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Lexical stress constrains English-learning infants' segmentation in a non-native language

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Lexical stress constrains English-learning infants' segmentation in a non-native language

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Running head: English infants segment Spanish words

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Research Highlights

- Monolingual English-learning infants successfully segment Spanish trochees.
- They also segment Spanish but not French iambs.
- Both Spanish and French are rhythmically different from English
- Thus, the unfamiliar rhythm of a non-native language does not block word segmentation.
- Infants can also segment words in a non-native language if stress is used lexically.

Abstract

Infants’ ability to segment words in fluent speech is affected by their language experience. In this study we investigated the conditions under which infants can segment words in a non-native language. Using the Head-turn Preference Procedure, we found that monolingual English-learning 8-month-olds’ can segment bisyllabic words in Spanish (trochees and iambs) but not French (iambs). Our results are incompatible with accounts that rely on distributional learning, language rhythm similarity, or target word prosodic shape alone. Instead, we show that monolingual English-learning infants are able to segment words in a non-native language as long as words have stress, as is the case in English. More specifically, we show that even in a rhythmically different non-native language, English-learning infants can find words by detecting stressed syllables and treating them as word onsets or offsets.

1. Introduction

The ability to find words from fluent speech is crucial for learning language. This is so because words are rarely produced in isolation, even in speech addressed to infants (Aslin, 1993; Brent & Siskind, 2001; van deWeijer, 1997). In this paper, we investigated infants' ability to find words in a non-native language, a critical first step in investigating the bases of bi/multilingual acquisition in infancy. This is particularly important given that there are more children growing up bilingual than monolingual (Associated Press, 2001; Grosjean, 2010), and infants' success at finding words has been found to be positively correlated with later language outcomes (Cristia, Seidl, Junge, Soderstrom, & Hagoort, 2014; Höhle, Pauen, Hesse, & Weissenborn, 2014; Newman, Row, & Ratner, 2015; Singh, Reznick, & Xuehua, 2012).

Previous cross-linguistic research shows that early in development, infants rely on statistical cues to find words (Goodsitt, Morgan, & Kuhl, 1993; Saffran, Aslin, & Newport, 1996; Pelucchi, Hay, & Saffran, 2009). One such statistical cue is the probability of co-occurrence of syllables. Young infants' sensitivity to syllable co-occurrence probabilities has been typically demonstrated in artificial language experiments (e.g. Saffran et al., 1996). A *distributional learning* account predicts successful segmentation by infants in any non-native language, given sufficient information about syllable co-occurrence probabilities.

With increasing age, infants' ability to find words in fluent speech is affected by their language experience (*English*: e.g., Bortfeld, Morgan, Golinkoff, & Rathbun, 2005; Jusczyk & Aslin, 1995; Polka & Sundara, 2012; *German:* Höhle & Weissenborn, 2003; *Dutch:* Houston, Jusczyk, Kuijpers, Coolen, & Cutler, 2000; *French:* Goyet, Nishibayashi, & Nazzi, 2013; Nishibayashi, Goyet, & Nazzi, 2014; Nazzi, Iakimova, Bertoncini, Frédonie, & Alcantara, 2006; Nazzi, Mersad, Sundara, Iakimova & Polka, 2014; Polka & Sundara, 2012; Shi, Marquis, Gauthier, Bamman, Magnitskaia, & Zaller, 2006; *Spanish & Catalan:* Bosch, Figueras, Teixidó, & Ramon-Casas, 2013). For instance, English-learning 8-month-olds segment two-syllable words with stress on the first syllable (trochees e.g., *hamlet* and *kingdom*) but not two-syllable words with stress on the second syllable (iambs, e.g., *guitar* and *beret;* Jusczyk, Houston, & Newsome, 1999). Analysis of conversational speech shows that 90% of content words in English begin with a stressed syllable (Cutler & Carter, 1987). Thus, English-learning infants segment words within the first year of life by treating stressed syllables as onsets (*Metrical Segmentation Strategy*, Cutler & Norris, 1988).

In addition to stress, infants also use other language-specific cues like the coarticulation between syllables (Johnson & Jusczyk, 2001), probability of sound sequences or phonotactics (Mattys, Jusczyk, Luce & Morgan, 1999) as well as the differences in the instantiation of consonants and vowels or allophonic variation (Jusczyk, Hohne, & Baumann, 1999).

