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Language specific prosodic preferences during the first half year of life: Evidence from German and French infants

Barbara Höhle[a,*], Ranka Bijeljac-Babic[b,c], Birgit Herold[a], Jürgen Weissenborn[d], Thierry Nazzi[b]

[a] *Universität Potsdam, Department Linguistik, Germany*
[b] *Université Paris Descartes, CNRS, Laboratoire Psychologie de la Perception, France*
[c] *Université de Poitiers, Département de Psychologie, France*
[d] *Humboldt-Universität zu Berlin, Berlin, Germany*

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ABSTRACT

There is converging evidence that infants are sensitive to prosodic cues from birth onwards and use this kind of information in their earliest steps into the acquisition of words and syntactic regularities of their target language. Regarding word segmentation, it has been found that English-learning infants segment trochaic words by 7.5 months of age, and iambic words only by 10.5 months of age [Jusczyk, P. W., Houston, D. M., & Newsome, M. (1999). The beginnings of word segmentation in English-learning infants. *Cognitive Psychology, 39*, 159–207]. The question remains how to interpret this finding in relation to results showing that English-learning infants develop a preference for trochaic over iambic words between 6 and 9 months of age [Jusczyk, P. W., Cutler, A., & Redanz, N. (1993). Preference for the predominant stress patterns of English words. *Child Development, 64*, 675–687]. In the following, we report the results of four experiments using the headturn preference procedure (HPP) to explore the trochaic bias issue in German- and French-learning infants. For German, a trochaic preference was found at 6 but not at 4 months, suggesting an emergence of this preference between both ages (Experiments 1 and 2). For French, 6-month-old infants did not show a preference for either stress pattern (Experiment 3) while they were found to discriminate between the two stress patterns (Experiment 4). Our findings are the first to demonstrate that the trochaic bias is acquired by 6 months of age, is language specific and can be predicted by the rhythmic properties of the language in acquisition. We discuss the implications of this very early acquisition for our understanding of the emergence of segmentation abilities.

1. Introduction

It is a well established finding that from birth onwards, infants are equipped with a specific sensitivity to the prosodic information contained in the speech input. Indeed, it has been shown that newborns and a-few-month-old infants can discriminate different prosodic patterns at the phrase level (Christophe, Guasti, Nespor, Dupoux, & Van Ooyen, 1997; Christophe, Mehler, & Sebastián-Gallés; Guasti, Christophe, van Ooyen, & Nespor, 2001; Nazzi, Bertoncini, & Mehler, 1998) and at the word level (Bull, Eilers, & Oller, 1984, 1985; Eilers, Bull, Oller, & Lewis, 1984; Nazzi, Floccia, & Bertoncini, 1998; Sansavini,

* Corresponding author at: University of Potsdam, Linguistics Department, Karl-Liebknecht-Str. 24, P.O. Box 601553, 14476 Potsdam, Germany.
E-mail address: hoehle@rz.uni-potsdam.de (B. Höhle).

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Bertoncini, & Giovanelli, 1997; Spring & Dale, 1977). Soon after, they show better processing of the global prosodic features of their target language indicating that they must already have learned something about its prosodic characteristics (Bosch & Sebastián-Gallés, 1997; Moon, Panneton-Cooper, & Fifer, 1993; Nazzi, Jusczyk, & Johnson, 2000). It has also been shown that this knowledge, given the overlap between prosodic and syntactic units such as clauses and phrases, helps the infant to segment the speech input into linguistically meaningful elements of the corresponding type (e.g., Hirsh-Pasek et al., 1987; Jusczyk et al., 1992; Nazzi, Kemler Nelson, Jusczyk, & Jusczyk, 2000; Seidl, 2007; Soderstrom, Seidl, Kemler Nelson, & Jusczyk, 2003). On the basis of the systematic relationship between the internal structure of prosodic and syntactic units, prosody may even contribute to the infant's determination of major syntactic properties of the adult language like the position of the head of syntactic phrases (e.g., Guasti et al., 2001; Nespor, Guasti, & Christophe, 1996), or the distinction between complements of the verb and adverbs (Höhle, Weissenborn, Schmitz, & Ischebeck, 2001).

Furthermore, recent research has provided evidence – at least for some languages – that prosodic information is also crucial for infants' ability to segment fluent speech into words. Word segmentation is far from being trivial for adults, since there are no clear acoustic markers of word boundaries at the sentence level in adult-directed speech (Cole & Jakimik, 1978, 1980). But infants are also confronted with the problem of segmenting utterances directed to them as again word boundaries are not clearly marked, and there are only very few utterances that consist of isolated words even in infant-directed speech (Brent & Siskind, 2001; Van de Weijer, 2001). It has however been shown that infants are able to segment words from about 7–8 months of age (Gout, 2001; Höhle & Weissenborn, 2003; Jusczyk & Aslin, 1995), and that they are doing so by relying on the processing of various linguistic cues that partly mark lexical boundaries. Prosody seems to provide such a cue, as attested by the fact that infants learning a stress-timed language like English, Dutch or German, are better at segmenting from fluent speech some types of stress patterns than others. Indeed, in their seminal paper, Jusczyk, Houston, and Newsome (1999) have shown that American 7.5-month-olds are able to segment trochaic bisyllables (e.g., *kingdom*), while they fail with iambic bisyllables (e.g., *guitar*).

These results support the assumption that 7.5-month-old English-learning infants already rely on a metrical segmentation procedure (Cutler, Mehler, Norris, & Segui, 1986; Cutler & Norris, 1988) by placing a word initial boundary before a metrical strong syllable and attaching a following weak syllable to form a trochaic foot. Given that about 90% of the content words are stressed on the first syllable in English (Cutler & Carter, 1987), extracting trochaic units makes for a very efficient prosodic segmentation procedure for this language. Results from German and Dutch suggest that not only English-learning infants, but also infants learning other stress-timed languages with a comparable trochaic structure of the lexicon use this procedure for early word segmentation (Höhle, 2002; Houston, Jusczyk, Kuijpers, Coolen, & Cutler, 2000).

The relevance of prosody for early language processing is further supported by the finding that English-learning 9-month-olds prefer to listen to lists of varied trochaic English words rather than lists of varied iambic English words (Jusczyk, Cutler, & Redanz, 1993). In contrast, 6-month-olds did not show any preference for either stress pattern list. These results had been interpreted as evidence that between 6 and 9 months of age, English-learning infants find out that the predominant stress pattern of the words of their native language is the trochaic pattern. Thus, based on these anterior results, the trochaic advantage in early word segmentation found in English-learning 7.5-month-olds was viewed as (a) a consequence of these infants' acquisition of the fact that English words are predominantly trochaic, and as (b) a signal that English-learning infants acquire this knowledge prior to 7.5 months. Accordingly, lexical stress pattern was proposed as a possible candidate to bootstrap into segmentation abilities. However, this proposal presents a chicken-and-egg-problem, as one needs to account for how infants would specify the predominant stress pattern of words in their language before the emergence of abilities to segment words from fluent speech.

Given this apparent paradox, Thiessen and Saffran (2003) offered an alternative to the proposal that word stress is the initial cue for word segmentation, namely that infants' first attempts at word segmentation rely on distributional analyses of the order of syllables in the input. On the basis of these segmented word units, infants would find out about the typical stress pattern of their native language, and develop a trochaic preference if this pattern is predominant in their native language. Thiessen and Saffran (2003) provide experimental evidence for this alternative. They presented syllable strings in which the distributional information regarding syllable order and stress information (trochaic pattern) led to different segmentation solutions. Under these circumstances of conflicting cues, 9-month-olds relied on the stress cue rather than on distributional information (see also Johnson & Jusczyk, 2001) while 7-month-olds showed the reverse pattern (although with a change in direction of the effect observed) with a stronger reliance on distributional cues than stress pattern. These findings were used to question the leading role assigned to prosodic information at the onset of word segmentation.

However, the implications of the Thiessen and Saffran (2003) data have been contested. In particular, it has been pointed out that the early distributional effects observed in this study might be due to the extremely simplified learning situation which is presented to the infants, the languages they have to learn being made up of only four different words that are repeated up to 90 times within a 2 min familiarization phase thus strengthening the weight of transitional probabilities (Johnson & Seidl, 2009). When confronted with more complex languages and input situations, such learning might not be as quick. In a similar vein, while a recent finding establishes that in a very controlled situation 6–8-month-old infants can acquire a new phonetic contrast within 2.3 min of exposure (Maye, Werker, & Gerken, 2002), it has been known for many years that effects of the acquisition of the native consonantal categories start after about 10 months of exposure to the native language (Werker & Tees, 1984), and those for the vocalic categories at about 6 months of age (Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992).

