Infants' sensitivity to non-adjacent dependencies across phonological phrase boundaries

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Abstract: Natural languages contain numerous non-adjacent relationships between words or morphemes in a sentence, often straddling phonological phrase boundaries (e.g., [*these sheep*] [*have* …]). Since phonological phrases are considered the main processing unit for infants, this may cause the acquisition of cross-phrase dependencies to be challenging. This study, however, shows that by 17 months of age, French-learning infants have nonetheless gained sensitivity to remote determiner-auxiliary co-occurrences that are interceded by phonological phrase boundaries. Infants thus possess a robust mechanism for tracking non-adjacent dependencies. This ability is essential for early grammatical development.

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1. Introduction

Sentences are more than simply lists of consecutive words. Words (or word categories) within an utterance relate to other words in that utterance. These relationships, often conveyed by function morphemes such as determiners (e.g., *the, a*) and inflections (e.g., *-s*, *-ing*), are the cement layer of language, keeping content words in place. An important landmark in language acquisition involves learning to track such interdependent relationships between function morphemes.

Computing relationships involves at least two steps. First, infants need to segment and store some function morphemes. This is typically accomplished within the first year of life. At seven to nine months of age, infants are able to segment function morphemes from running speech,[1] and shortly thereafter, they possess a fairly detailed representation of frequently occurring function words.[2–4] The second step involves gaining sensitivity to the co-occurrence of two items that form dependency relationships. Artificial language studies suggest that infants are skilled at tracking adjacent dependencies between syllables,[5] and at using items to predict specific abstract features of subsequent words.[6] Studies of grammatical categorization using natural languages show that infants are able to use function words to categorize adjacent content words by 14–16 months of age,[7,8] and at a slightly later age, infants also track relationships between function words and the adjacent lexical categories in online comprehension tasks.[9,10]

Co-occurrences, however, are not always adjacent. Morphosyntactic dependencies, such as subject-verb (e.g., *he laughs*) or tense (e.g., *is baking*) agreement, often involve two non-adjacent function morphemes intervened by a content word. These remote relationships are a crucial part of grammar, and may form an informative cue to the grammatical category of the intervening syllable.[11] For example, the co-occurrence of *the* and *in* is typically intervened by a

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noun, whereas *you* and *it* is mostly intervened by a verb. Tracking such dependencies may thus allow infants to infer the category membership of the intervening words and may consequently greatly impact further language acquisition. An interesting question concerns how and when these distant dependencies are acquired. The artificial language literature provides evidence that the basic skill to track remote dependencies is in place by 15 months of age.[12] Moreover, studies examining natural language processing show that only a few months later, infants prefer to listen to grammatical (e.g., *is baking*) over ungrammatical (e.g., **can baking*) sentences, indicating that they track the dependency between two remote elements in their native language.[13–15]

While the finding that infants can track non-adjacent dependencies in natural languages is impressive, those studies all tested dependencies within the same phonological phrase (e.g., *is X-ing*, *hat ge-X-t* '*has cried*', *het X-je 'the little X'*). Remote morphosyntactic dependencies, however, often span across phonological phrase boundaries (e.g., [*these sheep*] [*have slept*]). There is evidence that infants are sensitive to both major and minor prosodic boundaries in the speech signal, and that they use this information during sentence processing.[16,17] In addition, prosodic boundaries have been found to constrain infants' lexical access.[18,19] Infants familiarized with the bi-syllabic word *paper*, for example, would later better recognize that word in sentences when it did not span a phonological phrase boundary (e.g., [… *paper*]). When the same phoneme sequence *was* interceded by a phonological phrase boundary (e.g., [*the outstanding pay*] [*persuades him*…]), infants had difficulty perceiving the sequence as a word, thereby emphasizing the prevalence of phonological phrases as processing units.[18] Given this early importance of phonological phrases, tracking non-adjacent dependencies across phonological phrases may be hard for infants. Indeed, even adults experience difficulty when tracking dependencies across clausal boundaries.[20] Alternatively, it is possible that although infants *are* sensitive to prosodic phrasing for word and phrase segmentation, this sensitivity does not prevent them from computing distant relationships between words across different phonological phrases. This is reasonable because remote dependencies mostly involve frequent function morphemes that infants are sensitive to since early infancy.[2,3]

French provides an excellent case for testing these two alternatives, since it uses number marking on both determiners and verbs. The determiner within a subject NP and the verb must agree in number, resulting in a remote dependency between determiners and auxiliaries (e.g., *la fille a dormi* 'the_{SING} girl has_{SING} slept' vs *les filles ont dormi* 'the_{PLUR} girls $\text{have}_{\text{PLUR}}$ slept'). In running speech, these dependencies are typically intervened by a phonological phrase boundary in between the noun and the auxiliary (e.g., [*la fille*] [*a dormi*]). Here we test whether infants in the first half of their second year of life are able to track these non-adjacent morphosyntactic dependencies across phonological phrase boundaries. To test if infants possess the generalized ability to track remote dependencies, we use nonsense nouns intervening the function morphemes.[15] If infants are sensitive to non-adjacent dependencies spanning prosodic boundaries, they should prefer listening to sentences containing grammatical as opposed to ungrammatical dependencies. If, in contrast, infants are not yet able to track non-adjacent dependencies straddling these boundaries, no such listening preference should occur.