Due to its strong bases in language experience, it has been proposed that word segmentation abilities of infants, like those of adults, cannot be transferred to all languages. One account predicts the success or failure of word segmentation in a non-native language based on differences in the rhythm of languages (e.g., Cutler, Mehler, Norris, & Segui, 1986, 1992; more recently Murty, Otake & Cutler, 2007). The *rhythm* hypothesis differs crucially from a *distributional learning* account in that it explicitly predicts that infants' ability to find words is likely facilitated in some but not all bi/multilingual contexts.

Over the last century, there have been several attempts to classify languages into one of three rhythm classes – stress-timed (e.g. English, German, Dutch), syllable-timed (e.g. Spanish, French, Italian) and mora-timed (e.g. Japanese, Kannada). Early rhythm classification was based on prosodic and phonological characteristics of languages (Abercrombie, 1967; Dauer, 1983; Pike, 1946), but more recent attempts have focused on the durational properties of vocalic and intervocalic segments (Delwo & Wagner, 2003; Ling, Grabe, & Nolan, 2000; Ramus, Nespor, & Mehler, 1999; White & Mattys, 2007).

Despite controversy as to how successfully (if at all) rhythm metrics capture cross-category distinctions in rhythm (Arvaniti, 2009; Grabe & Ling, 2002; Ramus et al., 1999; White & Mattys, 2007; Wiget et al., 2010), categorization into rhythm classes has proved useful to explain human performance on speech perception tasks. For instance, newborns are able to distinguish languages from different, but not the same rhythm class (Mehler et al., 1988; Nazzi, Bertoncini, & Mehler, 1998; Ramus, Hauser, Miller, Morris, & Mehler, 2000); and adults learning languages from different rhythm classes have been shown to rely on different units for word segmentation (for a review see Cutler, 2005). Given fundamental differences in the unit for word segmentation, word segmentation skills are likely transferable within- rather than between-rhythm classes.

According to Cutler et al.’s *rhythm hypothesis*, monolingual infants, like adults, should segment words in a rhythmically-similar, but not a rhythmically-different language. The extant research on cross-linguistic word segmentation is consistent with the *rhythm hypothesis*. Thus, monolingual English- and Dutch-learning 9-month-olds can segment two-syllable words in both languages (Houston et al., 2000), presumably because Dutch and English are rhythmically similar. Further, monolingual English- and French-learning 8-month-olds fail to segment two-syllable words in the other, rhythmically-different language (Polka & Sundara, 2012).

Although the rhythm hypothesis captures the ease of segmenting a non-native language, Dutch, these results also do not rule out a *distributional learning* account. In experiments on cross-language segmentation infants are typically tested using a natural language paradigm where they are familiarized for about 1 minute to words in either their native or a non-native language. It is conceivable that infants might well succeed in segmenting unfamiliar, non-native languages using distributional cues given longer familiarization times. Under this account, English-learning infants fail to segment French two-syllable words with short familiarization durations, because they are unfamiliar with the language; but they are likely to succeed with extended familiarization.

Experiments by Pelucchi and colleagues lend support to the idea that infants succeed in segmenting in a rhythmically-different, non-native language with longer familiarization times (Pelucchi, Hay, & Saffran, 2009a, 2009b). Using artificial language learning paradigms with an extended familiarization period of 2-3 minutes, Pelucchi et al. showed that English-learning 8-month-olds successfully segmented trochees in Italian.

Pelucchi et al.'s choice of Italian is intriguing in that despite Italian being classified as a syllable-timed language, like Spanish and French, the prosodic properties of Italian are quite similar to those of English (White, Payne, & Mattys, 2009). First, like in English, the duration of vowels in stressed and unstressed syllables in standard Italian varies systematically. Stressed vowels, particularly in open syllables, are longer than unstressed vowels, and this difference in duration is especially salient in the penultimate position (Bertinetto, 1980; D'Imperio & Rosenthal, 1999; van Santen & D'Imperio, 1999; Vayra, Avesani, & Fowler, 1984). In fact, these vowel duration differences serve as primary cues to stress perception in Italian adults (Bertinetto, 1980). Second, like in English, in some dialects of Italian, vowel quality, specifically vowel reduction, is an important component of stress realization (Vayra, Avesani, & Fowler, 1999; White et al., 2009). These two factors make the durational profile and acoustic instantiation of stress in Italian similar to that of English. Consequently, based on durational variation captured by rhythm metrics, Italian is intermediate between English, a stress-timed language, and Spanish, the prototypical example of a syllable-timed language (White et al., 2009).

