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Developing knowledge of nonadjacent dependencies

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Abstract

Characterizing the nature of linguistic representations and how they emerge during early development is a central goal in the cognitive science of language. One area in which this development plays out is in the acquisition of dependencies—relationships between co-occurring elements in a word, phrase or sentence. These dependencies often involve multiple levels of representation and abstraction, built up as infants gain experience with their native language. We used the Headturn Preference Procedure to systematically investigate the early acquisition of one such dependency, the agreement between a subject and verb in French, at six different ages between 14–24 months. Our results reveal a complex developmental trajectory which provides the first evidence that infants might indeed progress through distinct stages in the acquisition of this non-adjacent dependency. We discuss how changes in general cognition and representational knowledge (from reflecting surface statistics to higher-level morphological features) might account for our findings. These findings highlight the importance of studying language acquisition at close time intervals over a substantial age range.

Keywords: language acquisition; linguistic representations; processing; morphosyntax; non-adjacent dependencies; head-turn preference procedure

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Introduction

A major goal in the study of human cognition is to characterize the nature of representations in different cognitive domains. Language development research plays a central role in this by investigating how linguistic representations are formed and change with age. While major debates in the field are centered around the extent to which early grammatical knowledge is abstract, it is widely acknowledged that children's representations are not static. Rather, they emerge and evolve as experience with the native language accumulates. One area in which this development plays out is in the acquisition of dependencies—relationships between co-occurring elements in a word, phrase or sentence. Artificial language learning studies have shown that infants as young as 4-8 months (Saffran et al., 1996; Aslin et al., 1998; Mersad & Nazzi, 2012) rapidly learn surface-level dependencies between adjacent elements (e.g., syllables in a word). Learning dependencies between *non-adjacent* elements in an artificial language is more challenging, but has been found in experimental learning studies at 15 months (Gómez & Maye, 2005).

While these studies suggest that a mechanism for tracking dependencies is in place very early in life, establishing when specific natural language dependencies are acquired by young infants is a distinct challenge. Work on the acquisition of word-internal phonology has suggested early knowledge of a number of non-adjacent patterns (Van Kampen et al., 2008; Gonzalez-Gomez & Nazzi, 2012). However, in the domain of morphology and syntax, dependencies present a more complex problem; such dependencies necessarily involve multiple levels of

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representation and abstraction, and thus the nature of infants' knowledge may change across development.

State-of-the-art methods for tapping into young infants' knowledge, like the Headturn Preference Procedure (HPP; Kemler Nelson et al., 1995), work by comparing infant's behavioral reactions to stimuli of interest. For example, HPP can establish *sensitivity* to differences between exemplars of stimuli, which conform to or violate a dependency. In principle, however, such sensitivity might reflect knowledge of any number of factors distinguishing the stimuli tested—from low-level properties like duration, pitch, word frequency or n-gram probability, to higher-level properties like morphological or syntactic well-formedness. In the case of morphosyntactic dependencies like subject-verb agreement, infants are likely sensitive to regularities at many levels over the course of development. For example, Fig. 1a illustrates the non-adjacent dependency between a subject and a verb in English. Sensitivity to this dependency could reflect surface-based phonological representations, that is, knowledge that a particular set of sounds are likely to co-occur, independently of their meaning (Soderstrom, 2008). Alternatively, it could reflect knowledge of higher-level representations corresponding to morphological features, which match for the subject and the verb (e.g., singular or plural). These morphological features would have conceptual or semantic content, being mapped to categories of referents in the world, in this case, entities of distinct numerosity. While morphologically specified representations are required for *comprehension*, sensitivity (i.e., discrimination of grammatical and ungrammatical stimuli) would be predicted in either case. Moreover, it remains to be established whether these levels of representation are acquired simultaneously or sequentially.
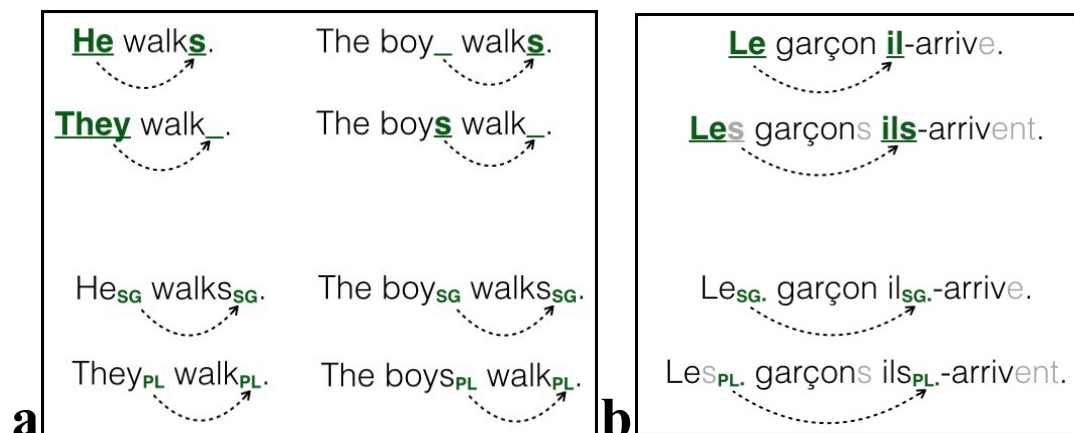
Fig. 1. (a) Surface-based versus featural representation of the non-adjacent dependency between subject and verb in English, and (b) a corresponding dependency in French involving prefixal agreement on the verb (here the gray letters are silent, and the dependent elements are phonologically realized as [lə...ilariv] and [le...izariv]).