Therefore, other solutions to the apparent paradox with the proposal of an anteriority of prosody as a segmentation cue need to be considered. First, the trochaic bias could be innate (c.f. Allen & Hawkins, 1978), and early segmentation abilities might rely on the extraction of trochaic units independently of the language to-be-acquired. This innate bias might manifest itself from birth, an unlikely possibility given the finding of an emergence of the trochaic bias between 6 and 9 months of age in English-learning infants (Jusczyk et al., 1993). Alternatively, it might emerge at a later age independently of the prosodic properties of the language to which the infant is exposed, and even for the numerous languages such as French and Turkish in which words do not conform to a trochaic pattern. Note that in order to account for the results found on early segmentation in English, it should emerge no later than 7.5 months of age crosslinguistically. Note also that if early segmentation abilities are based on an innate trochaic bias, infants learning non-trochaic languages would initially be misled and their lexical development would be hindered by missegmentations. However, in this perspective, the above mentioned paradox is solved in the sense that infants need not be familiar with any words of the target language to start using a trochaic metrical segmentation procedure as found for English.

Second, infants could learn about the predominant stress pattern of their native language by words often heard in isolation. The infant's own name could constitute such a trigger (Johnson & Jusczyk, 2001). Proper names typically obey the typical metrical pattern of the language and this holds even stronger for nicknames. Indeed, in English as well as in German, full proper names having an iambic pattern (mostly loans from romance languages) are changed to a trochaic form (e.g., NiCOLE ≫ NIki; MiCHELLE ≫ SHELley). Support for such a possibility comes from the fact that infants do attend to their own names from very early on. By 4.5 months of age, infants prefer to listen to their own names as compared to other names (Mandel, Jusczyk, & Pisoni, 1995); by 6 months of age, they appear to recognize their names within fluent speech and benefit from the occurrence of their name in fluent speech to detect the word following it (Bortfeld, Morgan, Golinkoff, & Rathbun, 2005).

Third, Nazzi, Iakimova, Bertoncini, Frédonie, and Alcantara (2006) have proposed that early prosodic segmentation might be based on the rhythmic unit of their native language, and that such acquisition might proceed from infants' early sensitivity to linguistic rhythm (Nazzi, Bertoncini, et al., 1998; Nazzi & Ramus, 2003; Ramus, Hauser, Miller, Morris, & Mehler, 2000). According to this proposal, infants acquiring English, Dutch and German, which are all stress-based languages, would start segmenting on the basis of the trochaic unit (which is consistent with the data collected in those languages), while infants acquiring a syllable-based language such as French would segment on the basis of the syllable. This latter prediction was confirmed by the finding that French-learning infants segment both final and initial syllables of bisyllabic words before being able to segment the bisyllables as whole, coherent units (Nazzi et al., 2006). Note that although a direct link between newborns' sensitivity to linguistic rhythm and the acquisition of the appropriate prosodic segmentation procedure has not been demonstrated, current research based on an adaptive dynamical model is suggesting that such an acquisition could be possible (McLennan, 2005). According to this prosodic bootstrapping view, the emergence of the trochaic bias in stress-based languages is not a chicken-and-egg problem, given that language-general rhythmic sensitivity at the sentence level would allow the emergence of segmentation procedures appropriate to language specific word segmentation. Therefore, the trochaic bias observed in English, Dutch and German would not correspond to the acquisition of the predominant lexical stress pattern of these languages, but to the acquisition of the rhythmic unit of these languages.

This rhythmic-acquisition proposal is partly supported by recent neurophysiological data from German- and French-learning infants that point to very early differences in processing trochaic and iambic bisyllables, raising the possibility of an even earlier acquisition of the trochaic bias than suggested by the Jusczyk et al. (1993) study (Friederici, Friedrich, & Christophe, 2007). In this ERP study, an oddball paradigm was used to present 4-month-olds with syllable strings in which either single trochaic bisyllables (deviant) appeared within a string of iambic bisyllables (standard) or in which single iambic bisyllables appeared within a string of trochaic bisyllables.

For German infants, the ERP pattern revealed a mismatch response when the deviant stimulus was an iambic bisyllable, but not when it was a trochaic one. These data first show that 4-month-olds process trochaic and iambic stimuli differently, which might translate to discrimination effects at the behavioral level. More importantly, the asymmetry of the trochaic/iambic discrimination might be taken as neurophysiological indication of a behavioral trochaic bias in German-learning infants. However, because we still do not fully understand the relationship between effects found at the electrophysiological level and effects found at the behavioral level, and given the potential theoretical implications of such an early trochaic bias, further behavioral research is clearly needed. Our study thus reassesses this issue in German-learning infants using the headturn preference procedure (HPP) commonly used in early language acquisition research.

The Friederici et al. (2007) study also brings data on French that bears on our stress pattern acquisition discussion. Indeed, an asymmetry in discrimination was also found for this population, but it was the opposite of the one found for German: the mismatch response was observed when the deviant stimulus was a trochaic bisyllable, but not when it was an iambic one. These data first suggest that French-learning 4-month-olds also process trochaic and iambic stimuli differently, which might again translate by discrimination effects at the behavioral level. Moreover, sensitivity to stress patterns appears to already differ crosslinguistically by 4 months of age, which would be more compatible with our rhythmic-acquisition hypothesis than with the hypothesis of an innate trochaic bias. Lastly, if the asymmetry in trochaic/iambic discrimination really is a neurophysiological indication of a behavioral bias, then French-learning infants would have an iambic bias. This is not predicted by our rhythmic-acquisition account, French being a syllable-based language. Our study will thus also use HPP to assess this issue in French-learning infants.

Our experiments, using a behavioral method (HPP), will thus focus on determining whether a trochaic bias effect can be observed early in development in two infant populations learning two different languages: German and French. Our first aim is to establish the presence of a trochaic bias in German-learning infants by 6 months of age, that is before the onset of segmentation abilities found to emerge between 6 and 8 months in various languages including English (Jusczyk & Aslin, 1995; Jusczyk et al., 1999), German (Höhle & Weissenborn, 2003) and French (Gout, 2001). Evidence of a trochaic bias at or before 6 months would bring important support in favor of our rhythmic-acquisition segmentation hypothesis of an anteriority of the use of prosodic information for segmentation, as opposed to the proposal made by Thiessen and Saffran (2003) that initial word segmentation relies on distributional analyses of the order of syllables.

Our second aim is to evaluate the impact of the phonological/rhythmic properties of the ambient language on the development of the trochaic bias, by comparing infants from different linguistic backgrounds, and more specifically learning two languages with different rhythmic properties and different rhythmic units: German, whose rhythmic unit is the trochaic unit, and French, whose rhythmic unit is the syllable. Based on the Nazzi et al. (2006) proposal according to which the trochaic bias is taken as reflecting the acquisition of the rhythmic unit of the native language (used to segment fluent speech), we predict that a trochaic bias should be found in German-learning infants, while French-learning infants from the same age would not show any bias. On the contrary, the hypothesis of an innate trochaic bias that would lead to language-independent initial trochaic segmentation predicts that a trochaic bias should be observed in both populations around the age of emergence of segmentation abilities. Note that the choice of these two languages will also allow comparisons of our behavioral data with the recent electrophysiological data presented above (Friederici et al., 2007).

Experiment 1 was designed to start addressing our first aim of finding behavioral evidence for a trochaic bias by the age of 6 months. This is motivated by the fact that the only behavioral study on this issue so far suggests an emergence of the trochaic bias between 6 and 9 months of age in English, so around but not necessarily prior to the onset of segmentation abilities (Jusczyk et al., 1993). However, one potential reason for the lack of such an effect at 6 months might relate to the use of lists of phonetically varied trochaic and iambic words, as phonetic variability might have made it more difficult for infants to manifest a preference on the orthogonal prosodic dimension. This possibility is supported by evidence showing that newborns can discriminate stress patterns when consonants vary and vowels are kept constant (Sansavini et al., 1997), but not when both consonants and vowels vary (Van Ooijen, Bertoncini, Sansavini, & Mehler, 1997). Accordingly, we decided to use in the present study several repetitions of the same simple CVCV sequence (*gaba*) that were either pronounced with a trochaic or an iambic pattern. This change from the Jusczyk et al. (1993) study might focus infants' attention to prosodic information, thus enabling the finding of evidence for a trochaic bias in infants younger than 9 months even though it makes the material used in the experiments less comparable to natural language sequences that do present more segmental variation. However, according to our hypothesis that the trochaic bias is acquired during development, such a bias would be observed in these simplified conditions only if infants had been able to learn this regularity of their native language prior to the test session, hence from phonetically varied input. Experiment 1 investigated the possibility of finding a trochaic bias in these simplified testing conditions in German-learning 6-month-old infants.

