A perceptual equivalent of the labial-coronal effect in the first year of life

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(Received 11 March 2009; revised 13 May 2009; accepted 30 May 2009)

Several studies have investigated infants' acquisition of the phonological (prosodic or phonotactic) regularities of their native language at the lexical level, by showing that infants around 9/10 months of age start preferring lists of words that have a more versus less frequent phonological structure. The present study investigates whether a similar acquisition pattern of preferences can be found for labial-coronal (LC) words over coronal-labial (CL) words, a bias classically interpreted in terms of production constraints but that could also be explained in terms of relative frequency of frequent LC and less frequent CL words in many languages including French, the language used here. Results show that a preference for bisyllabic LC words emerges between 6 and 10 months of age in French-learning infants (Experiment 1), and that the non-preference at 6 months is not due to the infants' inability to discriminate the two lists of words (Experiment 2). The present study thus establishes an early perceptual equivalent of the LC bias initially found at the onset of word production. Implications of this finding for an understanding of the perception-production relationship are discussed. © *2009 Acoustical Society of America.* [DOI: 10.1121/1.3158931]

PACS number(s): 43.71.Ft [RSN] Pages: 1440–1446

I. INTRODUCTION

A great deal of attention has been devoted in the past decades to specify how infants' initial language-general abilities change into abilities that are attuned to the language they are acquiring. These studies have given a better picture of the main steps in phonological acquisition (for a review see Jusczyk, 1997). The present study was conducted in this perspective, and aimed at establishing whether, early in life, infants have a perceptual equivalent of the labial-coronal (LC) bias. This LC bias was first found in early word production studies, infants initially producing more LC than coronal-labial (CL) words. While initially interpreted in terms of phonological constraints of markedness (Ingram, 1974), this bias is now usually interpreted in terms of production constraints (MacNeilage and Davis, 2000). The present study will evaluate the possibility that perceptual learning might contribute to the explanation of this bias. Before presenting data on the LC bias and the rationale of the present study in more detail, they first review the literature on early phonological acquisition.

Numerous studies attest the acquisition of native language properties during the first year of life. Prosodic acquisition is suggested by the fact that language discrimination for languages of the same rhythmic class is limited to pairs including the native language around 4/5 months of age (Bosch and Sebastian-Galles, 1997; Nazzi *et al.*, 2000). It is also reflected in the emergence of various preference biases around the same age: for words in the native language over foreign words when the words have different prosodic properties (by 6 months, Jusczyk *et al.*, 1993b), and for words with the predominant trochaic stress pattern of their native language (between 6 and 9 months for English, Jusczyk *et al.*, 1993a; between 4 and 6 months for German, Höhle *et al.*, 2009). Finally, it is also attested by a decline in sensitivity to tone contrasts between 6 and 9 months of age in infants learning a non-tonal language, English, but not in infants learning tonal (Mandarin or Cantonese) Chinese (Mattock and Burnham, 2006).

At the segmental level, a similar acquisition pattern has been observed. Effects of the native language appear around 6 months of age for vowel perception (Kuhl *et al.*, 1992; Polka and Bohn, 1996; Polka and Werker, 1994) and around 10 months of age for consonant perception (Rivera-Gaxiola *et al.* 2005; Werker and Tees, 1984).

Lastly, a few studies have shown that between 6 and 9 months of age, infants become sensitive to the phonotactic properties of their native language, that is, to the constraints on the possible order of consecutive phonemes within words. Dutch- and English-learning infants have been shown to start preferring words in their native language (English or Dutch) than in the other language when the words presented differed only by their phonotactic properties between those two ages (Jusczyk *et al.*, 1993b). Dutch 9-month-olds have also been found to listen longer to words containing phonotactically legal clusters than illegal ones (Friederici and Wessels, 1993). A similar result was found at 10 months with Catalan-dominant Catalan-Spanish bilingual infants (Sebastián-Gallés and Bosch, 2002). Moreover, English 9- but not 6-month-olds have been found to prefer to listen to words containing frequently-occurring rather than infrequent sequences of phonemes (Jusczyk *et al.*, 1994). Phonotactic knowledge also appears to impact on the ability to discriminate word forms, as shown by crosslinguistic data on Japanese- and English-learning 6-, 12-, and 18-month-olds (Kajikawa *et al.* 2006; Mugitani *et al.*, 2007).