To summarize, existing cross-language segmentation data from English-learning infants are somewhat consistent with both the *rhythm* hypothesis as well as a *distributional learning* account. If infants' word segmentation abilities transfer to rhythmically-similar but not rhythmically-dissimilar non-native languages, then we can account for English-learning infants' success in segmenting two-syllable words in Dutch, but not French. Infants' success in segmenting Italian bisyllabic words, albeit with a longer familiarization duration, might then be accounted for by the *rhythm hypothesis* because Italian is less similar rhythmically to English than Dutch, but more so than French.

Under a *distributional learning* account, English-learning infants successfully segment a non-native language Italian, with a longer familiarization phase, but not a non-native language French, with a shorter familiarization phase. What is problematic then is English-learning infants' success at segmenting Dutch, another non-native language, even with short familiarization duration.

These results are also consistent with a third, *Metrical Segmentation* account. The bisyllabic words used to test Dutch as well as Italian word segmentation were trochaic. In contrast, the bisyllabic words used to test French segmentation were, if anything, iambic. Thus, English-learning infants' attested difficulties in treating stressed syllables as word offsets (Jusczyk et al., 1999) alone could account for their failure in segmenting French, but not Dutch or Italian.

Finally, the extant research is consistent with a fourth, *lexical stress* account. Under this account, English-learning infants succeed in segmenting words only in languages where stress is used at the word level, as in English. This would account for their success in segmenting Dutch and Italian, but not French. French, unlike English, Dutch or Italian, does not use stress at the word level. Instead, in French, final syllables of words are stressed, but only if they are at the end of a phrase.

In Part I, we report results from four experiments to adjudicate whether the *rhythm* hypothesis, the *distributional learning* account, the *Metrical Segmentation* account, or the *lexical stress* account better explains infants' segmentation in a non-native language. For this we tested monolingual English 8-month-olds' ability to find bisyllabic words in two syllable-timed languages, French and Spanish. Although French bisyllabic words may be iambic — if they have any stress at all — Spanish has lexical stress and bisyllabic words can be either trochaic or iambic. We tested infants on both kinds of words in Spanish. We used a natural language paradigm and hypothesized as follows. If the *rhythm* hypothesis is correct, then English-learning 8-month-olds should fail to segment in both Spanish and French, regardless of the length of familiarization. If the *distributional learning* account is correct, then English-learning 8-month-olds were expected to segment in both French and Spanish with long, but not short familiarization durations. If the *Metrical Segmentation* account is correct, English-learning infants were expected to succeed in segmenting Spanish trochees, but not iambs in either Spanish or French. Finally, if the *lexical stress* account is correct, English-learning infants were expected to segment trochees and iambs in Spanish but not in French. Then, in Part II, experiments 5-7, we investigated the nature of English-learning infants' representation of newly segmented words in Spanish.

Part I

2. Experiment 1

Spanish, like French, is classified as a syllable-timed language (Ramus et al., 1999; White & Mattys, 2007). However, it differs from French in how stress is used at the word level. Unlike French, which is considered a fixed-stress language with stress on the final syllable of the phrase (Delattre, 1966), Spanish is a variable stress language with a rich diversity of stress patterns that are not aligned with word boundaries. In fact, all polysyllabic words in Spanish have one syllable with primary stress; and although typically penultimate, this syllable can be anywhere in the word (LEXESP database: Sebastián-Gallés, Martí, Carreiras, & Cuetos, 2000).

Among Spanish bisyllables, roughly 60% have stress on the initial syllable (Alcina & Blecua, 1975; Álvarez, Carreiras, & de Vega, 1992; Guerra, 1983; Quilis, 1981). In contrast, 90% of English content words start with a stressed syllable (Cutler & Carter, 1987). Additionally, Spanish stress assignment is sensitive to the structure of the syllable. Specifically, syllables ending in consonants attract stress — 95.3% CVC.CV words are trochees whereas only 7.1% of CV.CVC words are trochees (Hualde, 2005; see Pons & Bosch, 2010 for a detailed breakdown of syllable weight and stress assignment in Spanish bisyllabic words). Research shows that Spanish-learning 9-month-olds are sensitive to this link between stress assignment and syllable shape. They listen significantly longer to CVC.CV trochees compared to iambs; similarly for CV.CVC words, 9-month-olds listen significantly longer to iambs compared to trochees (Pons & Bosch, 2010).

Although developmental research suggests that English-learning 9-month-olds are not sensitive to syllable shape (Turk, Jusczyk, & Gerken, 1995), stress assignment in English is sensitive to syllable shape (Hayes, 1981; Ryan, 2011). Specifically, heavy syllables, that is, syllables that either contain a long, tense vowel, or are closed by a consonant that belongs to that syllable, are likely to be stressed. Thus, syllables ending in consonants attract stress in both English and Spanish. All stressed syllables in the target words used in this study were CVC because closed syllables attract stress in both English and Spanish. We also did this because in the future we are interested in investigating Spanish-learning infants' word segmentation abilities; and Spanish-learning infants have been shown to be sensitive to the relationship between syllable shape and stress.