Previous work on early knowledge of non-adjacent dependencies suggests that in some languages, surface-level representations may be in place *much* earlier than higher-level morphological representations. For example, HPP studies have found sensitivity to agreement dependencies in English-learning infants between 16–19 months (Santelmann & Jusczyk, 1998; Soderstrom et al., 2007), but comprehension of these dependencies in experimental tasks is not definitively found until 5–6 years (Johnson et al., 2005; Legendre et al., 2014). An apparent lag between sensitivity and comprehension has also been reported for Spanish (Perez-Leroux, 2005; Legendre et al., 2014) and German (with comprehension between 3–4 years; Höhle et al., 2006; Brandt-Kobele & Höhle, 2010; Van Heugten & Johnson, 2010). In French, the progression

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appears to be faster, with initial sensitivity between 14 and 18 months (Van Heugten & Shi, 2010; Nazzi et al., 2011) and comprehension by 30 months (Legendre et al., 2010). If comprehension is only possible once children have acquired the relevant morphological features and their mapping to semantic categories, then the nature of their earliest knowledge is likely based on surface properties of the dependency.

While the collective results of these studies are consistent with the idea that the acquisition of higher-level feature-based dependencies is built on earlier surface-based knowledge of sound co-ccurrences, direct evidence of changing representations and their timescale for a given property or language is lacking. A potential source of evidence comes from work investigating the relationship between the robustness of infants' knowledge and the direction of their preferences in HPP and related paradigms. Houston-Price & Nakai (2004), following Hunter & Ames (1988), argue that differences in direction of preference—for example, longer listening to familiar stimuli at one age but novel stimuli at a later age—reflect the robustness of infants' knowledge (see also Rose et al., 1982; Wagner & Sakovits, 1986; Roder et al., 2000; Aslin, 2007). A schematic representation of predicted changes in preference over time is shown in Fig. 2. Switches from familiarity to novelty preferences depending on factors like age (assumed to reflect developmental progression in language, memory, etc.), task and stimulus complexity are well-documented, and have been found in many domains, including vision (e.g., Roder et al., 2000; Shinskey & Munakata, 2010), phonology and speech segmentation (e.g., Thiessen et al., 2005; Seidl, 2007; Seidl et al., 2009; Butler et al., 2011; Bosch et al., 2013), rule learning (Gerken & Knight, 2015; Gerken et al., 2015) and

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morphosyntax (e.g., Gomez & Maye, 2005; Sundara et al., 2011). Most of these studies involve

an in-task exposure period, where familiar items are those included in the exposure set and novel

items are not. However, in studies assessing infants' knowledge of a non-adjacent dependency in

their native language, the familiarity/novelty distinction maps directly onto the distinction

between grammatical and ungrammatical stimuli. Importantly, switches from grammaticality to

ungrammaticality preferences with age have been found in such studies as well (e.g., Sundara et

al., 2011), suggesting that HPP can be used to investigate the evolution of native language
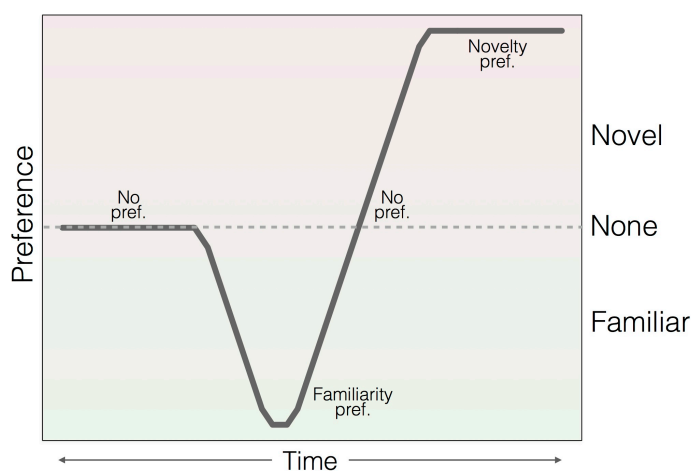
representations.

Fig. 2. Illustration of changing preference directions (where time is increasing duration of

exposure in an experimental task, or age), based on Hunter & Ames (1988).

Key to the idea of exploring developmental changes in representations is to track infants'

sensitivity beyond what appears to be the first emergence of an effect (or preference). This

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means testing infants across a range of ages, using the same stimuli and procedure. For example, Liu and Kager (2014) investigated tone discrimination across five age groups of Dutch-learning infants (ranging from 5 to 18 months), and found an unexpected U-shaped developmental curve; robust discrimination was found in the youngest infants, this effect diminished as predicted by perceptual reorganization, but then reappeared strongly for the oldest infants. While their finding points to the potential of this approach to shed light on developmental changes, such studies remain rare. Indeed, previous studies of the acquisition of agreement typically use different methods *and* stimuli to target distinct stages of development. For example, experiments investigating the development of initial sensitivity to subject-verb agreement use different methods (HPP, vs. IPLP, or pointing), and stimuli (different sentence types, lengths, verbs) from studies targeting later comprehension. Although changes in methodology are necessary to confirm comprehension, we test below the hypothesis that important changes in representation may happen *before* that stage, using the method standardly used to evaluate sensitivity (HPP).