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The present study is based on the above perceptual findings. The authors' goal was to re-explore the phenomenon of the LC bias by taking this perceptual perspective. The LC bias was first pointed out in a production study on two infants, one learning English and one learning French (Ingram, 1974). It was later confirmed in a study of a group of English-learning infants showing that they tend to produce 2.55 times more LC words than CL words, this pattern being present in nine out of the ten 12-to18-month-old infants tested, the remaining infant presenting no bias (MacNeilage *et al.*, 1999). This bias, which is not present in babbling, was interpreted in the context of the frame/content theory as evidence of biomechanical constraints on early production that would make LC words easier to produce than CL words, because LC words require minimal articulatory movements: a simple mandibular oscillation to produce the labial and then a tongue movement to produce the coronal (MacNeilage and Davis, 2000). However, more recent results suggest that this bias may not be limited to production, and raise the issue of the involvement of perception in determining this bias.

First, two studies have explored the typology of languages in order to determine whether there is an asymmetry in the number of LC and CL structures present in the lexicon of these languages. In both studies, a wide range of languages from different linguistic families were investigated: English, Estonian, French, German, Hebrew, Japanese, Maon, Quichua, Spanish, and Swahili (MacNeilage *et al.*, 1999), and Afar, Finnish, French, Kannada, Kwakw'ala, Navaho, Ngizim, Quichua, Sora, and Yup'ik (Vallée *et al.*, 2001). The results of both studies converge in showing that LC structures are more frequent than CL structures in most of these languages.

In particular, the analyses of Vallée *et al.* (2001) for French (based on the BDLex corpus, Pérennou and de Calmès, 2002), the language of the infants tested in this study, show that the LC/CL asymmetry is pervasive. It appears to be present both across onsets of consecutive syllables (ratio of 1.69 at word onset; ratio of 1.56 in all lexical positions) and between the onset and the coda of the same syllable (ratio of 2.9 for word-initial syllables; ratio of 2.29 for all syllables). Given the studies on early phonological acquisition findings reported above, that have shown that infants start preferring to listen to the phonological structures which are more frequent in their native language, it appears possible that the LC asymmetry in the French language could give rise to the emergence of a preference for LC structures in young French-learning infants.

Second, a recent perception study found that French adults hearing the continuous alternation of a labial-initial syllable and a coronal-initial syllable tend to perceive them as LC rather than CL bisyllabic sequences (Sato *et al.*, 2007). These phenomena in adult perception further raise the possibility of the existence of an equivalent of the LC bias in early perception. Finding such an early perceptual LC bias would have implications regarding the determinants of the LC bias, challenging its classic interpretation in terms of motor constraints and raising the possibility that it (partly) arises from perceptual learning (that is, the acquisition of the predominant sound patterns present in the linguistic input).

Given the data on the acquisition of the phonological properties of the native language reviewed above showing the emergence of preferences for more typical, more frequent structures in the second half of the first year of life (for the most part, between 6 and 9/10 months of age), a perceptual equivalent of the LC bias might translate into a preference for LC words over CL words in infancy. Accordingly, the goals of Experiment 1 were to determine (a) whether a perceptual LC bias can be found in early infancy and (b) whether this bias is present early in life or whether it emerges during development as a reflection of the acquisition of native language properties. In order to do so, Experiment 1 explored whether French-learning infants prefer to listen to more frequent LC sequences over less frequent CL sequences at two different ages: 6 and 10 months. The stimuli used were CVCV bisyllabic words.