Finally, stress is instantiated differently in Spanish and English. Stressed and unstressed syllables have largely similar vowel quality in

Spanish (Contreras, 1963; Navarro-Tomás, 1914, 1948; Ortega-Llebaria & Prieto, 2007, 2011; Quilis, 1971, 1981; Quilis & Esgueva, 1983), and differ primarily in duration, albeit with a much smaller magnitude than in English (Delattre, 1965; Ortega-Llebaria, & Prieto, 2011). In contrast, in English, although stressed and unstressed syllables differ supra-segmentally — in duration and intensity — they are primarily distinguished by vowel quality; unstressed syllables tend to have reduced vowels (Beckman & Edwards, 1994; Campbell & Beckman, 1997; Morrill, 2012; Patel, Niziolek, Reilly, & Guenther, 2012). Thus, stress in English is entirely predictable from vowel quality.

This mismatch in how stress is instantiated in English and Spanish hinders the perception of lexical stress in adult L2 learners of Spanish who have English as their first language. Specifically, English L2 learners of Spanish erroneously rely on vowel quality, viz. vowel reduction, instead of the subtle duration cues to stress in Spanish (Ortega-Llebaria, Gu, & Fan, 2013). It is possible that cross-linguistic differences in how stress is instantiated in the native versus non-native language also impairs English-learning infants' ability to detect Spanish stressed syllables, just like that of adult L2 learners. This would be another reason why English-learning infants may fail to segment words in Spanish.

In Experiment 1, we used the Headturn Preference Procedure to test segmentation of Spanish trochaic CVC.CV words by monolingual English-learning 8-month-olds. As previously mentioned, English and Spanish belong to different rhythm classes; however, bisyllabic words of the form CVC.CV are predominantly trochaic in both languages. As is typical in the natural language paradigm, we familiarized infants with two Spanish passages till they accumulated 45s of listening time to each passage, as in Jusczyk et al., (1999). During the test phase, infants were presented four isolated word lists, two containing previously familiarized words, and two containing novel words. If infants' ability to segment words in a non-native language is blocked by its unfamiliar rhythm, then we expected English-learning infants to fail to segment Spanish trochees.

2.1 Participants

Twenty monolingual English-learning infants (10 girls) between the ages of 7.7- and 9.5-months (*M* = 8.6) participated in the study. All infants were recruited from Los Angeles and its surrounding suburbs. None of the subjects had a history of speech, language, or hearing difficulties, nor did they have a cold or ear infection on the day of testing. Based on parental reports of language use by caregivers in contact with the infant (see Bosch, & Sebastián-Gallés, 2001; Sundara & Scuterallo, 2011), only infants with at least 90% English input were included in the final sample (mean exposure to English = 99%, range = 95-100). Eight additional infants were tested but their data was excluded because they failed to complete testing due to fussiness.

Table 1. Spanish passages with CVC.CV target words
Gancho passage Ese **gancho** le rasgó la camiseta. Se necesita un **gancho** para pescar. Mi madre colgó el abrigo en el **gancho**. El ladrón le hirió con el **gancho**. Hay un **gancho** detrás de la puerta. El **gancho** sobresalía de la pared.
Salsa passage Esa **salsa** era muy picante. Me encanta la **salsa** de mi abuela. Se ensució la ropa con una **salsa**. No es tan difícil escoger una **salsa**. Busca la **salsa** para la pasta. La **salsa** bechamel es mi favorita.
Gesto passage Un **gesto** bonito siempre gusta. No me gustó el **gesto** que me hizo. Le dije que viniera con un **gesto**. Cuando lo echó le hizo este **gesto**. Juan le hizo un **gesto** de aprobación. El **gesto** de Mona Lisa es un misterio.
Venda passage La **venda** le tapaba la rodilla. Quítate ya la **venda** de los ojos. Se cubrió la herida con esa **venda**. La enfermera le puso una **venda**. Llevaba una **venda** en la mano. La **venda** le apretaba demasiado.