French-learning infants' early acquisition of non-adjacent agreement dependencies presents an ideal testing ground for this approach. On the one hand, several studies (including Legendre et al,. 2010; Barrière et al., 2016) have established that comprehension of verbal agreement is found at 30 months. Infants' representations must therefore have developed sufficiently and rely on abstract knowledge of morphological features by 30 months. On the other hand, an early preference for grammatical subject-verb agreement was identified at 18 months in Nazzi et al. (2011). This suggests that infants progress from initial sensitivity to comprehension over a relatively short time period of time.

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However, these two sets of studies used different methods (IPLP/pointing versus HPP, respectively), and also tested different instantiations of subject-verb agreement in French. Nazzi et al. (2011) tested agreement distinctions indicated by changes to the verb stem (e.g., *fait* [fɛ] 'make$_{sg}$' versus *font* [fõ] 'make$_{pl}$'), while Legendre et al. (2010) targeted prefixal agreement (e.g. *il-apporte* [ilapɔrt]'bring$_{sg}$' versus *ils-apportent* [izapɔrt] 'bring$_{pl}$'). To investigate the time course of development at a more fine-grained level, we therefore tested infants between 14 and 24 months of age, holding the method and stimuli constant across ages. We used the prefixal paradigm since we know that comprehension of that subsystem of agreement comes into place sometime between 24 and 30 months (Legendre et al., 2010). Following Nazzi et al. (2011), we included a subject NP, as illustrated in Fig. 1b, since here we are interested specifically in the grammatical *dependency* between an overt subject and a verb. These two elements together can be used to construct grammatical and ungrammatical instantiations of that dependency. Based on the relationship between robustness of infants' knowledge and listening-time behavior laid out in Fig. 2, we expected to see age-dependent switches in direction of preference within this time frame. If the youngest infants show a preference, it should be for grammatical (familiar) stimuli, while older infants' more robust knowledge should lead to an ungrammaticality (novelty) preference. Further, if the nature of the representations of this dependency are changing (from encoding surface-level statistics to higher level morphological features), this should in principle be reflected in the patterns of preference. A preference for ungrammatical stimuli at one age may shift *back* to a grammaticality preference at a later age as conceptually grounded representations begin to emerge. For example, if from 14–18 months, infants are in the process of developing

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robust surface-based representations of agreement (as suggested by Nazzi et al., 2011), then they should move from grammaticality to ungrammaticality preference within that time frame. If they subsequently begin developing representations based on morphological features like singular and plural, then we predict a second such cycle after 18 months.

Method

Participants

Four groups of 20 infants were initially tested, with 3 months between age groups: 15, 18, 21, and 24 months. All groups revealed significant or marginally significant preferences (results for 18 and 24 months in Table 3; 15 months: trend for ungrammaticality preference, *p = .056*; 21 months: grammaticality preference, *p = .013*). However, inspection of the data revealed that looking times for infants in the 15-month-old (14m 7d–15m 9d) and 21-month-old (20m 18d–22m 4d) groups were bimodally distributed: in each case a cluster of infants showed a relatively clear grammaticality preference, and a second cluster showed an ungrammaticality preference. To investigate this, we used statistical clustering analysis to determine whether the data in each of the four initial groups (each N=20) was best fit by a model including more than a single cluster (using the R package mclust, Fraley & Raftery, 2002; Fraley et al., 2012). This analysis confirmed that for the 15- and 21-month-old groups two clusters were present, compared to a single cluster for 18- and 24-month-old groups. We therefore decided to split the 15-month-old group into 14- and 15-months (with the cut-off at 14 and a half months), and the 21-month-old group into 21- and 22-months (with the cut-off at 21 and a half months). Testing continued until

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all 4 new groups included 20 infants. Across these six age groups, a total of one-hundred-twenty full-term infants from monolingual French-speaking families were thus tested in Paris at the Université Paris Descartes and their data included in the analyses. A summary for each age group is provided in Table 1. Sample sizes per group are based on average size across similar studies (e.g., Nazzi et al., 2011; Tincoff et al., 2000).

Table 1. *Summary of participants tested.*

Age group	(N)	Months, days (range)	Sex
14 months	(20)	13m, 28d (13m, 17d–14m,14d)	8F, 12M
15 months	(20)	14m, 28d (14m, 16d–15m, 9d)	8F, 12M
18 months	(20)	18m, 9d (17m,28d–18m, 26d)	6F, 14M
21 months	(20)	21m, 4d (20m, 18d–21m, 13d)	8F, 12M
22 months	(20)	21m, 27d (21m, 15d–22m, 10d)	6F, 14M
24 months	(20)	24m, 12d (24m, 1d–24m, 25d)	8F, 12M

Additional data from 60 infants (fifteen 14-month-olds, fifteen 15-month-olds, five 18 month-olds, eleven 21-month-olds, twelve 22-month-olds, and two 24-month-olds) were not included in the analysis for the following reasons: fussiness (24), parental interference (4), technical problems (5), at least three short looks of less than 1.5 s (1), or two consecutive short looks (12), or both (5), more than 2 SDs above or below the group mean (9). This rate of rejection is within the norm for such studies (e.g., Shi & Melançon, 2010; Van Heugten & Johnson, 2010; Soderstrom et al., 2007).