2. Experiment 1

2.1. Method

2.1.1. Participants

Twenty-four 6-month-olds (12 girls and 12 boys) were tested in this experiment. Their mean age was 6 months and 12 days (range: 6 months 1 day to 6 months 28 days). All infants were born full-term and had parents who only talked to their infants in German. None of the infants was known to suffer from hearing impairment. To achieve this number four additional infants were tested but did not complete the experiment due to fussiness.

2.1.2. Stimuli

The CVCV sequence *gaba* either stressed on the first or on the second syllable served as stimulus for this experiment. Sixteen tokens of each stress pattern were recorded by a female German native speaker. The desired stress patterns were explained to her by examples of comparable existing trochaic and iambic German words. Since the speaker had a linguistic background and was experienced in recording experimental stimuli the conscious manipulation of the different stress pattern did not pose any specific problem to her.

After recording, the stimuli were digitized and saved as computer files. An acoustical analysis of durational and pitch features was conducted with the speech editing and analyzing software PRAAT. These features were selected since they are considered to be the most reliable acoustic correlates of stress in German (Jessen et al., 1995). The first syllable of the trochaic sequences had a mean duration of 283 ms (SD = 20.8), the second syllables of the trochaic sequences one of 308 ms (SD = 25.0). The analysis of pitch revealed an average of 195 Hz (SD = 3.9) on the first and 163 Hz (SD = 15.9) on the second syllable. The first syllables of the iambic sequences had an average duration of 173 ms (SD = 11.0) whereas the second syllables had a mean duration of 430 ms (SD = 21.2). The average pitch of the first syllable was 186 Hz (SD = 5.2), that of the second syllable 183 Hz (SD = 5.9).

An ANOVA on syllable duration with the main between-item factor of stress pattern (trochaic versus iambic) and the main within-item factor of syllable position (first versus second syllable) revealed no main effect for stress pattern ($F(1,30) = 2.40$;

$p = .13$), but a main effect for syllable position, $F(1,30) = 520.4$, $p < .001$, and a significant interaction, $F(1,30) = 354.4$, $p < .001$. Planned comparisons showed that the first syllable was significantly shorter than the second syllable for both the trochaic sequences, $t(30) = 2.38$, $p = .03$, and the iambic sequences, $t(30) = 8.06$, $p < .001$.

A similar ANOVA on pitch values revealed a significant main effect for stress pattern, $F(1,30) = 4.85$, $p = .03$, for syllable position, $F(1,30) = 62.73$, $p < .001$ and a significant interaction, $F(1,30) = 33.0$; $p < .001$. Planned comparisons showed that the first syllable had a significantly higher pitch than the second syllable for both the trochaic sequences, $t(30) = 7.63$, $p < .001$, and the iambic sequences, $t(30) = 2.44$, $p = .02$.

Even though the differences of the means point into the same direction for the two stress patterns, the significant interactions suggest that the longer duration of the second syllable compared to the first one is more pronounced in the iambic sequences than in the trochaic sequences. In contrast, the higher pitch of the first compared to the second syllable is much clearer for the trochaic than for the iambic sequences. This suggests that for the naturally recorded trochaic bisyllables, the strong–weak pattern is mainly characterized by the higher pitch of the first syllable as compared to the second syllable. The durational patterns seem to be massively influenced by final lengthening due to the isolated recordings of the bisyllables. In contrast, the durational structure of the iambic sequences is more consistent with what is expected for an iambic pattern. Here we find a clear difference in the duration between the first and the second syllable in favor of a much longer duration for the second syllable. But in this case, there is no such clear difference in pitch between the two syllables. This analysis is another demonstration that stress has no consistent physical correlate but that the acoustic features of stress interact with other characteristics of the speech signal, in this case for example the position of the crucial syllable within the utterance (cf. Hayes, 1995).

From these different tokens of each stress pattern, six files for each rhythmical pattern were created for presentation during the experiment. Each speech file contained the same set of tokens of the same rhythmic pattern with pauses of 600 ms between each token. They differed only in the order of concatenation of the tokens. The trochaic speech files contained 16 tokens and had an average duration of 18.39 s (range: 18.28–18.51 s). The iambic files contained 15 tokens and their average duration was 18.01 s (range: 18.00–18.07 s). The difference in number is due to the fact that the iambic bisyllables had a slightly longer average duration (603 ms) than the trochaic bisyllables (591 ms). Out of methodological reasons, given that the speech files for the different stress patterns have to be of the same length, it was decided to use different numbers of tokens in the speech files.

2.1.3. Procedure and apparatus

The procedure used is the headturn preference paradigm as introduced by Hirsh-Pasek et al. (1987). The experiment was run by an AST Bravo MS P/75 computer. During the experimental session, the infant is seated on the lap of a caregiver in the center of a test booth. The caregiver listens to music over headphones to prevent influences on the infant's behavior. Furthermore, he or she is instructed not to interfere with the infant's behavior during the experiment. Inside the booth, three lamps are fixed: a green one at the center wall, and red ones at each of the side walls. Directly above the green lamp on the center wall is a hole for the lens of a video-camera. On the outside of the test booth, two loudspeakers are mounted at the same height as the red lamps. Each experimental trial is started by the blinking of the green center lamp. When the infant orients to the green lamp, this lamp goes out and one of the red lamps on a side wall starts to blink. When the infant turns her head towards the red lamp, the speech stimulus is presented from the loudspeaker on the same side as the blinking red lamp. The stimuli, stored digitally, were delivered by JBL Contol 1 loudspeakers via a Sony TA-F261R audio amplifier. The trial ends when the infant turns her head away for more than 2 s, or when the end of the speech file is reached. If the infant turns away for less than 2 s, the presentation of the speech file is continued but the time spent looking away is not included in the total listening time.

The first two speech files – one of the trochaic and one of the iambic pattern – served as warming-up trials and were not included into the data analysis. The remaining 10 experimental speech files were presented in a random order. The exact duration of each experimental session depended on the infant's behavior and varied approximately between 3 and 5 min.

2.2. Results and discussion

To neutralize any potential effect of the slightly longer duration of the trochaic stimuli, all individual orientation times exceeding 18 s were reduced to 18 s. Two trials were cut off, accounting for .7% of all trials. We also excluded two trials that were shorter than 1.5 s, as this is done automatically by the software used with the French infants (Experiments 3 and 4). From these values, mean orientation times for each of the two rhythmical patterns were calculated for each infant. On average, infants oriented for 8.24 s (SD = 3.11) to the trochaic sequences and for 6.92 s (SD = 2.29) to the iambic sequences. This difference was significant, $t(23) = 2.30$, $p = .03$, two-tailed.[1] Nineteen of the infants had longer orientation times to the trochaic than to the iambic sequences ($p = .003$, binomial test).

Our results show that German-learning 6-month-olds prefer to listen to trochaic over iambic bisyllables. This early preference for trochaic units, prior to the onset of segmentation abilities in German (between 6 and 8 months of age), supports the

[1] A statistical analysis of the original orientation times without the cutting-off correction and the removal of the two short trials lead to very similar means and t-values. The same is true for all experiments reported in the present paper.

proposal that infants might use prosodic information to start segmenting words (Nazzi et al., 2006), rather than a property they learn following the segmentation of their first words (Thiessen & Saffran, 2003). Given that most German words are trochaic, this would allow the emergence of an efficient segmentation procedure for German.

Compared to previous results, we were able to find a trochaic bias in German-learning infants at 6 months of age, rather than an emergence between 6 and 9 months as found in infants learning American English (Jusczyk et al., 1993). Although this might reflect some phonological differences between German and English (see Section 6), this age difference might simply reflect differences in the stimuli used in both studies (the experiments being otherwise similar). Indeed, we underlined earlier the fact that Jusczyk et al. (1993) used many different English words in each stress pattern, and suggested that the phonetic variations might have made it more difficult for the English-learning infants to manifest a preference for the trochaic words (based on data on newborns, c.f. the comparison of Sansavini et al., 1997; Van Ooijen et al., 1997). We had therefore decided to neutralize phonetic variation by presenting several tokens of only one single phonotactically very simple CVCV sequence. A preference was found at 6 months. This is compatible with the idea that this manipulation indeed helped infants express a trochaic bias. More definitive evidence for this will nevertheless require evaluating the trochaic bias either in English-learning 6-month-olds in the absence of phonetic variation, or in German-learning 6-month-olds in the presence of phonetic variation.

Finally, given that German-learning 6-month-olds already have a preference for trochaic over iambic words, and given the asymmetrical discrimination found at 4 months by Friederici et al. (2007), we decided to replicate the present experiment with a group of German-learning 4-month-olds in order to determine if such a preference can be found at an earlier age. The procedure used was again HPP; however, the setup was slightly adapted to take into account the younger age of the infants (see below).