2. Experiment 1

Sixteen normally developing Canadian-French-learning 17-month-olds (age range: 17;03–17;29, mean age: 17;18) were tested. Another 12 infants were excluded from the analysis due to parental interference (1), equipment error (1), or fussiness or failure to complete the study (10).

Three singular auxiliaries were selected: *est* 'is', *a* 'has', and *va* 'will'. Each auxiliary was combined with two grammatical (*le, la* – both singular) and two ungrammatical determiners (*les, des* – both plural) such that there was a total of 12 dependencies, six grammatical and six ungrammatical (see Table 1). Each dependency appeared in a sentence containing an intervening phonological phrase boundary. Note that the plural-s on French nouns is silent and that the definite article is thus the sole cue to grammaticality of the dependency. To ensure that infants would respond to generalized dependencies rather than previously encountered chunks of speech (i.e., memorized three-word chunks), nonsense words (always bisyllabic) were used

Table 1. Overview of the grammatical and ungrammatical dependencies used in this study.

Grammatical dependency	Ungrammatical dependency
La coupile va bientôt conduire.	Les coupile(s) va bientôt conduire.
The$_{SG}$ X *will*$_{SG}$ *soon drive*.	*The*$_{PL}$ X *will*$_{SG}$ *soon drive*.
Bien sûr le mupon est toujours venu.	Bien sûr des mupon(s) est toujours venu(s).
Of course the$_{SG}$ X *has*$_{SG}$ *always come*.	*Of course the*$_{PL}$ X *has*$_{SG}$ *always come*.
Le proutique a rarement marché.	Les proutique(s) a rarement marché.
The$_{SG}$ X *has*$_{SG}$ *rarely walked*.	*The*$_{PL}$ X *has*$_{SG}$ *rarely walked*.
La fotiste est parfois peu subtile.	Les fotiste(s) est parfois peu subtile(s).
The$_{SG}$ X *is*$_{SG}$ *sometimes not very subtle*.	*The*$_{PL}$ X *is*$_{SG}$ *sometimes not very subtle*.
Demain le fipare va beaucoup manger.	Demain des fipare(s) va beaucoup manger.
Tomorrow the$_{SG}$ X *will*$_{SG}$ *eat a lot*.	*Tomorrow the*$_{PL}$ X *will*$_{SG}$ *eat a lot*.
On sait que la soquile a souvent mal dormi.	On sait que des soquile(s) a souvent mal dormi.
It is known that the$_{SG}$ X *has*$_{SG}$ *often slept poorly*.	*It is known that the*$_{PL}$ X *has*$_{SG}$ *often slept poorly*.

to intercede each dependency. Half of the dependencies occurred sentence-initially, half sentence-medially.

A native Canadian-French speaker recorded the stimuli at a slow pace in an infant-directed register. Three (grammatical) variations of each sentence were recorded. The first contained a singular article as well as a singular auxiliary (e.g., *le proutique a rarement marché*) and the second contained the plural article in a grammatical plural sentence (e.g., *les proutiques ont rarement marché*). The third differed from the first utterance only in the selection of the article, though both articles were singular (e.g., *la proutique a rarement marché*). These recordings were then cross-spliced. For both the first and the second variations, everything up to the syllable-initial consonant of the second syllable of the nonsense word (e.g., *le prout-; les prout-*) was spliced off. These two chunks were each combined with the carrier (e.g.,*-ique a rarement marché*) spliced from the third variation, yielding a grammatical and ungrammatical version of each dependency for the final stimuli set (e.g., grammatical: *le proutique a rarement marché*; ungrammatical: **les proutiques a rarement marché*).

All infants were presented with six grammatical and six ungrammatical trials alternating during the experiment. Each grammatical trial contained all six grammatical sentences, and each ungrammatical trial contained all six ungrammatical sentences. Between-sentence pauses were approximately 750 ms, and the total length was 24.72 s for each trial. The condition of the first trial (grammatical or ungrammatical) was counterbalanced between infants.

Infants were tested in the Visual Fixation Procedure. They sat on their parents' lap in a sound-attenuated booth facing a 42-in. TV. A blind observer outside the booth watched the infant through a video camera, starting each trial when the infant looked toward the TV, and keeping a button pressed to code the infant's looking time. During a trial, a stationary orange-colored checkerboard and the auditory stimulus were simultaneously presented. A trial ended when the infant looked away from the screen for two consecutive seconds or when the maximum trial length was reached. A colorful moving screensaver combined with a cricket sound served as the attention getter. Parents wore headphones delivering masking music.