2.2 Stimuli

A 26-year-old female native speaker of Mexican Spanish recorded the stimuli. She was born and raised in Mexico and moved to the United States at the age of 19. At the time of recording, she had spent 7 years in Los Angeles and reported using Spanish on a daily basis. She recorded four passages each featuring a trochaic CVC.CV target word. All target words were selected to be phonotactically legal in both languages. The target words were: “gancho” hook ['gan.tʃo], “salsa” sauce ['sal.sa], “gesto” gesture ['hes.to], and “venda” bandage ['ben.da]. Each passage consisted of six sentences with the target word occurring once per sentence, twice at the beginning, twice in the middle, and twice at the end. The passages are presented in Table 1. The speaker was also asked to produce 20-25 repetitions of each bisyllabic word. Passages and words were produced in infant-directed speech. The stimuli were recorded in a soundproof booth using a Shure SM10A head-mounted microphone (sampling frequency 22050Hz; 16-bit quantization).

To characterize the acoustic properties of the Spanish stimuli we segmented the two syllables of each target word in the passages as well in the lists. Subsequently, duration, average fundamental frequency (f0) and average intensity measurements were obtained for each syllable using PRAAT (Boersma & Weenink, 2013). These measures are presented in Table 2. Overall, duration was the only reliable cue to distinguish the first and second syllable of the Spanish target words embedded in both passages and lists; as expected, the first syllable was longer than the second. In lists, the first syllable of the Spanish target words was also higher in pitch and louder than the second. Paired *t*-tests with Bonferroni’s correction (0.05/3 = 0.02) confirmed this (Table 2).

Table 2. Acoustic characteristics of the two syllables of the trochaic words from Spanish passages and lists, the standard deviations are reported in parentheses.

Measures	S1	S2	Statistical comparison
Passage words			
Duration (ms)	300 (43)	220 (65)	$t(23) = 4$, $p < 0.001$*, $d = 1.45$
Average f0 (Hz)	240 (55)	235 (62)	$t(23) = 0.3$, $p = 0.8$, $d = 0.09$
Average Intensity (dB)	71.9 (3.2)	69.7 (5.3)	$t(23) = 2.1$, $p = 0.04$, $d = 0.5$
List words			
Duration (ms)	343 (52)	267 (57)	$t(55) = 7.9$, $p < 0.001$*, $d = 1.39$
Average f0 (Hz)	269 (80)	216 (45)	$t(55) = 3.6$, $p < 0.001$*, $d = 0.82$
Average Intensity (dB)	75.6 (2.9)	72.5 (2.5)	$t(55) = 7.2$, $p < 0.001$*, $d = 1.15$

To characterize the stimuli, we also calculated the backward and forward transitional probabilities (Pelucchi et al., 2009b) for each of the target words in the passages. There are multiple ways to calculate transitional probabilities – over syllables, words, or morphemes. It seems unlikely that English-learning infants know, for example, that Spanish *un* and *una* are the same morpheme. Thus, we report transitional probabilities calculated over syllables. The transitional probability information for Spanish passages and French passages used in this paper are summarized in Table 3.

We have also included the same measures for Jusczyk et al.’s (1999) English passages, and Pelucchi et al.’s (2009a) Italian passages for ease of comparison..

Backward TP, the likelihood of syllable X preceding Y, was calculated over the full target word (i.e., how often [gan.tʃo] is preceded by syllable X), the first syllable (i.e., how often [gan] is preceded by syllable X), and the second syllable (i.e., how often [tʃo] is preceded by syllable X). Forward TP, the likelihood of syllable Y following X, was also calculated over the full target word (i.e., how often [gan.tʃo] is followed by syllable Y), the second syllable (i.e., how often [tʃo] is followed by syllable Y), and the first syllable (i.e., how often [gan] is followed by syllable Y). Notice that a lower transitional probability arises as a result of greater variation in the syllables adjacent to the target. Thus, lower transitional probabilities across the target word along with higher transitional probabilities within the contiguous syllables that form a target word provide the strongest cues to word boundaries.

Table 3. Transitional probabilities for the Spanish, French, English, and Italian passages.

Target words used in the passages	Backward TP			Forward TP		
	Across Target Word		Within Target Word	Across Target Word		Within Target Word
	Full word	First Syllable	Second Syllable	Full Word	Second Syllable	First Syllable
Spanish	0.33	0.33	0.63	0.18	0.16	1.00

trochees	(0.17)	(0.17)	(0.38)	(0.04)	(0.03)	
Spanish iambs	0.29	0.25	1.00	0.18 (0.04)	0.18 (0.04)	0.75 (0.25)
French iambs	0.17	0.16	1.00	0.18 (0.04)	0.18 (0.04)	0.79 (0.21)
English iambs (Jusczyk et al., 1999)	0.17	0.17	1.00	0.23 (0.11)	0.23 (0.11)	1.00
Italian trochees (Pelucci et al., 2009a)	0.17	0.17	1.00	0.17	0.17	1.00

In the passages, the Spanish trochaic targets were preceded by one of 3 different syllables; and they were followed by one of 5 or 6 different syllables. We will compare these transitional probabilities for stimuli used in subsequent experiments.