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Stimuli

Stimuli were comprised of sentences of the type in Fig. 1b. Exact stimuli were as in (1), that is, a

subject noun phrase (always *le(s) garçon(s)* 'the boy(s)'), followed by a subject pronoun, a

vowel-initial verb, and a direct object. Direct object nouns were pseudowords in order to match

this feature of the stimuli used in previous studies of French agreement (Legendre et al., 2010;

Nazzi et al., 2011). These pseudowords were used by Legendre et al (2010) in comprehension

studies using IPLP in order to prevent a collective interpretation (across both scenes presented)

of plural stimuli by allowing each scene to use a distinct, unfamiliar object (as also discussed in

Kouider et al., 2006).

    (1) a. le garçon il-attrape le voube. [l**ǝ**.gar.sõ.i.**l**a.trap]

       'The boy catches the voub.'

     b. les garçons ils-attrapent le voube. [l**e**.gar.sõ.i.**z**a.trap]

      'The boys catch the voub.'

Note that the orthographic distinctions between the singular and plural nouns (*garçon, garçons*)

and verbs (*attrape, attrappent*) are not in fact pronounced. Rather, it is the determiner in the

noun phrase (*le* or *les*) and the subject pronoun (*il, ils*)—prefixed to the verb by a phonological

process called *liaison*—which indicate number agreement. There is strong evidence that subject

pronouns are indeed functioning as verbal agreement affixes in these constructions (Pierce, 1992;

Culbertson, 2010). Here we target only third person forms in the largest conjugation class in

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French, all of which are homophonous in the singular and plural. We chose twelve frequent

vowel-initial verbs (*attacher* 'attach'*, apporter* 'bring'*, envoyer* 'throw'*, arracher* 'pull'*, habiller*

'dress'*, embrasser* 'kiss'*, arrêter* 'stop'*, allumer* 'turn on'*, essuyer* 'wipe'*, accrocher* 'hang'*,

attraper 'catch'*, enlever* 'remove'). In all cases, the singular and plural forms of the verb are

distinguished only by the liaison consonant (singular /l/ or plural /z/) of the agreement prefix, as

in (1).

A native French speaker recorded two samples of each singular and plural sentence using

child-directed speech style. Then a cross-splicing method was used to create ungrammatical and

grammatical sentences for each verb. This ensured that ungrammatical sentences would not

sound more unnatural than grammatical sentences. The four sentence types generated by this

method are illustrated in Table 2. Grammatical singular stimuli were made by cross-splicing the

subject from the first recording of a given verb (e.g., *le garçon* 'the boy') with the verb phrase of

the second recording (e.g., *il-apporte le vipe* 'carries the vip'). Similarly, grammatical plural

stimuli were made by cross-splicing the subject and verb phrase from the first and second

recordings of the plural for a given verb. Ungrammatical singular stimuli were made by cross-

splicing the subject from the first recording of the singular sentence (e.g., *le garçon* 'the boy')

with the verb phrase of the second recording of the plural sentence (e.g., *ils-apportent le vipe*

'carry the vipe'). Finally, ungrammatical plural stimuli were made by cross-splicing the subject

from the plural of the first recording (*les garçons* 'the boys') with the verb phrase from the

second singular recording (*il-apporte le vipe* 'carries the vip').

Table 2. *Cross-splicing method and stimulus examples.*

Segment 1	recording #	Segment 2	recording #	Type
le garçon	(1)	*il apporte le vipe*	(2)	grammatical (sg.-sg.)
les garçons	(1)	*ils apportent le vipe*	(2)	grammatical (pl.-pl.)
le garçon	(1)	*ils apportent le vipe*	(2)	ungrammatical (sg.-pl.)
les garçons	(1)	*il apporte le vipe*	(2)	ungrammatical (pl.-sg.)

With twelve verbs and four sentence types, shown in Table 2, there are 48 possible sentences. We used these sentences to create eight passages, each containing six sentences of the same type. In each age group, half of the infants were randomly assigned to one of two subgroups of those eight passages, shown in (2), which counterbalanced the type of sentence a given verb was presented in. Thus each infant heard four unique passages (one with each type in Table 2), played twice each (see Procedure below). Each passage was 14.2s long (the inter-stimulus interval between sentences in the passages being approximately 800ms).

(2) Group 1.

sg.-sg. and sg.-pl.{attacher, apporter, envoyer, arracher, habiller, embrasser}

pl.-pl. and pl.-sg.{arrêter, allumer, essuyer, accrocher, attraper, enlever}

Group 2.

sg.-sg. and sg.-pl.{arrêter, allumer, essuyer, accrocher, attraper, enlever}

pl.-pl. and pl.-sg.{attacher, apporter, envoyer, arracher, habiller, embrasser}

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Procedure and apparatus

Infants were tested while held on a caregiver's lap inside a soundproof room, in a three-sided test booth. A closed-circuit video system was monitored by an observer who used a response box to control the trials. To prevent bias, both the observer and the caregiver listened to masking music over tight-fitting closed headphones. Following the Head-turn Preference Procedure, each trial began with the green light on the center panel blinking until the infant oriented in that direction. Then, the center light was extinguished and the red light on one of the side panels was illuminated. When the infant looked at the light, the stimulus for that trial began to play from a loudspeaker hidden behind the light. Stimuli were delivered by the loudspeakers via an audio amplifier. Each stimulus was played to completion (i.e., when all 6 sentences had been presented) or stopped immediately after the infant stopped orienting towards the light for 2 consecutive seconds (200 ms fade-out). If the infant turned away from the target light for less than 2s and then turned back again, the trial continued but the time spent looking away was not included in the orientation time. Thus, the maximum orientation time for a given trial was the duration of the entire speech sample. If a trial was less than 1.5s, the trial was repeated once and the original orientation time was discarded. The flashing red light remained on for the entire duration of the trial.