II. EXPERIMENT 1

A. Method

1. Participants

Thirty-two infants from French-speaking families were tested and their data included in the analyses: 16 6-month-olds (mean age=6.18 months; range: 6.01–7.09; 10 girls, 6 boys) and 16 10-month-olds (mean age =10.16 months; range: 10.05–11.05; 10 girls, 6 boys). The data of 2 additional 6-month-olds were not included in the analyses, due to fussiness or crying. The data of 5 additional 10-month-olds were not included in the analyses: 3 infants for fussiness or crying, and 2 infants for having at least 3 orientation times in the test phase shorter than 1.5 s (this criterion was used to ensure that infants heard at least one or two words of the list).

2. Stimuli

Recordings were made in a sound-attenuated booth. A female native speaker of French recorded several tokens of 24 French bisyllabic words. Twelve words had a LC structure: 3 bVdV words (/bödo/, /bode/, /bude/), 3 pVtV words (/pote/, /patĩ/, /pitö/), 3 bVtV words (/bato/, /byte/, /butõ/), and 3 pVdV words (/padi/, /pedã/, /pãda/); and 12 words had a CL structure: 3 dVbV words (/deby/, /döbu/, /dobe/), 3 tVpV words (/tapi/, /tupe/, /topĩ/), 3 tVbV words (/tõbe/, /tabu/, /tyba/), and 3 dVpV words (/depi/, /depo/, /dopã/). Words in both lists were made up of exactly the same consonants, and vowels were almost completely balanced across lists. Two tokens of each word were selected. Overall, the duration of the LC and CL tokens was similar [541 versus 537 ms, $t(46)<1$, n.s.].

Four lists were made up: two lists with the 12 LC words (different tokens, the order of the words in the two lists being reversed) and two lists with the 12 CL words (different tokens, the order of the words in the two lists being reversed). The duration of all the lists was 18.00 s.

3. Procedure and apparatus

The experiment was conducted in a three-sided test booth made of pegboard panels. Except for a small section of

pre-existing holes in the front panel used for monitoring the infant's headturns, the panels were backed with white cardboard to prevent the infant from seeing behind the panels. The test booth had a red light and a loudspeaker (SONY xs-F1722) mounted at eye level on each of the side panels and a green light mounted on the center panel. Directly below the center light a 5 cm hole accommodated the lens of a video camera used to record each test session. A white curtain suspended around the top of the booth shielded the infant's view of the rest of the room. A PC computer terminal (COD) and response box were located behind the center panel, out of view of the infant. The response box, which was connected to the computer, was equipped with a series of buttons. The box was controlled by an observer hidden behind the center panel, who looked through a peephole and pressed the buttons of the response box according to the direction of the infant's headturns, thus starting and stopping the flashing of the lights and the presentation of the sounds. The observer, and also the infant's caregiver, wore earplugs and listened to masking music over tight-fitting closed headphones, which prevented them from hearing the stimuli presented. Information about the direction and duration of the headturns and the total trial duration were stored in a data file on the computer.

The classic version of the headturn preference procedure (HPP) was used in the present study (c.f. Jusczyk *et al.*, 1993a). Each infant was held on a caregiver's lap. The caregiver was seated in a chair in the center of the test booth. Each trial began with the green light on the center panel blinking until the infant had oriented in that direction. Then, the center light was extinguished and the red light above the loudspeaker on one of the side panels began to flash. When the infant made a turn of at least 30° in the direction of the loudspeaker, the stimulus for that trial began to play. Each stimulus was played to completion (i.e., when the 12 words had been presented) or stopped immediately after the infant failed to maintain the 30° headturn for 2 consecutive seconds (200 ms fade-out). The stimuli were stored in digitized form on the computer, and were delivered by the loudspeakers via an audio amplifier (Marantz PM4000). If the infant turned away from the target by 30° in any direction for less than 2 s 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. 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 headturn to each side before the test session itself. The test phase consisted of three test blocks (in each of which the two LC and the two CL lists were presented). The order of the different lists within each block was randomized.