3. Experiment 2

3.1. Method

3.1.1. Participants

Twenty-four infants around 4 months of age (12 girls and 12 boys) participated in this experiment. The mean age of the infants was 3 months 26 days (range: 3 months 19 days to 4 months 16 days). The criteria for selecting the participants were the same as in Experiment 1. Twelve additional infants were tested but could not complete the experiment either due to not orienting to the stimuli either from the beginning or for more than one successive trial during the experiment (8) or due to fussiness (4).

3.1.2. Stimuli

The same stimuli as in Experiment 1 were used.

3.1.3. Procedure and apparatus

As in Experiment 1, the headturn preference paradigm was used. The apparatus was the same as in Experiment 1. However for this experiment with younger infants, the positions of the red lamps and the loudspeakers were changed. They were no longer fixed at the side walls of the testing booth but at the edges of the front wall. This meant that the younger infants only needed a minimal headturn or even an eye movement to fixate one of the red lamps. The distance between the red lamps and the green central lamp was 1 m; therefore, the distance between the two red lamps was 2 m. These distances were large enough for the experimenter to decide whether the infant looked at the central green lamp or at one of the red lamps. All other details of the procedure were identical to Experiment 1.

3.2. Results and discussion

As for Experiment 1, all individual orientation times exceeding 18 s were reduced to 18 s to neutralize any potential effect of the slightly longer duration of the trochaic stimuli. Thirty-five trials were cut off, accounting for 12.2% of all trials. As for Experiment 1, we also excluded two trials that had orientation times shorter than 1.5 s, accounting for .7% of all trials. On average, infants oriented for 12.42 s (SD = 3.29) to the trochaic sequences and for 12.52 s (SD = 3.14) to the iambic sequences. This difference was not significant, $t(23) = .20$, $p = .84$, two-tailed. Fourteen infants had longer orientation times to the trochaic sequences than to the iambic ones ($p = .15$, binomial test). Thus, the 4-month-olds tested in the present experiment do not show a significant preference for the trochaic words.

In order to compare the results from Experiments 1 and 2, an ANOVA with the within-subject factor of stress (trochaic versus iambic) and the between-subject factor of age (4 versus 6 months) was conducted. It revealed a significant effect of age, as the orientation times of the 4-month-olds (12.47 s) were much longer than those of the 6-month-olds (7.58 s), $F(1,46) = 40.28$, $p < .001$. There was no overall effect of stress, but a marginal interaction between both factors, $F(1,46) = 3.48$, $p = .069$. This marginal interaction (significant interactions being difficult to obtain when comparing experiments in infant studies) is due to the fact that a preference for trochaic sequences is found for 6-month-olds, $F(1,46) = 5.96$, $p = .018$, but not for 4-month-olds, $F(1,46) = .04$, $p = .84$.

This initial analysis was completed by two other analyses. First, we conducted a chi-square analysis to determine whether the numbers of infants having longer OTs to the trochaic versus iambic sequences differ across the two ages (6-month-olds: 19 versus 5; 4-month-olds: 14 versus 10). The age difference failed to reach significance on this analysis, $\chi^2 = 1.55$, n.s. (correction for continuity applied). Second, given the large age effect, we conducted another ANOVA on age-normalized OTs. Raw OTs were normalized by dividing each infant's two OTs by the overall mean for its age group (12.47 s for the 4-month-olds, 7.58 s for the 6-month-olds). Accordingly, the effect of age disappeared. There was a marginal effect of stress, $F(1,46) = 3.72$, $p = .06$, and a significant stress × age interaction, $F(1,46) = 4.51$, $p = .039$. The interaction was again due to a preference for trochaic sequences in 6-month-olds, $F(1,46) = 8.21$, $p = .006$, but not in 4-month-olds, $F(1,46) = .02$, $p = .89$.

The trochaic preference difference found between both age groups is compatible with the possibility that the preference for trochaic sequences emerges during development, between 4 and 6 months of age. This pattern of emergence of the trochaic bias is also compatible with the results on English by Jusczyk et al. (1993), although there is an age lag between both studies that is likely due, as already discussed above, to the fact that we removed phonetic variation in our study. Given that several studies have successfully used HPP with 4-month-old infants (Bosch & Sebastián-Gallés, 2001; Mandel et al., 1995; Seidl & Cristià, 2008), the null effect in the younger infants is unlikely to be due to the fact of having used a method not suitable for infants of the age tested. Furthermore, with the same experimental setup and the same stimuli as in the present experiment but a modification of the procedure from a familiarity to a discrimination technique (similarly to what was done in Experiment 4 of the present study), Herold, Höhle, Walch, Weber, and Obladen (2008) found that German-learning 4-month-olds can discriminate trochaic from iambic sequences.[2] This was attested by an induced preference for the trochaic over the iambic sequences following a 1-min familiarization with trochaic sequences. Thus, 4-month-old German-learning infants are able to discriminate between trochaic and iambic sequences, even though they do not prefer one kind of pattern over the other.

Summarizing at this point, it appears clear that 6-month-old German infants do show a trochaic bias. This result is compatible with the data by Friederici et al. (2007) showing an even earlier asymmetry in German-learning infants' discrimination of trochaic versus iambic patterns using ERPs by 4 months of age, a finding that had been presented as possible evidence for a trochaic bias in this population. Our results are also compatible with previous data by Jusczyk et al. (1993) showing the emergence of a trochaic bias between 6 and 9 months of age. Our study shows that evidence of a trochaic bias can be found earlier when presenting infants with less phonetically varied stimuli (see also discussion of possible crosslinguistic differences in Section 6). Note however that the acquisition of this bias would have happened prior to their visit to the laboratory, and would be the result of infants' processing of the complex linguistic stimuli present in their environment.

In the following, we address the second issue we raised in Section 1, namely the determination of whether the trochaic bias is found independently of the language in acquisition, or whether it is determined by the phonological/prosodic properties of that language. One way to address this issue is to use the same stimuli to test infants growing up hearing a language with prosodic properties that should not support a trochaic bias. As discussed earlier, French is a good candidate for such a study, and for several reasons: it is syllable- rather than stress-based; stress is not clearly marked at the lexical level; and if a bisyllabic word appears in a stressed phrasal position, its final syllable is lengthened. Experiment 3 thus presented French-learning 6-month-olds with the same stimuli, using the same method. If the trochaic bias observed in German-learning 6-month-olds reflects a sensitivity to the prosodic properties of that language, French-learning 6-month-olds should not show such a bias. It remains to see whether they will show no bias (as predicted by the Nazzi et al., 2006, proposal) or an iambic bias as potentially suggested by the Friederici et al. (2007) ERP study, and in line with the phrase-final lengthening observed in that language. Alternatively, if the results obtained for the German infants are language general and independent of linguistic input, then a similar trochaic bias should be found with French infants.

4. Experiment 3

4.1. Method

4.1.1. Participants

Twenty-four 6-month-olds (11 girls and 13 boys) were tested in this experiment. Their mean age was 6 months and 8 days (range: 5 months 21 days to 7 months 7 days). The criteria for selecting the participants were equivalent to that of the previous experiments: All infants were born full-term, grew up in Paris, had parents who only talked to their infants in French, and none of the infants was known to suffer from hearing impairment. To achieve this number two additional infants were tested but did not complete the experiment due to fussiness.

4.1.2. Stimuli

The same stimuli as in Experiment 1 were used.

[2] Discrimination was found for infants born at term, like the infants tested in the present study, while it was not found for preterm infants.

4.1.3. Procedure and apparatus

The present experiment was run by a Dell Optiplex computer; the stimuli were delivered by SONY xs-F1722 loudspeakers via a Marantz PM4000 audio amplifier. The procedure was the same as in Experiment 1, with one difference only. Due to the use of a different software in the Parisian laboratory, infants could only be presented with two different trochaic and two different iambic files during the test phase, these four files being repeated three times over the course of the test phase (leading to six trochaic and six iambic trials). Note that this difference is minimal, as infants in both language groups heard the exact same stimuli. This is because the only difference among the various trochaic (or iambic) files was the order of concatenation of the trochaic (or iambic) tokens. As a result, each French infant, like each German infant, heard all the trochaic tokens and all the iambic tokens. As a counterbalancing measure, we nevertheless made sure to use all six trochaic files and all six iambic files the same number of times across infants.

The software used in the Parisian laboratory also differed from the one used in Potsdam in the fact that if for a trial, the infant's orientation time is shorter than 1.5 s, that trial is immediately replayed and the initial OT is discarded (a total of four trials were replaced, accounting for 1.4% of all trials).