Each experimental session began with two musical trials, one on each side (randomly ordered) to give infants' an opportunity to practice one head-turn to each side before the test session itself. The test phase consisted of two blocks, with each block including the same set of four passages. The order of passages was randomized within each block and across infants.

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Results

Looking times for grammatical and ungrammatical passages were averaged for each infant. A

Mixed ANOVA using a within-subject factor of grammaticality (grammatical or ungrammatical)

and between-subject factors of age (14, 15, 18, 21, 22, or 24 months) and subgroup (one of two

mappings of verb to sentence type) was conducted. This revealed a significant grammaticality x

age interaction, $F(5,108) = 5.84$, $p < .001$, indicating that the effect of grammaticality changed

across age groups. No other significant effects were found. To compare average looking times

for grammatical and ungrammatical stimuli, we calculated 95% confidence intervals for each age

group as well as paired t-tests (see Table 3).

Table 3. *Average looking times (sec) for grammatical and ungrammatical passages, looking time difference and 95% confidence intervals for each age group. Colored cells indicate preference directions confirmed by CIs and two-tailed t-tests.*

Age group	Ungram.	Gram.	Diff.	95% CI	T-test (df=19)
14 months	5.30	5.92	−0.62	[−1.17, −0.07]	t= −2.37, $p = .029^*$
15 months	6.13	5.00	1.12	[0.21, 2.04]	t = 2.58, $p = .019^*$
18 months	8.95	7.61	1.34	[0.37, 2.32]	t = 2.88, $p = .010^*$
21 months	7.08	8.67	−1.59	[−2.79, −0.40]	t = −2.79, $p = .012^*$
22 months	8.23	8.21	.023	[−1.20, 1.24]	t = 0.04, $p = .97$
24 months	8.79	7.24	1.55	[0.14, 2.96]	t = 2.3, $p = .033^*$

These changes in preference direction are illustrated in Fig. 3, which for clarity, plots the

difference in looking time between ungrammatical and grammatical stimuli. Bars below zero are

indicative of a familiarity preference for grammatical stimuli. Bars above zero are indicative of a

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novelty preference for ungrammatical stimuli. Summarizing, 14- and 21-month-olds showed a

grammaticality (familiarity) preference; 15-, 18-, and 24-month-olds showed an

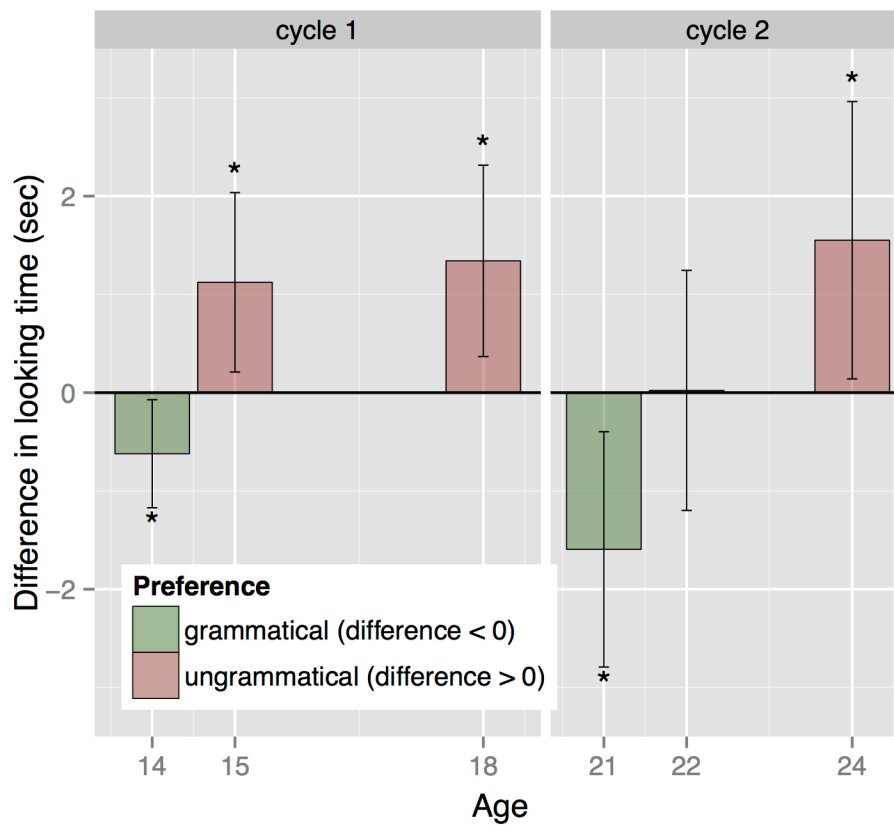ungrammaticality (novelty) preference; 22-month-olds showed no preference.

Fig. 3. Difference in average looking time to ungrammatical vs. grammatical stimuli across all

age groups tested. Each cycle corresponds to a progression from grammaticality to

ungrammaticality preference. Cycle 2 starts with the reversal back to a grammaticality

preference at 21 months. Error bars represent 95% confidence intervals.