Initial trials in this procedure are often unstable,[21] and the first two trials (one grammatical, one ungrammatical) were thus excluded from the analyses. Mean listening times to the remaining grammatical and ungrammatical trials were calculated for each infant. Infants on average listened longer to grammatical (5.02 s) than to ungrammatical (3.79 s) trials (see Fig. 1), with 12 out of the 16 infants exhibiting this pattern. A two-tailed paired-sample t-test showed that this difference (1.23 s; SEM=0.513) was statistically significant [$t(15)=2.396$; $p=0.030$], suggesting that 17-month-old French learners track the non-adjacent co-occurrence between determiners and auxiliaries, even though the two elements do not belong to the same phonological phrase. Since nonsense words were used to intervene the dependency, this effect cannot be due to the storage

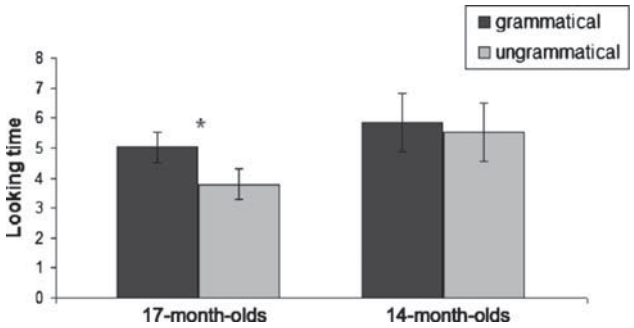

Fig. 1. Infants' mean looking times in seconds (and standard errors of the difference scores) to grammatical and ungrammatical trials broken down by Age.

of any previously encountered word chunks. Rather, it reflects a generalized ability to respond to non-adjacent dependencies that is not restricted to phrase-internal elements. In order to determine when this sensitivity emerges, Experiment 2 was designed to test younger infants.

3. Experiment 2

Sixteen normally developing Canadian-French-learning 14-month-olds were tested (age range: 14;01–14;30, mean age: 14;21). An additional 4 infants were tested, but excluded from the analysis due to equipment error (1), parental interference (1), or fussiness or failure to complete the study (2). The materials, design, and procedure were identical to Experiment 1.

As before, for each infant the mean looking times to grammatical and ungrammatical dependencies were calculated, excluding the first two trials. Infants listened to the grammatical trials for an average of 5.86 s and to the ungrammatical trials for 5.53 s (see Fig. 1), with 6 infants listening longer to grammatical trials. This difference (0.33 s; SEM=0.98) was not significant [$t(15)=0.338$; $p=0.74$]. Thus, unlike the 17-month-olds, 14-month-olds tested on the same materials showed no evidence of tracking the non-adjacent determiner-auxiliary dependency. Although this does not exclude the possibility that 14-month-olds may track this dependency under different listening conditions, the absence of this effect is not entirely surprising given previous studies showing that infants around 15 months do not yet track remote dependencies in natural languages.[14]

4. General discussion

This study shows that French-learning infants start tracking non-adjacent determiner-auxiliary dependencies some time before 17 months of age, similar to the performance of 18-month-olds in other languages.[13,14] Furthermore, non-adjacent dependencies are tracked even when the determiner and the auxiliary belong to different phonological phrases, thus crossing a phonological phrase boundary. This is remarkable, because phonological phrases are considered the main processing units for infants. By 17 months of age, infants thus already possess a robust mechanism for tracking non-adjacent dependencies across different prosodic units.

These findings together with existing evidence on prosodic perception suggest that infants process prosodic cues in an elegant way. Words or constituents always occur within a phonological phrase, and hence infants do not consider straddling units to belong to the same word. Morphosyntactic dependencies, in contrast, often do spread across different phonological phrases, and hence infants take into account the possibility that phrase-external elements form relationships. Thus, infants do not just simply break up the speech signal into different phonological phrases and constrain their focus on elements within those units. Instead, their use of prosodic cues depends on the task at hand.

The finding that infants efficiently compute remote dependencies across phonological phrase boundaries validates corpus studies that examine distributional properties of non-

adjacent dependencies in infant-directed speech.[11,15] One potential issue with these corpus studies is that phonological phrase boundaries are not taken into account, as transcriptions typically do not label prosodic phrasing below the clause boundary level. If infants lacked sensitivity to dependencies across phonological phrases, this would thus have rendered the value of these corpus studies, which inevitably contain many dependencies straddling phonological phrases, insignificant. The finding that infants *are* sensitive to these dependencies, however, indicates that the corpus distributions do provide valuable cues to the child and can predict the rate of acquisition of non-adjacent dependencies.[15]

In sum, by 17 months, an age when infants just start acquiring distant relationships between words, French-learning infants are sensitive to non-adjacent co-occurrences of function morphemes that are interceded by phonological phrase boundaries. This ability is generalized and not tied to the memory of any previously encountered specific word chunks, indicating that a robust mechanism for tracking non-adjacent dependencies is in place at a very young age.

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