2.3 Procedure

The version of the Headturn Preference Procedure (HPP; Kemler-Nelson et al., 1995) described in Jusczyk & Aslin (1995) was used to assess word segmentation abilities. Infants sat on their caregiver’s lap in the center of a three-sided pegboard booth. The two side panels had a red light at eye level and a loudspeaker mounted behind it. The center panel had a blue light mounted at the same level. Above the center light, a 10×10cm cut-out accommodated a SONY digital video camera was used to record each test session. At the beginning of each trial, the blue light on the center panel flashed, attracting the infant’s gaze. Once the infant oriented towards the center panel, one of the red lights on the side panels began to flash. When the infant turned and looked towards the red light, the auditory stimulus began to play. The stimulus presentation continued until the infant looked away from the flashing light for more than two consecutive seconds or at the end of the trial (max duration = 17s). The experimenter was seated outside the pegboard booth and looked at the live feed on a computer screen connected to the video camera. She recorded the direction and duration of the infant’s head turns which determined stimulus presentation. Both the caregiver and experimenter wore noise-cancelling headphones and listened to music with lyrics to eliminate potential biases. Testing lasted approximately 5-7 min.

2.4 Design

Each experimental session began with a familiarization phase in which infants heard repetitions of two of the passages: “gancho” and “salsa” or “gesto” and “venda”. Familiarization continued until the infant had accumulated at least 45 seconds of listening time to each passage. The stimuli continued to alternate randomly until the criterion was met for both passages. The test phase began immediately after and consisted of all four word lists. The four lists were presented in three blocks for a total of 12 test trials. The order of presentation of the target word lists was randomized in each block. Listening time to familiar and novel target word lists were averaged separately and compared statistically.

2.5 Analysis

Listening time data were analyzed using linear mixed effects models in R using *lme4*. All models included a random intercept for subject, to allow for differences in baseline listening times. This is the maximal level random effects structure justified by our design. Fixed effects were evaluated using the anova() function, F-values greater than 2 are reported as significant.

2.6 Results & Discussion

Using t-tests, we first confirmed that the infants tested on the two familiarization conditions (*gancho/salsa* vs. *gesto/venda*) were comparable on total familiarization time, $t(18) = -2.02$, $p = 0.06$. Figure 1 shows the mean looking time to the familiar ($M = 7.2$s; $SD = 2.0$) and novel word lists ($M = 7.8$s; $SD = 2.9$) in the test phase. Out of the 20 infants tested, 7 listened longer to the familiar words compared to the novel words.

Listening time data from the test phase were analyzed using a linear mixed effects model with Listening Time as the dependent variable, Trial Type (familiar, novel) as the within-subjects variable and Condition (*gancho/salsa*, *gesto/venda*) as the between-subjects variable. Main effects and interactions were included as fixed effects in the model. Neither the main effect of Trial Type ($F = 1.6$) or Condition ($F = 0.3$), nor their interaction

(F = 0.6) was significant. Thus, English-learning infants were not successful at segmenting bisyllabic trochees in Spanish, a language that is rhythmically different from English, at least given a short familiarization phase. In Experiment 2, we familiarized English-learning infants to Spanish for a longer duration during familiarization.

3. Experiment 2: Spanish trochaic words

In Experiment 2 we extended the familiarization time for English-learning infants from 45s to 60s to confirm that the unfamiliar rhythm of Spanish blocked word segmentation. We were inspired to do so based on Pelucchi and colleagues' (Pelucchi, Hay, & Saffran, 2009a, 2009b; see also Bijeljac-Babic, Serres, Höhle, & Nazzi, 2012 for another demonstration of the effects of extended familiarization times).

If non-native rhythm blocks word segmentation in 8-month-old English-learning infants, we expected infants to fail in Experiment 2 as well. However, if English-learning infants use distributional learning, stress-based segmentation, or are always able to segment trochees — but need a longer familiarization period with non-native languages — they were expected to successfully segment Spanish trochees given an extended familiarization phase.

3.1 Participants

Twenty monolingual English-learning infants (8 girls) between the ages of 7.7 and 9.6 months (*M* = 8.3) participated in the study. Recruitment and subject inclusion criteria were the same as in Experiment 1 (mean exposure to English = 99%, range = 95-100). Seven additional infants were tested but their data excluded because they failed to complete testing due to fussiness (n = 6) or caretaker intervention (n = 1).