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Analysis of CDI data

Our results reveal *two* cycles of changes in the direction of infants' preferences between 14 and 24 months. The first shift from grammaticality to ungrammaticality preference occurs between 14 and 15 months, with 18-month-olds continuing to show an ungrammaticality preference. We refer to this as the first cycle, which ends with the reversal back to grammaticality preference by 21 months. The second cycle, between 21 and 24 months, contains a second shift back to ungrammaticality preference at 24 months. To provide additional support for our claim of a meaningful relationship between the patterns of behavior observed and linguistic development, we analyzed CDI data (the French adaptation of the MacArthur CDI "Words and phrases"; Kern & Gayraud, 2010, Fenson et al., 2007) collected for 107 (of 120) children. The correlation of interest here is the difference score (grammatical–ungrammatical looking time, indicating familiarity or novelty preference) and the CDI scores. We computed these correlations across age ranges where shifts in preference occurred: independently within cycles (14-18 months and 21-24 months), and across the transition between the two cycles (including 15-, 18- and 21-month-olds).

There was no correlation between the number of items reported as comprehended and performance in the task for any of the three age groupings tested. Productive CDI scores (items reported as comprehended and produced) were also not correlated for infants in the first cycle (which might be due to floor effects, since scores were very low: 14, 15 and 18 months, M=19.4, SD=35.2; r=—0.14, p=.31). However, the correlation between productive CDI and differences scores was significant for infants in the transition group (15, 18, and 21 months, M=51.2,

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SD=69.7; r=0.34, p=.01) and for infants in the second cycle (18, 21, and 24 months, M=177.2, SD=147.8; r=–0.28, p=.04). The direction of correlation is consistent with the idea that preference direction in our task is tapping into changes in linguistic development, at least from 15 months on: increases in productive CDI scores were correlated with a higher grammaticality preference in the transition period, but a higher ungrammatical preference in the second cycle. Lastly, in all groups, age was strongly correlated with both CDI scores (cycle 1: r=0.44, p=0.001; transition: r=0.34, p<0.001; cycle 2: r=0.48, p<0.001), and difference scores (cycle 1: r=–0.34, p<.01; transition: r=0.44, p<0.001; cycle 2: r=–0.42, p<.001), showing that infants' age is a reasonable proxy for vocabulary development.

General Discussion

Dependencies are a ubiquitous feature of language which very young infants have the capacity to track and use to build up grammatical representations. Adjacent dependencies between syllables provide clues for word segmentation (Saffran et al., 1996; Aslin et al., 1998; Mersad & Nazzi, 2012), and dependencies among the resulting words can be used to acquire lexical categories and early syntax (Mintz et al., 2002). The acquisition of non-adjacent morphosyntactic dependencies—like those involved in subject-verb agreement—presents an especially revealing case of how linguistic knowledge may be built up sequentially across development. This is because these dependencies encode surface-level information (e.g., based on phonological features of the stimuli), *and* higher-level morphological feature-based information supporting comprehension. Here, we used HPP to systematically investigate the acquisition of a subject-

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verb agreement dependency in French at a number of points during a critical interval in which representations are quickly evolving. This critical interval was identified on the basis of previous experimental work: studies using HPP found that initial sensitivity to stem-based subject-verb agreement in French appears between 14 and 18 months (e.g., Nazzi et al., 2011), and further work using IPLP found evidence for comprehension of prefixal subject-verb agreement emerging between 24 and 30 months (e.g., Legendre et al., 2010). These results suggested that infants' knowledge of agreement might be evolving during this age range. Based on the model of infant familiarity and novelty preferences put forward by Houston-Price & Nakai (2004), we therefore predicted that between 14 and 24 months, French-learning infants' developing representations should lead to shifts in preference direction. We proposed that these shifts might reflect changes in both the robustness of a given representation, and the nature of the representations themselves.

The results of our experiment revealed a complex picture of fine-grained changes in behavior. Globally, we observed two sequential cycles of shifts from a preference for grammatical stimuli to a preference for ungrammatical stimuli. The grammaticality preference found for infants at 14 months changes to an ungrammaticality preference at 15 and 18 months, *reverses back* to grammaticality by 21 months, and finally switches again to ungrammaticality at 24 months. This pattern of changes represents the first evidence suggesting that the way in which French-learning infants process this kind of stimuli changes several times between 14 and 24 months.

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How likely is it that the changes in behavior observed here reflect changes in infants' knowledge of subject-verb agreement? The connection between shifts from familiarity to novelty preferences and the *robustness* of representations was first put forward by Hunter & Ames (1988), and has since been documented in a number of studies, often over a relatively short developmental timescale (e.g., Roder et al., 2000; Houston-Price & Nakai, 2004; Aslin, 2007). In the domain of morphosyntax, Gomez and Maye (2005) trained infants on a novel non-adjacent dependency. They report no preference for 12-month-olds, a familiarity preference for 15-month-olds but a novelty preference for 17-month-olds, suggesting that infants' ability to track such structures is maturing during this age range. Sundara et al. (2011) reported a shift from grammaticality to ungrammaticality preference among 22- to 27-month-old English-learning infants for stimuli with grammatical and ungrammatical third person singular –s in sentence-final position. They interpreted this as indicating a change in the robustness of infants' perceptual representations. In the domain of word segmentation, even more rapid shifts have been documented in the first year of life. For example, Bosch et al. (2013) reported a familiarity-to-novelty shift from 6 to 8 months reflecting development in Spanish-learning infants (the age difference between the oldest 6-month-olds and the youngest 8-month-olds being only 2 weeks). Nishibayashi and Nazzi (2016) found a reversal in relative weight given to vowels and consonants in recognizing segmented words between 6 and 8 months in French-learning infants. In object perception, a switch in preference interpreted as indicating representational robustness has been reported from 7 to 11 months (Shinskey & Munakata, 2010).