4.2. Results and discussion

As for the previous experiments, all individual orientation times exceeding 18 s were reduced to 18 s; 14 trials were cut off, accounting for 4.9% of all trials. On average, infants oriented to the trochaic sequences for 10.47 s (SD = 2.13) while they oriented to the iambic sequences for 10.39 s (SD = 2.76). This difference was not significant, $t(23) = .22$; $p = .83$, two-tailed. Moreover, only 11 infants had longer orientation times to the trochaic sequences than to the iambic ones ($p = .42$, binomial test).

An ANOVA was conducted to compare 6-month-old infants' preference for trochaic versus iambic sequences across languages. It revealed a significant effect of language, as the orientation times of the German infants (7.58 s) were much shorter than those of the French infants (10.42 s), $F(1,46) = 19.36$, $p < .001$. Although this group effect may reflect the fact that the stimuli were recorded by a German speaker sounding non-native for the French infants (but see below and Experiment 4), they might more simply result from differences in the setup in the two labs, as variations in the brightness of the room illumination or the brightness of the lamps or the relation of those could affect infants' general level of orientation. There was also a marginal effect of stress, $F(1,46) = 3.64$, $p = .06$, and a marginal interaction between both factors, $F(1,46) = 2.63$, $p = .11$. This marginal interaction is due to the fact that a preference for trochaic sequences is found for German 6-month-olds, $F(1,46) = 6.24$, $p = .016$, but not for French 6-month-olds, $F(1,46) = .04$, $p = .84$.

As for the age comparison between Experiments 1 and 2, this initial analysis was completed by two other analyses. First, we conducted a chi-square analysis to determine whether the numbers of infants having longer OTs to trochaic versus iambic differed across the two languages (German: 19 versus 5; French: 11 versus 13). This language difference was significant, $\chi^2 = 5.02$, $p = .025$ (correction for continuity applied). Second, given the large language effect, we conducted another ANOVA on language-normalized OTs. Raw OTs were normalized by dividing each infant's two OTs by the overall mean for its language group (7.58 s for German infants; 10.42 s for French infants). Accordingly, the effect of language disappeared. There was a significant effect of stress, $F(1,46) = 4.33$, $p = .04$, and a marginal stress × language interaction, $F(1,46) = 3.42$, $p = .07$. The interaction was again due to a preference for trochaic sequences in German 6-month-olds, $F(1,46) = 7.73$, $p = .008$, but not in French 6-month-olds, $F(1,46) = .03$, $p = .87$.

Taken together, the present results suggest that French-learning 6-month-olds, contrary to German-learning infants of the same age, do not have a preference for either trochaic or iambic sequences. This pattern is compatible with the proposal that the trochaic bias is not language general, but rather reflects some knowledge of the prosodic properties of the language in acquisition. It also raises interesting issues regarding the link between behavioral and electrophysiological data.

However, before launching into a discussion on these issues, we would like to address a more trivial possibility. Indeed, it could be that the French-learning infants did not show a trochaic/iambic preference in the present experiment because they perceive the stimuli as foreign, and thus equally disliked or maybe liked (as possibly suggested by the longer OTs found for the French infants) both types of sequences. This possibility seems unlikely for several reasons. First, the stimuli themselves do not sound particularly un-French, and 6-month-olds are only starting to acquire the phonetic categories of their native language (vocalic categories by 6 months: Kuhl et al., 1992; consonantal categories by 10 months: Werker & Tees, 1984). Second, the Friederici et al. (2007) ERP study reports stress pattern discrimination data by 4-month-old French-learning infants for similar stimuli also recorded by a German speaker. Third, a recent behavioral study by Skoruppa et al. (2007) reports stress pattern discrimination by 9-month-old French-learning infants in similar conditions for other foreign stimuli recorded by a Spanish speaker.

In spite of all this converging indirect evidence, we decided to directly verify that French-learning 6-month-olds are processing the present stimuli by testing them on their ability to discriminate between trochaic or iambic sequences. This is done using HPP as a discrimination paradigm, by familiarizing infants with one type of stress pattern (counterbalanced across infants) for 1 min, before presenting them with trials of trochaic versus iambic stimuli (see Nazzi, Jusczyk, et al., 2000, for a similar use of HPP). Accordingly, infants were first familiarized with 1 min of either trochaic or iambic sequences, and then tested with both types of sequences. The rationale is that the familiarization phase is going to induce in the test phase a (transient) preference for one kind of stress pattern.

5. Experiment 4

5.1. Method

5.1.1. Participants

Twenty-four 6-month-olds (13 girls and 11 boys) were tested in this experiment. Their mean age was 6 months and 19 days (range: 5 months 26 days to 7 months 29 days). The criteria for selecting the participants were the same as in Experiment 3. To achieve this number two additional infants were tested but did not complete the experiment due to fussiness.

5.1.2. Stimuli

The same stimuli as in Experiments 1 were used.

5.1.3. Procedure and apparatus

The apparatus was the same as in Experiment 3. The procedure was the same as in Experiment 3, with a modification that changed the experiment from a preference to a discrimination experiment. Infants were familiarized with one of the six trochaic or iambic files until they reached a familiarization criterion of 60 s of orientation times. Half of the infants were familiarized with the trochaic pattern, the other half being familiarized with the iambic pattern. Once the familiarization criterion was reached, infants were tested with two different files of the same stress pattern, and two files of the opposite stress pattern. This block of four files was repeated three times, with varied random presentation orders, leading to the presentation of 12 test trials, half of the same and half of the opposite stress pattern. As a counterbalancing measure, the file used during familiarization and the four files used during test, chosen among the six trochaic and six iambic files, were varied across infants.

As in Experiment 3, trials with orientation times shorter than 1.5 s were immediately replaced. There were 11 such trials, accounting for 3.82% of all trials.

5.2. Results and discussion

As for the previous experiments, we checked for individual orientation times exceeding 18 s to control for potential effects of the slightly longer duration of the trochaic stimuli, but none were found. On average, infants oriented to the sequences with the familiar stress pattern for 7.61 s (SD = 3.29) while they oriented to the sequences with the new stress pattern for 6.82 s (SD = 3.00). This difference was marginally significant, $t(23) = 2.00$; $p = .058$, two-tailed. Sixteen infants had longer orientation times to the sequences with the familiar stress pattern ($p = .076$, binomial test). An ANOVA with the main within-subject factor of familiarization (familiarized versus new stress pattern) and the main between-subject factor of condition (familiarization with trochaic versus iambic pattern) revealed a marginal effect of familiarization, $F(1,22) = 3.82$, $p = .063$. The effect of condition was not significant, $F(1,22) = .91$, $p = .35$, nor was the interaction between both factors, $F(1,22) = .008$, $p = .93$.

The above analyses converge in showing a weak discrimination effect of the trochaic and iambic patterns at 6 months of age. Why is this effect so weak? One possibility is that the introduction of a familiarization phase seems to have induced larger individual differences in overall attention to sounds in this group of infants. Indeed, mean OTs ranged from 2.23 s to 13.14 s in the present experiment, while they only ranged from 6.13 s to 13.74 s in Experiment 3. In order to take this individual variation into account, we calculated for each infant the proportion of time spent orienting to the familiar versus new patterns in the test phase. Infants listened 52.93% of their total time to sequences with the familiar pattern versus 47.07% of their total time to sequences with the new pattern, $t(23) = 2.36$; $p = .027$, two-tailed. An ANOVA with the main within-subject factor of familiarization (familiarized versus new stress pattern) and the main between-subject factor of condition (familiarization with trochaic versus iambic pattern) revealed a significant effect of familiarization, $F(1,22) = 5.32$, $p = .031$. The effect of condition was not significant, $F(1,22) = .01$, $p = .92$, nor was the interaction between both factors, $F(1,22) = .036$, $p = .85$.

Overall, the present results suggest that French-learning 6-month-olds, although they do not have a preference for either trochaic or iambic sequences, are capable of discriminating both types of stimuli that had been recorded by a German speaker. These results are consistent with the evidence found in other studies looking at stress pattern discrimination by 4–9-month-old French-learning infants that all used stimuli produced by foreign speakers, a constraint due to the fact that French does not use stress pattern contrastively at the lexical level (Friederici et al., 2007; Skoruppa et al., 2007).

By showing that French-learning 6-month-olds discriminate trochaic and iambic sequences, the present data suggest that the lack of a trochaic/iambic bias in Experiment 3 was not due to methodological- or stimuli-based reasons, but rather to the fact that they genuinely do not prefer one pattern over the other. These findings at the behavioral level are interesting given the discrimination asymmetry found by Friederici et al. (2007) at the electrophysiological level. Although ERP asymmetrical discrimination at 4 months of age coincided with a behavioral bias at 6 months of age for the German-learning infants, the same does not appear to be true for French-learning infants. This confirms the need for further research evaluating the articulation between data obtained with different methods and at different levels of processing.