B. Results and discussion

Mean orientation times to the LC and the CL lists were calculated for each infant. The data for the two age groups are presented in Fig. 1. A two-way analysis of variance with

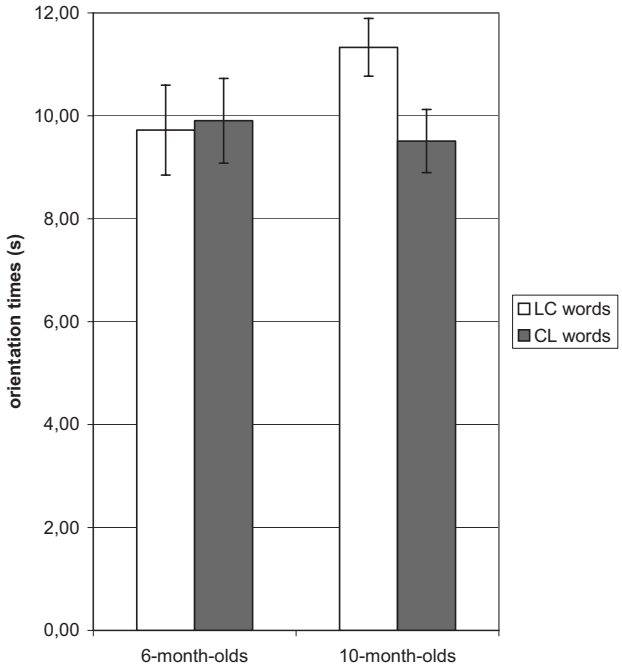

FIG. 1. Mean orientation times (s) to the bisyllabic LC words versus the bisyllabic CL words in Experiment 1. The error bars indicate the standard error of the mean. Left panel: 6-month-old infants; Right panel: 10-month-old infants.

the main between-subject factor of age (6 and 10 months) and the main within-subject factor of lexical structure (LC versus CL words) was conducted. The effect of lexical structure approached significance, $F(1,30)=4.05$, $p=.053$, indicating that the infants tended to have longer orientation times to the LC words than to the CL words. However, there was a significant age × lexical structure interaction, $F(1,30)=6.05$, $p=.020$, indicating that the effect of lexical structure changed with age. The effect of age was not significant, $F(1,30)<1$.

In order to specify the age × lexical structure interaction, planned comparisons were conducted. The effect of lexical structure failed to reach significance at 6 months $F(1,30)<1$, indicating that these infants had similar orientation times to the LC words ($M=9.72$ s, SD=3.50) and the CL words ($M=9.90$ s, SD=3.29). Only half of the 16 6-month-olds oriented longer to the LC words. However, the effect of familiarity was significant at 10 months, $F(1,30)=9.99$, $p=.004$, indicating that 10-month-old infants had longer orientation times to the LC words ($M=11.33$ s, SD=2.24) than to the CL words ($M=9.51$ s, SD=2.46). This pattern of LC preference was found for 13 of the 16 infants ($p=.01$, binomial test).

The first goal of the present experiment was to determine whether a perceptual equivalent to the LC bias is present in infancy. Accordingly, infants heard two lists of CVCV bisyllabic words, a list of varied LC words and a list of varied CL words. The present results show that 10-month-old infants prefer to listen to the LC words. Since LC words are predominant in French, this pattern is similar to that found in previous studies showing that infants around 9–10 months of age prefer to listen to types of words that are more frequent in their native language (Friederici and

Wessels, 1993; Höhle *et al.*, 2009; Jusczyk *et al.*, 1993a, 1993b, 1994; Sebastián-Gallés and Bosch, 2002). Given that these effects are found before the onset of word production, and given that the LC bias in production is found in early word production but not in babbling, this result suggests that the LC bias in production might not necessarily or at least not solely arise from production constraints, an issue further discussed later.

The second goal of the present experiment was to determine whether, if present, such a LC bias is present early in life, or whether it emerges during development. The present data support the latter possibility given the lack of a preference in 6-month-olds, and the significant difference in behavior between the two age groups. However, the significance of this developmental pattern of change would be stronger if it were possible to specify that the failure at 6 months is really due to a lack of preference between the two structures, rather than difficulties with the HPP task or the discrimination between two phonotactic patterns each exemplified by 12 phonetically-varied words.