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These diverse findings suggest that changes in the robustness of infants' representations and the ability to build new representations can occur relatively rapidly. In our study, the shift across cycles (from ungrammaticality to grammaticality between 18 and 21 months) and within the second cycle (from grammaticality to ungrammaticality between 21 and 24 months) both occur over three months, similar to the timescale of Sundara et al. (2011), for example. The same shift in the first cycle appears to occur within a single month (from 14 to 15 months), without a clear transition through a neutral preference. While this may reflect rapid development, note that the familiarity preference in this case corresponded to a smaller difference score (less than 1s) for this group compared to the others. It is therefore also possible that this group includes the upper range of infants presenting a grammaticality preference (which might start at an even earlier age) along with some infants having a neutral preference (falling into the grammaticality-to-ungrammaticality transition). As a consequence, the preference shift would appear to be faster than it really is. As it stands though, this potentially rapid change in behavior along with the fact that CDI data and difference scores were not significantly correlated for this first cycle calls into question whether an interpretation in terms of developing representations of the dependency tested is the best explanation for these results.

More general cognitive changes are also likely to be occuring within the age range we tested, including changes in vocabulary development and memory capacity. As discussed above, age and CDI scores are strongly correlated for the infants we tested. This could drive behavior in several ways. First, the changes observed within and between the cycles may be a direct result of changes in familiarity with the specific verbs used as stimuli. Of these, 9 are present on the

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French CDI. On average, infants in the first cycle (14, 15, 18 months) produced none of these verbs, and were reported to comprehend 1.6 on average (SD=0.4). Infants in the second cycle (21, 21, 24 months) produced on average 1.3 (SD=2.8) and comprehended 3.5 (SD=2.4). No significant correlations were found between CDI scores for these verbs and difference scores in the task for either cycle, or in the transition across cycles (15, 18, 21 months). While we might be dealing with statistical power or floor effects, there is nevertheless no support for the idea that familiarity with the particular verbs tested–or memory for particular strings infants have heard–is what drives shifts in preference within or between the two cycles.

A second possibility is that as vocabulary size grows, processing of pseudowords changes. Our stimuli featured direct object pseudonouns, not involved in the dependency itself, which may nevertheless be more costly to process at certain ages. Perhaps young infants initially ignore them, while older infants attempt to process them. Under this scenario, the two later preference switches might reflect not changes in the representation of the dependency, but rather changes in the ability to process the pseudonouns. If infants only begin to process this part of the stimuli between 18 and 21 months, this may drive a change back towards a grammaticality preference (e.g., if this demands additional processing capacity). The susbsequent shift towards an ungrammaticality preference would follow between 21 and 24 months as infants' ability to process the pseudonouns improved. While this is a possibility, it leaves unclear what might be driving the preference change within the first cycle (between 14 and 18 months). Moreover, infants and toddlers hear unknown words very frequently, and many studies of fast-mapping in the second year of life show that infants can easily process pseudowords and map them to novel

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referents (e.g., Havy & Nazzi, 2009; Nazzi, 2005; Jaswal & Markman, 2001; Horst & Samuelson, 2008; Spiegel et al., 2011).

A general increase in memory or processing capacity is also likely occuring during the age range tested. Assuming infants have some representation of the dependency, increased short-term memory capacity could make discrimination easier, and increased long-term memory capacity could lead to more robust representations. Without any qualitative change in the representations between 14 and 24 months, better discrimination could lead to a shift in preference direction for the younger infants, and better representations to a similar shift in the older infants. This is fully compatible with the connection between robustness of representations and preference shifts within cycles outlined above. What memory and processing capacity do not readily explain by themselves, however, is the reversal back to grammaticality preference between the two cycles identified.

While aspects of general cognitive development may contribute to the complex pattern of results uncovered here, the existence of these two cycles suggests a change in infants' knowledge of the dependency itself. As we have discussed above, such a change is indeed expected if representations of subject-verb agreement at different ages encode distinct levels of the dependency. Based on the present experiment alone, the precise content of infants' representations during the two cycles cannot be determined. However, below we outline a hypothesis regarding such content on the basis of previous findings on the early acquisition of agreement in French.

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Infants in our first cycle are 14-18-month-olds, therefore they are at a similar level in development to those tested in Nazzi et al. (2011). That HPP study tested sensitivity to the stem-changed based verbal agreement system and revealed that 18-month-olds have a preference for grammatical dependencies across a range of verbs with phonologically distinct stem changes. The authors interpreted their results as evidence that 18-month-olds have created form-based categories of determiners and verbs from distributional cues. While they are sensitive to the dependencies between these categories and show an early ability to generalize across form-based categories, they are not yet associated with morphological features like singular and plural. If infants in the present study are at roughly this same level of development, then their representations of the agreement subsystem tested here are likely also surface-based. There is only a single manifestation of the singular-plural distinction in the verbs, so these representations might encode a dependency between the phonological form of the determiner ([lə] or [le]) and the initial consonant of the agreement prefix ([l] or [z]).