These results with the French-learning infants also have implications regarding our understanding of what the trochaic bias stands for. Indeed, the crosslinguistic difference observed shows for the first time that the trochaic bias is not language general. This is consistent with the idea that the trochaic preference in German-learning infants at 6 months of age reflects some knowledge of the prosodic properties of that language. In the following, we discuss the implications of all these results for prosodic acquisition and the emergence of segmentation abilities.

6. General discussion

The first aim of the present study was to provide evidence of a trochaic bias in a stress-based language before the onset of segmentation abilities, that is, before 7.5 months of age. Accordingly, we tested German-learning infants' preference for trochaic over iambic bisyllables at 4 and 6 months of age (Experiments 1 and 2). Our results fail to show a trochaic bias at 4 months, but show a clear trochaic bias at 6 months. These two experiments, together with the discrimination data at 4 months by Herold et al. (2008), suggest that a trochaic bias emerges between 4 and 6 months of age in German-learning infants. Importantly, these results are the first to unambiguously demonstrate a trochaic bias in German-learning infants before the onset of segmentation abilities, an issue to which we return shortly.

Our second aim was to evaluate whether the trochaic bias is language-general or whether it is the reflection of the prosodic properties of the native language. Given that German-learning infants show a trochaic bias at 6 months of age, the language-general hypothesis predicts that such a bias should be found at the same age independently of the language in acquisition, while it should not be found for languages that do not support a trochaic bias. This was evaluated by determining whether the trochaic bias found for German at the age of 6 months is also found for French at the same age. Our results show that this is not the case, French-learning infants showing no bias for either stress pattern (Experiment 3), even though we were able to confirm the finding from other studies (Friederici et al., 2007; Skoruppa et al., 2007) that they do discriminate stress patterns at that age (Experiment 4). These results thus establish for the first time that the trochaic bias is language-dependent, and our results are compatible with the predictions that could be made on the basis of rhythmic classes.

In the following, we discuss several implications of our results. We start with a comparison of the results of our behavioral study with those of a recent electrophysiological study conducted on stress pattern processing (Friederici et al., 2007). Both methods converge in showing discrimination of trochaic and iambic sequences in both German- and French-learning infants: at 6 months in the present behavioral study (Experiments 1 and 4, respectively), at 4 months in the ERP study (with behavioral evidence in German-learning 4-month-olds by Herold et al., 2008).

However, the results obtained with both methods differ when it comes to establishing potential biases. At 6 months, our study shows that German-learning infants have a behavioral trochaic bias (Experiment 1) while French-learning infants appear to have no bias (Experiment 3). But at 4 months, the ERP study shows that trochaic/iambic discrimination is asymmetrical in both languages, with a reversal of the asymmetry between the two populations, suggesting a trochaic bias in German and an iambic bias in French. Thus, the trochaic bias in German suggested by the ERP study at 4 months is confirmed at the behavioral level at least at 6 months, while the iambic bias in French suggested by the ERP study is not found at the behavioral level. This complex pattern suggests that at present, we still need a better understanding of the articulation of behavioral and electrophysiological data, which will require comparing the outcome of parallel studies conducted at both levels.

We now discuss the implications of our results for the early segmentation of fluent speech. As mentioned earlier, there is a paradox in claiming that English-learning infants start segmenting fluent speech by extracting trochaic units which correspond to the predominant stress pattern of English words, unless one offers an explanation of how these infants learn this property of English words prior to the onset of segmentation abilities. As already discussed, several solutions to this problem have been offered. First, Thiessen and Saffran (2003) suggested that infants actually start by performing distributional analyses of the input, which allow them to segment fluent speech into word-like units, from which English-learning infants will be able to specify that the trochaic pattern is predominant in their language. Second, given the proposal that the trochaic bias is innate (Allen & Hawkins, 1978), infants could start segmenting speech by extracting trochaic units independently of the language they are acquiring. Third, Nazzi et al. (2006) have suggested that infants' sensitivity to rhythmic types from birth allows them to rapidly learn the rhythmic unit of their native language, which would be attested by the emergence of a trochaic bias in English- or German-learning infants, and to then use this rhythmic unit to start segmenting fluent speech. The first and third proposals make radically different predictions regarding the relative onset of segmentation abilities and the trochaic bias: segmentation abilities should emerge before the trochaic bias according to Thiessen and Saffran (2003), while they should emerge after the trochaic bias according to Nazzi et al. (2006). The second and third proposals make different crosslinguistic predictions when it comes to the observation of a trochaic bias, which should be found for all languages according to the innate trochaic bias proposal but only for stress-based languages according to the rhythm-acquisition proposal.

Regarding this latter comparison, the observation of a trochaic bias at 6 months in German- but not French-learning infants favors the rhythm-acquisition account over the innate trochaic bias account. Indeed, given that segmentation abilities are about to emerge at 6 months of age, if French-learning started segmenting trochaic units (which is not confirmed by recent segmentation studies on French, Nazzi et al., 2006), they should have exhibited a trochaic bias here. Thus, the difference in behavior between the German- and French-learning infants suggests that some prosodic acquisition has taken place by 6 months of age. What our results do not show, given the difficulty at interpreting the absence of a trochaic bias in the German 4-month-olds, is whether a trochaic bias emerges in German-learning infants between birth and the age of 6 months due to their acquisition of the trochaic unit as the rhythmic unit of their native language, or whether all infants initially have a trochaic bias,[3] and that this trochaic bias has disappeared in French-learning infants as a consequence of their acquisition of the syllable as the rhythmic unit of their native language. This possibility would be similar to Mattock and Burnham (2006) finding of a decrease in infants' sensitivity to prosodic dimensions not contrastive in the native language (tone contrasts for English-learning infants) between 6 and 9 months of age. Both developmental accounts are compatible with Nazzi et al. (2006) rhythm-acquisition account.

Let us now turn to the respective evaluation of the distributional and rhythm-acquisition accounts. Given that the existing evidence suggests that neither English-, German- nor French-learning 6-month-olds are able to segment words out of natural continuous speech (Gout, 2001; Höhle & Weissenborn, 2003; Jusczyk & Aslin, 1995), and the absence of evidence of distributional-based segmentation before 7 months (Thiessen & Saffran, 2003), the present finding of a trochaic bias in German-learning infants at 6 months of age appears in line with the rhythm-based account (Nazzi et al., 2006). Accordingly, infants about to start segmenting words would prefer trochaic sequences not because they correspond to the predominant stress pattern of English or German words, but because they correspond to the rhythmic unit of these languages. This use of trochaic units to segment speech into words would be appropriate for English and German because words in these languages are predominantly trochaic. In line with this rhythmic-based acquisition account, recent data from syllable-based French provided evidence that French-learning infants use the rhythmic unit of their native language (the syllable) at the onset of segmentation abilities (Nazzi et al., 2006).

Discussing now the timing of observation of the trochaic bias, we compare our data to previous findings on English-learning infants (Jusczyk et al., 1993; Morgan & Saffran, 1995). Our results show a trochaic bias in German-learning infants at 6 months of age, thus earlier than the trochaic bias reported to emerge in English between 6 and 9 months. As previously discussed, one explanation for these diverging results might be related to methodological differences between the English and German experiments with respect to the stimuli used. While Jusczyk et al. (1993) used many phonetically varied English trochaic and iambic words, our material was restricted to different tokens of a single CVCV sequence (*gaba*). The fact that the different stress patterns were carried by segmentally identical strings might have made the prosodic differences between the stimuli perceptually more salient for the German infants, while the higher segmental variation in the English stimuli might have diverted English-learning infants' attention from the prosodic properties of the stimuli. Both elements might have made it harder for the English-learning infants in Jusczyk et al. (1993) to provide early evidence of a trochaic bias (c.f. convergent data on newborn stress pattern discrimination by comparing Sansavini et al., 1997; Van Ooijen et al., 1997).

This explanation is supported by newer data providing some evidence for a trochaic bias in English learners as young as 7 months (Thiessen & Saffran, 2003). They found that infants familiarized with trochaic strings showed shorter listening times to bisyllables with level stress than infants familiarized with iambic strings. Based on a model by Hunter and Ames (1988), this asymmetry was interpreted as the reflection of the reduced similarity of the familiarized iambic strings to the items with level stress, leading to a novelty effect after iambic familiarization. A similar observation has been made with respect to the so-called perceptual magnet effect in the area of vowel discrimination. Infants as young as 6 months show weaker discrimination reactions to phonetic differences between two tokens of a category when the token they have been familiarized to is a prototypical instance of the category (Kuhl, 1991). Since vowel categories are structured differentially across languages the magnet effect is the result of learning the vowel categories of the ambient language (Kuhl et al., 1992). Transferring this to the data from Thiessen and Saffran (2003) would suggest that English-learning 7-month-olds already recognize the trochaic pattern as being more typical in their native language.