3.2 Stimuli

We used the same stimuli as in Experiment 1.

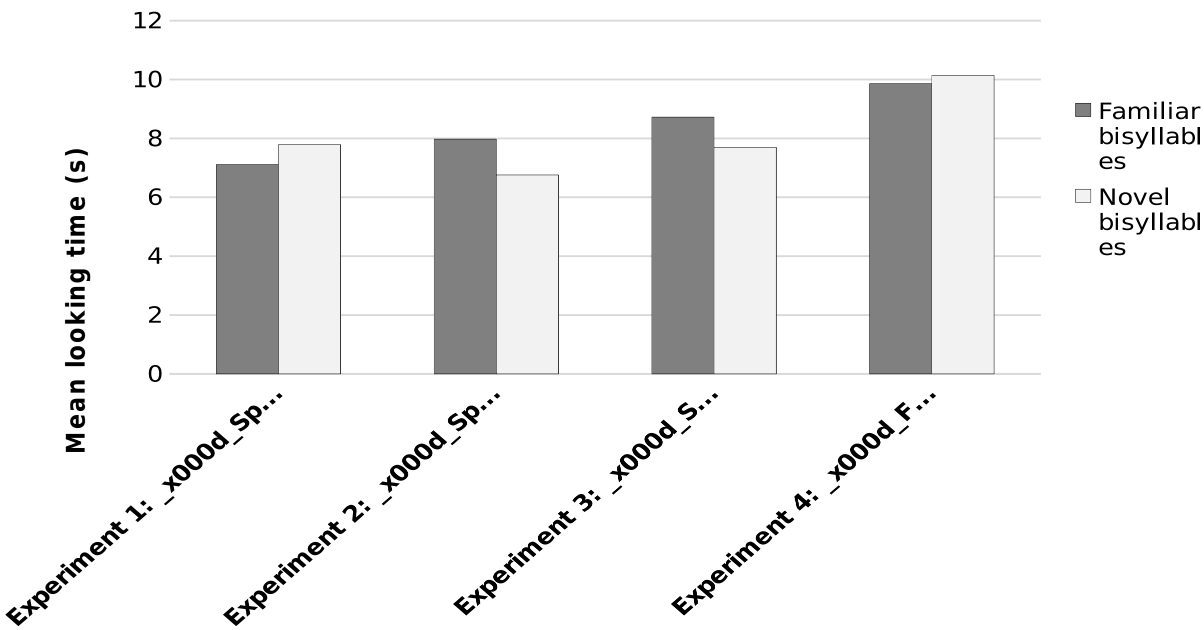
3.3 Procedure

We used the same procedure as in Experiment 1, except that the familiarization phase was extended from 45 to 60 seconds.

3.4 Results & Discussion

Again, using *t*-tests we confirmed that infants tested on the two familiarization conditions (*gancho/salsa* vs. *gesto/venda*) were comparable on total familiarization time, $t(18) = -0.26$, $p = 0.8$. Figure 1 shows the mean looking time to the familiar (*M* = 8.0s; *SD* = 2.6) and novel word lists (*M* = 6.8s; *SD* = 2.3) in the test phase of Experiment 2. Out of the 20 infants tested, 15 listened longer to the familiar words compared to the novel words.

In an lme model with Listening Time as the dependent variable, and Trial Type (familiar, novel) as a within-subjects variable, Condition (*gancho/salsa*, *gesto/venda*) as the between-subjects variable, and its interaction as the fixed effects, only the main effect of Trial Type was significant, (F = 7.95). The main effect of Condition was marginally significant, F = 1.99, whereas the interaction of Trial Type and Condition was not, F = 1.3. Thus, English-learning 8-month-olds listened significantly longer to familiar compared to novel Spanish trochaic word lists, demonstrating successful segmentation.



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igure 1. Monolingual English-learning 8-month-olds' mean listening time (+/- *SE*) to the familiar and the novel Spanish and French bisyllabic words.

To further confirm that the increase in familiarization time resulted in successful segmentation, we compared Experiment 1 and 2 using another lme model with Listening Time as the dependent variable, Trial Type (familiar, novel) and Condition (*gancho/salsa*, *gesto/venda*) and Familiarization Time (45s, 60s) and their interactions as fixed effects. As expected, only the interaction of Trial Type and Familiarization Time was significant, (F = 7.7). These results indicate that English-learning infants were successful in segmenting Spanish trochees given a familiarization time of 60s but not 45s. Thus, even though English and Spanish belong to different rhythm classes, English-learning infants successfully segmented trochaic words in Spanish.