In order to better understand the lack of a LC preference in 6-month-olds, Experiment 2 was conducted to evaluate whether they are nevertheless able to discriminate between the lists of LC and CL words used in the present experiment. This was done by familiarizing infants with one type of structure (counterbalanced across infants) for 1 min, before presenting them with trials of LC versus CL stimuli (see Höhle *et al.*, 2009, for a similar use of HPP). Note that if infants succeed in this discrimination paradigm, this will unambiguously show that the lack of a bias in the present experiment was not due to methodological or perceptual issues; however, if they fail, the interpretation of the lack of a bias will remain ambiguous.

III. EXPERIMENT 2

A. Method

1. Participants

Sixteen 6-month-old infants (mean age=6.18 months; range: 6.01–7.09; 10 girls, 6 boys) from French-speaking families were tested and their data included in the analyses. The data of one additional infant were not included in the analyses, due to fussiness.

2. Stimuli

The stimuli were the same as those used in Experiment 1 (2 files made up of different tokens of 12 LC words, and 2 files made up of different tokens of 12 CL words).

3. Procedure and apparatus

The apparatus was the same as in Experiment 1. The procedure was the same as in Experiment 1, with one crucial modification that changed the experiment from a preference to a discrimination experiment. Infants were familiarized with either a LC or a CL file until they reached a familiarization criterion of 60 s of orientation times. Half of the infants were familiarized with the LC words, the other half being familiarized with the CL words. Once the familiarization criterion was reached, infants were tested with the other file of the same structure (same words repeated in a different order), and one of the other two files of the opposite structure. These two files were repeated four times in randomized order, leading to the presentation of eight test trials, half of the same and half of the opposite structure.

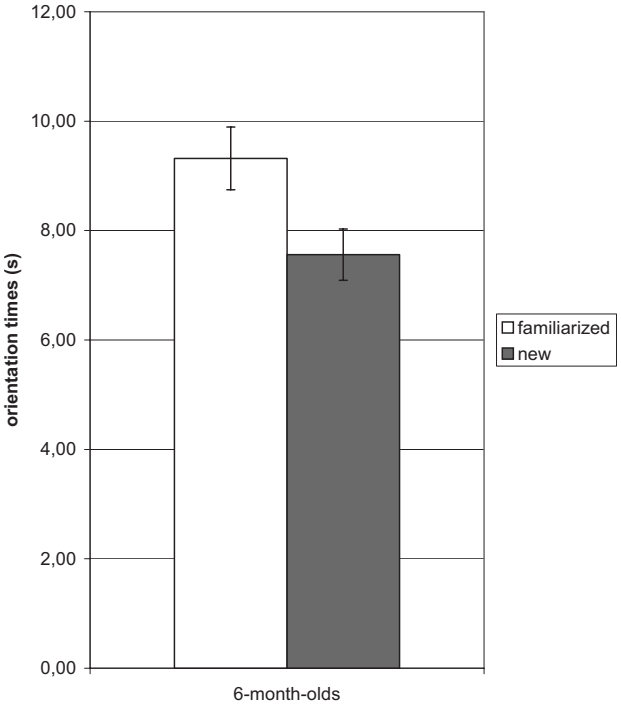

FIG. 2. Mean orientation times (s) at 6 months to the familiarized versus non-familiarized words in Experiment 2.

B. Results and discussion

Mean orientation times to the files with the familiarized and new structures were calculated for each infant. The data are presented in Fig. 2. On average, infants oriented to the sequences with the familiarized structure for 9.32 s (SD =2.30) while they oriented to the sequences with the new structure for 7.56 s (SD=1.89). This difference was significant, $t(15)=3.12$; $p=0.007$, two-tailed. 12 of the 16 infants had longer orientation times to the sequences with the familiarized structure ($p=0.038$, binomial test).