The conclusion that French-learning 18-month-olds do not yet represent subject-verb agreement in a way that encodes the morphological features needed for comprehension accords with work on older infants using IPLP. Legendre et al. (2010) showed that by 30, but not 24 months, French-learning children can associate singular and plural prefixal agreement (i.e., *il-attrape le voub* 'he catches the voub' vs. *ils-attrapent le mique* 'they catch the mique') with videos depicting singular and plural actors respectively. Barrière et al. (2016) extended this finding to vowel-initial pseudoverbs, suggesting that comprehension is sufficiently abstract by 30 months to allow generalization. Infants in the second cycle (21 to 24 months) are approaching

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this age. To set the stage for comprehension by 30 months, they should therefore be developing

representations of the subject-verb agreement dependency that encode not just surface statistics

but morphological features (here singular versus plural). Further support comes from results

suggesting that, across languages, conceptual knowledge of number emerges at around 22

months (Kouider et al., 2006; Barner et al., 2007; Li et al., 2009; Wood et al., 2009). Barner et al.

(2007) found a shift in performance on manual search tasks between 20 and 22 months,

suggesting the emergence and strengthening of abstract number representations during this

developmental period. Whether infants' representations of agreement are *sufficiently robust* at 24

months to reveal successful comprehension of this dependency using IPLP will require further

work; recall that only an agreement prefix was used in Legendre et al. (2010), while our stimuli

included both an agreement prefix *and* a determiner, providing a redundant cue to number. Since

redundancy has been found to facilitate number processing (Kouider et al., 2006), it is possible

that evidence of comprehension could be found for these stimuli at 24 months. However, in

addition to robust representations of feature-based agreement, success in comprehension studies

requires children to match speech stimuli to (dynamic) visual stimuli. This is inherently more

challenging than simply processing grammatical and ungrammatical sentences as in our HPP
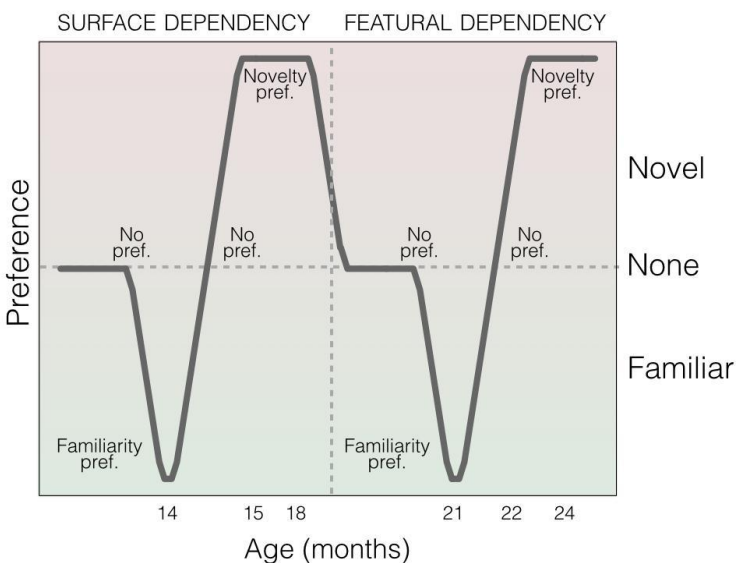
study.

Fig. 4. Two distinct cycles of changing preference directions in French-learning children. First cycle during learning of surface-based representations of the dependency. Second cycle during learning of featural (morphological) representations.

The hypothesis we have explored to explain the complex pattern of behavior revealed by our study starts from the idea that switches in preference direction from grammaticality to ungrammaticality indicate increasing robustness of representations. From 14 to 24 months, the infants in our study were found to go through such a progression *twice*, with a transition period in which they reverse from an early ungrammaticality preference to a later grammaticality preference. Above we have suggested that this change may correspond to the evolution of French-learning children's representations of subject-verb agreement dependencies from surface-based to morphological feature-based. This change in the nature of the representations is in line with previous work on the acquisition of agreement in French and on the conceptual

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development of number more generally. The proposed developmental cycles are graphically

illustrated in Fig. 4, and are strikingly similar to the results shown in Fig. 3. Nevertheless,

additional converging evidence is needed to fully explore the relative contributions of

representational and general cognitive changes occuring during the age range investigated here.

Even if developing representations are, as we have argued, the major underlying cause of infants'

behavior in our study, and more targeted work following up on our suggestions above is needed

to further specify the precise content of infants' representations at each stage. Moreover, the shift

from grammaticality to ungrammaticality appears to happen faster in the first cycle compared to

the second. We do not yet know how this might be tied to the nature of infants' representations,

if at all.

These further questions aside, the complex developmental trajectory revealed by our

study provides the clearest evidence yet documented for distinct stages of knowledge in the

acquisition of a non-adjacent morphosyntactic dependency. Our results further support the idea

that infants' evolving knowledge can be traced over development through shifts in preference

between familiar and novel stimuli. As originally suggested by Houston-Price & Nakai (2004) in

their explanation of novelty and familiarity effects in infant habituation paradigms, these shifts

(here for preferences resulting from acquisition outside the laboratory) can only be meaningfully

interpreted by testing infants across a range of ages, using the same stimuli and procedure (see

also Liu & Kager, 2014). Importantly, this involves going beyond just the first evidence of

sensitivity. Here this approach has allowed us to begin to address when early knowledge of

morphosyntactic dependencies emerges in French-learning children *and* when this knowledge

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changes, identifying critical ages to investigate further. Such changes during the acquisition of complex dependencies can inform theories of the trajectory and time-course of the development of linguistic representations, and shed light on the cognitive mechanisms underlying language.

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