looking procedures is often not possible to be predicted. In our experiment a uniform looking preference to one type of test trials (correct or incorrect agreement) was crucial for the interpretation that toddlers perceived the distinct structures and the agreement, but which direction did not matter. Either a familiarity preference or a novelty preference would support this hypothesis as long as the direction was the same across the groups. In a recent study (Koulaguina et al. 2019) French-learning toddlers who were tested on subject-verb number agreement (for example, grammatical vs. ungrammatical sentences with conjoined subjects) uniformly preferred to

listen to grammatical sentences, supporting abstract agreement knowledge. Their familiarity preference contrasts with the novelty preference shown in our toddlers. We may ask what this difference (between the two studies) might tell us. One consideration could be the task. Koulaguina et al. used the head-turn preference procedure (HPP), with physical lights in different locations co-occurring with speech stimuli. We used a central monitor presenting visual stimuli accompanied by speech. These procedural differences might have somehow caused the distinct preferential directions. A more important consideration might be children's processing and representation. Previous research showed that the direction of preference can be affected by various factors such as stimuli complexity, age of children, and training duration. A novelty preference might be associated with more robust processing whereas a familiarity preference with less strong processing, as shown in studies in which specific factors were manipulated in the same task (e.g., Hunter & Ames 1988; Thiessen & Saffran 2003). The novelty preference in our study suggests that the knowledge of gender agreement is robust in toddlers, likely due to the fact that gender is an inherent feature of each noun and is acquired solidly during word learning. Indeed, the learning of noun gender is observed in French-learning infants from around 18 months of age (Cyr & Shi 2013; Van Heugten & Christophe 2015). Gender might thus be easier for processing than number. In general, number is not a lexical property, and number agreement is computed only postlexically at the level of phrasal combination, which might be costly for processing and more likely to yield a familiarity preference. What is crucial is that the two studies (Koulaguina et al. and our study) each showed a consistent preference for one type of trials across toddler groups, a response that could only be explained by an ability to track feature agreement.

Acquiring a language certainly requires input, and infants' ability to compute statistical and distributional information from linear input has been well demonstrated in the literature. However, linear statistical/distributional learning does not seem to fully account for early acquisition and the richness of children's structural knowledge, as shown by the 30–31-month-olds in our present experiment (and by the 17–18-month-olds in our follow-up experiment (Shi, Emond & Badri 2020)), in which the two structures needed to be distinguished in order to track the feature agreement. Importantly, since input speech provides little statistical evidence for the two structures, sequential learning from linear input cannot explain toddlers' successful performance in our study. Although there may exist other possible input-based mechanisms that might account for the learning, we believe that our toddlers' analysis was likely driven by hierarchical structures in UG. To conclude, we suggest that while children are capable of engaging in statistics-based induction, this learning is constrained, and they are likely guided by their internal knowledge, especially for structures that lack sufficient support in the input. Our finding revealed the possible impact of the structure dependence principle in UG on toddlers' interpretation of phrase structures. That is, children's internal knowledge may contribute to their discovery of just the right grammar.

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