The present experiment shows that 6-month-old infants presented with a list of 12 words later prefer to listen to a different list of the same words (different tokens, different order of presentation) than to a list of 12 different words. This familiarity effect (similar to that found by Höhle *et al.*, 2009, using the exact same procedure) suggests that 6-month-old infants discriminate between LC and CL words in spite of all the phonetic variability present. Although it remains unclear whether the present effect would emerge if a different list of words with the structure used during familiarization had been presented, the present results nevertheless rule out the possibility that the lack of a preference for LC words found at 6 months in Experiment 1 was due to methodological or perceptual issues. More likely, 6-month-old infants do not have a preference for LC over CL words at that age (although preferences can be found at that age, if they

are based on prosody, Jusczyk *et al.*, 1993b, Höhle *et al.*, 2009), and the preference emerges between 6 and 10 months due to exposure to the native language.

IV. GENERAL DISCUSSION

The present results first establish that infants' preferences for some kinds of word patterns over others emerge between the ages of 6 and 10 months. Indeed, a preference for LC words over CL ones is found at 10 months of age, but not at 6 months (Exp. 1). Moreover, the fact that 6-month-olds were able to discriminate the two lists of words (Exp. 2) suggests that their lack of a preference (Exp. 1) is not due to methodological or perceptual issues. Given that LC words are more frequent than CL words in French, this pattern of results is in line with previous results showing that during the second part of the first year of life, infants start preferring the structures that are more frequent in their native language. In those previous studies, infants around 6- to -10 months of age were found to start preferring words having the predominant stress pattern of their native language (for English, Jusczyk *et al.*, 1993a, 1993b; for German, Höhle *et al.*, 2009), or being made up of more frequent phonotactic sequences (for Dutch. Friederici and Wessels, 1993; for English. Jusczyk *et al.*, 1993b, 1994; for Catalan; Sebastián-Gallés and Bosch, 2002). The present study is the first to provide data establishing the emergence of a preference for words with a structure that is predominant in the native language for French-learning infants.

The timing of this emergence is in line with results showing that infants start learning the phonetic inventory of their native language during that time period. But, like the data contrasting words on their phonotactic properties, the present results go beyond these phonetic acquisition findings. The emergence of a preference for phonotactically legal over illegal, phonotactically frequent over infrequent, and, here, LC over CL words between 6 and 10 months of age is likely to reflect some phonological acquisition regarding the constraints on how phonemes are ordered within word-form units in the native language. Thus, taken together, these results suggest that infants start preferring structures that follow a predominant pattern in their native language once they have learned that this pattern is predominant. These acquisitions are probably made possible by the onset of word-form segmentation abilities between these two ages (Gout, 2001; Höhle and Weissenborn, 2003; Houston *et al.*, 2004; Jusczyk and Aslin, 1995; Nazzi *et al.*, 2005; Nazzi *et al.*, 2006; Nazzi *et al.*, 2008).[1]

The present results also raise the issue of how the present early perception bias impacts on the classical interpretation of the LC bias in terms of articulatory constraints. On a strong version of this proposal (denying any role of perceptual processes), one would have predicted that a perceptual preference would not have emerged before infants start producing LC (and CL) structures. In theory, it might not have emerged before the onset of word production, as the LC bias has been found in early word production but not in babbling. These predictions were not supported by the present results. Indeed, 10-month-olds preferred to listen to LC words over CL words. Yet, the infants in the present study did not produce words. Moreover, an ongoing follow-up of the present study established for another group of 10-month-old infants that infants at that age do not even produce babbling in which consonants vary, that is, they do not produce LC and CL sequences (Nazzi *et al.*, 2009).

Does this mean that the LC bias is actually the sole product of the perceptual properties of the auditory/speech perception system? This position (denying any role of production processes) is also unlikely given evidence that producing LC words is easier than producing CL words. Rather, what seems to be at play here is the result of a production-perception loop in which types of words that are easier to produce due to articulatory constraints end up being more frequent in (most) languages, and consequently, become preferred at the perceptual level due to their higher frequency (an idea to be related to the notion, put forward in the motor theory of speech perception, of a coevolution of perception and production skills, c.f. Galantucci *et al.*, 2006, for a recent review).