Another possible explanation for the earlier effect in German is that features of the German language might make the trochaic pattern more prominent in the German input than in the English input. Cutler and Carter (1987) report that 12% of all English content word types of the MRC Psycholinguistic Database are monosyllabic words. We conducted a similar analysis in the Celex-Lexical Database, and found that only 3% of German content word types are monosyllabic. One feature that may contribute to this low amount of monosyllabic words might be the more differentiated inflectional system of German for different kinds of word classes. German inflectional endings are often syllabic and add a syllable to the word stem leading to a bisyllabic trochaic form even for words that are monosyllabic in their base form. Even high frequent function words like determiners are inflected in German and often form a bisyllabic trochaic unit, e.g., most of the forms of the indefinite article *ein* are bisyllabic: *ei-ne* (nom. fem.), *ei-ner* (gen. fem.), *ei-nen* (acc. masc.), *ei-nem* (dat. masc.), etc. This has two important implications in terms of the rhythmic structure of the input received by German-learning infants compared to English-learning infants. At the lexical level, they will hear trochaic patterns much more frequently. But, more importantly given the proposal by Nazzi et al. (2006), infants will hear more regular alternations of strong and weak syllables at the sentence level. Both phenomena should favor German-learning infants' acquisition of the trochaic bias compared to English-learning infants.

At this point, in order to tease apart the two main interpretations we offered for the developmental lag between English- and German-learning infants, one would need to conduct either an experiment presenting English 6-month-olds with various tokens of the same CVCV sequence contrasted on their stress pattern (as in the present study), or an experiment

[3] Recent studies on adults have stared exploring how acoustic variation in alternating syllables gives rise to the perception of trochaic versus iambic groupings (e.g., Hay & Diehl, 2007). Intensity variations induced trochaic groupings while duration variations induced iambic groupings in both English- and French-speaking adults. Future studies on this issue will have to explore whether similar effects can be found in infants, and how groupings are made when variations in both dimensions are put in conflict (which would be the case for English trochaic words as pointed out by Hay and Diehl, 2007).

presenting German-learning infants with many different words contrasted on their stress pattern (as done in Jusczyk et al., 1993).

Going back to French, our finding that 6-month-olds do not show a preference for either stress pattern was predicted by the Nazzi et al. (2006) proposal given the rhythmic properties of French. The absence of an iambic preference for the French learners at the behavioral level is in line with the phonological description of French as being both a syllable-timed language (with no lexical stress), and a language with phrasal lengthening rather than an iambic language. In addition, the absence of an iambic bias provides further support for the assumption that word stress is not used as an early cue for word segmentation in French-learning infants, in line with Nazzi et al. (2006) evidence for syllable-based segmentation in French. The results of the French infants might be interpreted as an indication that lexical stress does not attract the attention of learners of syllable-timed languages to such a degree as seen by learners of stressed-timed languages like English, German and Dutch. This is reminiscent of the findings of reduced (though not to the point of "deafness") sensitivity to lexical stress in French adults (Dupoux, Pallier, Sebastián, & Mehler, 1997; Dupoux, Peperkamp, & Sebastián-Gallés, 2001). On the other hand, the lack of an iambic preference could be due to the fact that in French phonology, the domain of stress assignment is the phonological phrase and not the phonological word. Further research should focus on the question of whether this non-reaction to lexical stress is specific to French learners or whether it could be found in learners of other syllable-timed languages. One interesting language to look at would be syllable-timed Turkish. Indeed, in contrast to French, Turkish has stress at the lexical level with the primary word stress falling in most cases, but not always, on the final syllable (Kabak & Vogel, 2001). If the acquisition of the native language rhythmic properties is driven by its global rhythmic/timing properties, we would expect Turkish 6-month-olds to behave like French infants in showing no bias at all. If on the other hand, rhythmic acquisition is influenced by the domain of stress assignment, we would expect Turkish 6-month-olds to show an iambic bias.

To sum up, the crosslinguistic approach taken in our study clearly suggests a very early impact of the rhythmic structure of the ambient language on infants' processing of stress information. We showed that the emergence of a trochaic bias in German-learning infants between 4 and 6 months of age results from the trochaic properties of this stress-based language, as attested by the lack of a similar bias in 6-month-old infants acquiring French, a syllable-based language without lexical stress. These results are in line with earlier findings beginning to show that crosslinguistic variation systematically related to the specific rhythmic properties of the target language is to be expected with respect to infants' use of stress information as a cue for word segmentation (Jusczyk et al., 1999; Höhle, 2002; Houston et al., 2000; Nazzi et al., 2006). Future crosslinguistic investigations on languages of different rhythmic types that vary with respect to their lexical stress pattern will have to be conducted to further specify the developmental link that we proposed between these early changes in stress pattern sensitivity and the emergence of word segmentation abilities.

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References

Allen, G. D., & Hawkins, S. (1978). The development of phonological rhythm. In A. Bell, & J. B. Hooper (Eds.), *Syllables and segments*. Amsterdam: North-Holland.

Bortfeld, H., Morgan, J. L., Golinkoff, R. M., & Rathbun, K. (2005). Mommy and me: Familiar names help launch babies into speech-stream segmentation. *Psychological Science*, *16*, 298–304.

Bosch, L., & Sebastián-Gallés, N. (1997). Native-language recognition abilities in 4-month-old infants from monolingual and bilingual environments. *Cognition*, *65*, 33–69.

Bosch, L., & Sebastián-Gallés, N. (2001). Evidence of early language discrimination in infants from bilingual environments. *Infancy*, *2*, 29–49.

Brent, M. R., & Siskind, J. M. (2001). The role of exposure to isolated words in early vocabulary development. *Cognition*, *81*, B33–B44.

Bull, D. H., Eilers, R. E., & Oller, D. K. (1984). Infants' discrimination of intensity variation in multisyllabic stimuli. *Journal of the Acoustical Society of America*, *76*, 13–17.

Bull, D. H., Eilers, R. E., & Oller, D. K. (1985). Infants' discrimination of final syllable fundamental frequency in multisyllabic stimuli. *Journal of the Acoustical Society of America*, *77*, 289–295.

Christophe, A., Guasti, T., Nespor, M., Dupoux, E., & Van Ooyen, B. (1997). Reflections on phonological bootstrapping: Its role for lexical and syntactic acquisition. *Language and Cognitive Processes*, *12*(5–6), 585–612.

Christophe, A., Mehler, J., & Sebastián-Gallés, N. (2001). Perception of prosodic boundary correlates by newborn infants. *Infancy*, *23*, 385–394.

Cole, R. A., & Jakimik, J. (1978). Understanding speech: How words are heard. In G. Underwood (Ed.), *Strategies of information processing* (pp. 67–116). New York, NY: Academic Press.

Cole, R. A., & Jakimik, J. (1980). How are syllables used to recognize words? *Journal of the Acoustical Society of America*, *67*, 965–970.

Cutler, A., & Carter, D. M. (1987). The predominance of strong initial syllables in the English vocabulary. *Computer Speech and Language*, *2*, 133–142.

Cutler, A., Mehler, J., Norris, D. G., & Segui, J. (1986). The syllable's differing role in the segmentation of French and English. *Journal of Memory and Language*, *25*, 385–400.

Cutler, A., & Norris, D. (1988). The role of strong syllables in segmentation for lexical access. *Journal of Experimental Psychology: Human Perception and Performance*, *14*, 113–121.

Dupoux, E., Pallier, C., Sebastián, N., & Mehler, J. (1997). A distressing "deafness" in French. *Journal of Memory and Language*, *36*, 406–421.

Dupoux, E., Peperkamp, S., & Sebastián-Gallés, N. (2001). A robust method to study stress "deafness". *Journal of the Acoustical Society of America*, *110*, 1606–1618.

Eilers, R. E., Bull, D. H., Oller, D. K., & Lewis, D. C. (1984). The discrimination of vowel duration by infants. *Journal of the Acoustical Society of America*, *75*, 1213–1218.

Friederici, A. F., Friedrich, M., & Christophe, A. (2007). Brain responses in 4-month-old infants are already language specific. *Current Biology*, *17*, 1208–1211.

Gout, A. (2001). *Etapes précoces de l'acquisition du lexique*. Unpublished Dissertation, Ecole des Hautes Etudes en Sciences Sociales, Paris, France.

Guasti, M. T., Christophe, A., van Ooyen, B., & Nespor, M. (2001). Pre-lexical setting of the head complement parameter. In J. Weissenborn, & B. Höhle (Eds.), *Approaches to bootstrapping: Phonological, lexical, syntactic and neurophysiological aspects of early language acquisition*. Amsterdam: Benjamins.

Hay, J. S. F., & Diehl, R. L. (2007). Perception of rhythmic grouping: Testing the iambic/trochaic law. *Perception & Psychophysics*, *69*, 113–122.

Hayes, B. (1995). *Metrical stress theory*. Chicago: The University of Chicago Press.

Herold, B., Höhle, B., Walch, E., Weber, T., & Obladen, M. (2008). Impaired stress pattern discrimination in very low birth weight infants during the first six months of life. *Developmental Medicine and Child Neurology*, *50*, 678–683.

Hirsh-Pasek, K., Kemler Nelson, D. G., Jusczyk, P. W., Wright Cassidy, K., Druss, B., & Kennedy, L. (1987). Clauses are perceptual units for young infants. *Cognition*, *26*, 269–286.

Höhle, B. (2002). *Der Einstieg in die Grammatik: Die Rolle der Phonologie/Syntax-Schnittstelle für Sprachverarbeitung und Spracherwerb*. Habilitationsschrift. Freie Universität Berlin.

Höhle, B., & Weissenborn, J. (2003). German-learning infants' ability to detect unstressed closed-class elements in continuous speech. *Developmental Science*, *6*, 122–127.

Höhle, B., Weissenborn, J., Schmitz, M., & Ischebeck, A. (2001). Word order regularities: The role of prosodic information for early parameter setting. In J. Weissenborn, & B. Höhle (Eds.), *Approaches to bootstrapping: Phonological, lexical, syntactic and neurophysiological aspects of early language acquisition*. Amsterdam: Benjamins.

Houston, D. M., Jusczyk, P. W., Kuijpers, C., Coolen, R., & Cutler, A. (2000). Crosslanguage word segmentation by 9-month-olds. *Psychonomic Bulletin & Review*, *7*, 504–509.

Hunter, M. A., & Ames, E. W. (1988). A multifactor model of infants' preferences for novel and familiar stimuli. *Advances in Infancy Research*, *6*, 69–95.

Jessen, M., Marasek, K., Schneider, K. & Clahßen, K. (1995). Acoustic correlates of word stress and the tense/lax opposition in the vowel system of German. In *Proceedings of the XIIIth international congress of phonetic sciences*. Vol. 4. Stockholm: Schweden.

Johnson, E. K., & Jusczyk, P. W. (2001). Word segmentation by 8-month-olds: When speech cues count more than statistics. *Journal of Memory and Language*, *44*, 1–20.

Johnson, E. K., & Seidl, A. H. (2009). At 11 months, prosody still outranks statistics. *Developmental Science*, *12*, 131–141.

Jusczyk, P. W., & Aslin, R. N. (1995). Infants' detection of the sound patterns of words in fluent speech. *Cognitive Psychology*, *29*, 1–23.

Jusczyk, P. W., Cutler, A., & Redanz, N. (1993). Preference for the predominant stress patterns of English words. *Child Development*, *64*, 675–687.

Jusczyk, P. W., Hirsh-Pasek, K., Kemler Nelson, D. G., Kennedy, L. J., Woodward, A., & Piwoz, J. (1992). Perception of acoustic correlates of major phrasal units by young infants. *Cognitive Psychology*, *24*, 252–293.

Jusczyk, P. W., Houston, D. M., & Newsome, M. (1999). The beginnings of word segmentation in English-learning infants. *Cognitive Psychology*, *39*, 159–207.

Kabak, B., & Vogel, I. (2001). The phonological word and stress assignment in Turkish. *Phonology*, *18*, 315–360.

Kuhl, P. K. (1991). Human adults and human infants show a "perceptual magnet effect" for the prototypes of speech categories, monkeys do not. *Perception & Psychophysics*, *50*, 93–107.

Kuhl, P. K., Williams, K. A., Lacerda, F., Stevens, K. N., & Lindblom, B. (1992). Linguistic experience alters phonetic perception in infants by 6 months of age. *Science*, *255*, 606–608.

Mandel, D. R., Jusczyk, P. W., & Pisoni, D. B. (1995). Infants' recognition of the sound patterns of their own names. *Psychological Science*, *6*, 314–317.

Mattock, K., & Burnham, D. (2006). Chinese and English infants' tone perception: Evidence for perceptual reorganization. *Infancy*, *10*, 241–265.

Maye, J., Werker, J. F., & Gerken, L. A. (2002). Infant sensitivity to distributional information can affect phonetic discrimination. *Cognition*, *82*, B101–B111.

McLennan, S. (2005). A dynamic adaptive model of linguistic rhythm. In *Proceedings of the I.S.C.A. workshop on plasticity in speech perception*, London, UK, June 15–17 2005, (p. 130).

Moon, C., Panneton-Cooper, R., & Fifer, W. P. (1993). Two-day-olds prefer their native language. *Infant Behavior and Development*, *16*, 495–500.

Morgan, J. L., & Saffran, J. R. (1995). Emerging integration of sequential and suprasegmental information in preverbal speech segmentation. *Child Development*, *66*, 911–936.

Nazzi, T., Bertoncini, J., & Mehler, J. (1998). Language discrimination by newborns: Toward an understanding of the role of rhythm. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 756–766.

Nazzi, T., Floccia, C., & Bertoncini, J. (1998). Discrimination of pitch contours by neonates. *Infant Behavior and Development*, *21*, 779–784.

Nazzi, T., Iakimova, I., Bertoncini, J., Frédonie, S., & Alcantara, C. (2006). Early segmentation of fluent speech by infants acquiring French: Emerging evidence for crosslinguistic differences. *Journal of Memory and Language*, *54*, 283–299.

Nazzi, T., Jusczyk, P. W., & Johnson, E. K. (2000). Language discrimination by English-learning 5-month-olds: Effects of rhythm and familiarity. *Journal of Memory and Language*, *43*, 1–19.

Nazzi, T., Kemler Nelson, D. G., Jusczyk, P. W., & Jusczyk, A. M. (2000). Six month olds' detection of clauses embedded in continuous speech: Effects of prosodic well-formedness. *Infancy*, *1*, 123–147.

Nazzi, T., & Ramus, F. (2003). Perception and acquisition of linguistic rhythm by infants. *Speech Communication*, *41*, 233–243.

Nespor, M., Guasti, M. T., & Christophe, A. (1996). Selecting word order: The rhythmic activation principle. In U. Kleinhenz (Ed.), *Interfaces in phonology*. Berlin: Akademie Verlag.

Ramus, F., Hauser, M. D., Miller, C., Morris, D., & Mehler, J. (2000). Language discrimination by human newborns and by cotton-top tamarin monkeys. *Science*, *288*, 349–351.

Sansavini, A., Bertoncini, J., & Giovanelli, G. (1997). Newborns discriminate the rhythm of multisyllabic stressed words. *Developmental Psychology*, *33*, 3–11.

Seidl, A. (2007). Infants' use and weighting of prosodic cues in clause segmentation. *Journal of Memory and Language*, *57*, 24–48.

Seidl, A., & Cristià, A. (2008). Developmental changes in the weighting of prosodic cues. *Developmental Science*, *11*, 596–606.

Skoruppa, K., Pons, F., Christophe, A., Bosch, L., Sebastian-Galles, N., Limissuri, R. A., et al. (2007). Language-specific stress perception by 9-month-old French and Spanish infants. In *Poster presented at the 32nd annual Boston University conference on language development* Boston MA, USA, November 2–4.

Spring, D. R., & Dale, P. S. (1977). Discrimination of linguistic stress in early infancy. *Journal of Speech and Hearing Research*, *20*, 224–232.

Soderstrom, M., Seidl, A., Kemler Nelson, D. G., & Jusczyk, P. W. (2003). The prosodic bootstrapping of phrases: Evidence from prelinguistic infants. *Journal of Memory and Language*, *49*, 249–267.

Thiessen, E. D., & Saffran, J. R. (2003). When cues collide: Use of stress and statistical cues to word boundaries by 7- to 9-month-old infants. *Developmental Psychology*, *39*, 706–716.

Van de Weijer, J. (2001). The importance of single-word utterances for early word recognition. In *Proceedings of ELA 2001* Lyon, France.

Van Ooijen, B., Bertoncini, J., Sansavini, A., & Mehler, J. (1997). Do weak syllables count for newborns? *Journal of the Acoustical Society of America*, *102*, 3735–3741.

Werker, J. F., & Tees, R. C. (1984). Cross-language speech perception: Evidence for perceptual reorganization during the first year of life. *Infant Behavior and Development*, *7*, 49–63.