Accordingly, the LC bias found at 10 months in the present study could be due to perceptual acquisition of input regularities reflecting articulatory constraints. Thus, the LC bias found here would be a direct perceptual effect, reflecting an indirect production effect. In the future, it would be interesting to explore this early perceptual LC bias in languages such as Japanese that, contrary to most languages, has been reported to have a small, but significant, input bias in the opposite CL direction (0.84, c.f. MacNeilage *et al.*, 1999). If this bias were to be confirmed in the input (MacNeilage *et al.*, 1999, only looked at a subset of the Japanese lexicon), then exploring the existence of a perceptual LC bias in Japanese 10-month-olds would provide a means to evaluate the respective contribution of production constraints and perceptual learning. Indeed, if production constraints predominate, then a LC bias should also be found in Japanese infants. But if the properties of the input (and the perceptual learning that follows) are the main drivers of the bias, then one predicts either no bias (due to the small size of the bias) or a coronal-labial perceptual bias in Japanese infants.

To finish, note that although the present study reveals a perceptual equivalent of the LC bias previously described in early production, the perceptual factors that give raise to the observed bias remain unspecified at this point. First, although vowels were matched as much as possible across the two lists of phonotactic patterns, perfect match was not possible due to the use of real bisyllabic words, so that the possibility that these subtle differences might have contributed to the effect observed cannot be entirely ruled out. Syllables were also different in the two lists of words, and frequency analyses later conducted on the Lexique 3 database (New *et al.*, 2004) revealed that the second syllables of the LC words were more frequent than those of the CL words, which again might have contributed to the bias observed. Note, however, that the rationale for using lists of phonetically-varied items is to elicit processing at levels beyond the acoustic/phonetic level (Bertoncini *et al.*, 1995; Bijeljac-Babic *et al.*, 1993; Jusczyk *et al.*, 1993a, 1993b). Second, although the effects observed have been discussed in

terms of the relative input frequency of the order of appearance of the labial and coronal consonants in the words presented, the present results on bisyllabic words leave open the question of whether the perceptual bias is best described in terms of the order of the consonants themselves, or the syllables they are embedded in. In the later case, the effect would be determined by the relative order of adjacent syllables, not by the relative order of non-adjacent consonants. Third, the present study does not rule out the possibility that the LC bias stems from a general preference for labial-initial words, even though labial-initial words are not more frequent than coronal-initial words in French (Lexique 3 database analyses, c.f. Nazzi *et al.*, 2009). All of these issues are currently being addressed in a parallel study exploring the emergence of a LC effect in French-learning infants using monosyllabic items, which allow for perfect vocalic match, frequency control, and can only be interpreted at the phonetic level (Nazzi *et al.*, 2009). The data show a bias for LC CVC words over CL CVC words at 10 months. Moreover, the results of a control condition in which infants were presented with recordings of the sole CV portion of the CVC items used in the main experiment failed to show any preference, reinforcing the present interpretation of the perceptual LC bias in terms of sensitivity to the relative frequency of the order of labial and coronal consonants within words.

V. CONCLUSIONS

In conclusion, the present study establishes the emergence between 6 and 10 months of age of a perceptual equivalent of the LC bias previously reported in production. This finding contributes to a growing literature showing infants' early acquisition of the phonological properties of their native language during the second half of the first year of life. The present findings thus show that the LC bias is unlikely to be the sole product of production constraints, but more likely to result from complex interactions between production constraints, the structure of the input, and early perceptual learning.

ACKNOWLEDGMENTS

This research was supported by an ACI grant "systèmes complexes" to T.N. and J.B. We would like to thank Jean-Luc Schwartz and Nathalie Vallée for fruitful discussions and help in selecting the stimuli, and the participants and their families for their time and cooperation.

[1]A similar claim has been made for the emergence of the trochaic bias (Jusczyk *et al.*, 1993a), although more recent data suggest that the trochaic bias might appear before the onset of word segmentation (Höhle *et al.*, 2009) and might therefore result from rhythmic acquisition at the sentence level rather than at the word level (Nazzi *et al.*, 2006).

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