4. Experiment 3: Spanish iambic words

Results from Experiment 2 provide evidence against the *rhythm hypothesis*. English-learning infants successfully segmented trochees in Spanish, a rhythmically different language. However, English-learning infants' success at segmenting Spanish trochees does not automatically indicate that English-learning infants treat stressed syllables as onsets of words in Spanish (the *Metrical Segmentation* account). Instead, it is possible that English-learning infants were using the co-occurrence probabilities of syllables to segment Spanish trochees (the *distributional learning* account).

If indeed English-learning infants were using co-occurrence probabilities of syllables to segment Spanish trochees, they should also successfully segment Spanish iambs given comparable syllable co-occurrence probabilities. To test this, in Experiment 3, we familiarized English-learning infants with iambic target words embedded in Spanish passages, and tested them on isolated iambs. If infants use syllable co-occurrence probabilities in Spanish to segment words, they should successfully segment Spanish iambs as well. However, if English-learning infants used stressed syllables as word onsets, they should fail to segment iambs in Spanish. Because we are interested in future research on Spanish-learning infants, all iambs were of the shape CV.CVC.

4.1 Participants

Twenty monolingual English-learning infants (6 girls) between the ages of 7.9 and 9.1 months (M = 8.3) participated in the study. Recruitment and subject inclusion criteria were the same as in Experiments 1 and 2 (mean exposure to English = 99%, range = 98-100). Five additional infants were tested but their data was excluded because they failed to complete testing due to fussiness.

4.2 Stimuli

The same female talker who recorded the stimuli for Experiments 1 and 2, recorded the stimuli for this experiment. She recorded four passages each featuring an iambic CV.CVC target word. All target words were selected to be phonotactically legal in both languages. The target words were: “botín” loot [bo'tin], “dedal” thimble [de'dal], “corral” corral [ko'ral], and “tifón” typhoon [ti'fon]. As in Experiments 1 and 2, each passage had six sentences with the target word occurring once per sentence, twice at the beginning, twice in the middle, and twice at the end (Table 4). The speaker was also asked to produce 20-25 repetitions of each bisyllabic word. Passages and words were produced in infant-directed speech. The recording set-up was identical to that for Experiment 1.

Table 4. Spanish passages with CV.CVC target words

Botín passage
Ese **botín** fue devuelto tras diez días. Donde hay un **botín** hay un pirata. El ladrón no pudo vender el **botín**. La policía encontró este **botín**. Descubrieron el **botín** en su ataúd. Un **botín** no es siempre dinero.
Dedal passage
Este **dedal** era de mi abuela. Te prestaré un **dedal** para coserlo. Sólo necesitas un hilo y un **dedal**. No sabemos quién inventó el **dedal**. Me compré este **dedal** hace dos años. El **dedal** evita que me pinche.
Corral passage
Un **corral** con gallinas es ruidoso. El toro de este **corral** es famoso. Metieron a la vaca en el **corral**. Encontramos al potro en este **corral**. Su casa era un **corral** de comedias. El **corral** de los cerdos está sucio.
Tifón passage
Ese **tifón** arruinó a los comercios. El ojo del **tifón** pasó por aquí. La tormenta no llegó a ser un **tifón.** La costa fue devastada por el **tifón**. Juan vio ese **tifón** por la ventana. Un **tifón** dejó cientos de

heridos.

To characterize the acoustic properties of the Spanish stimuli we segmented the two syllables of each target word in the passages as well in the lists. Subsequently, duration, average fundamental frequency (f0) and average intensity measurements were obtained for each syllable using PRAAT (Boersma & Weenink, 2013). These measures are presented in Table 5. Consistent with published results, duration was again the only reliable cue to distinguish the first and second syllable of the Spanish target words embedded in the passages and the lists; as expected, the second stressed syllable was longer than the first. The two syllables in the lists also differed in intensity, with the first being louder than the second. Paired *t*-tests with Bonferroni's correction (0.05/3 = 0.02) confirmed this.

Table 5. Acoustic characteristics of the Spanish passages and lists for the iambic words, the standard deviations are reported in parentheses.

Measures	S1	S2	Statistical comparison
Passage words			
Duration (ms)	148 (31)	318 (59)	$t(23) = -12.38$, $p < 0.001$*, $d = 3.56$
Average f0 (Hz)	253 (79)	218 (42)	$t(23) = 2.33$, $p = 0.03$, $d = 0.56$
Average Intensity (dB)	72 (4.9)	71 (4.3)	$t(23) = 0.71$, $p = 0.49$, $d = 0.17$
List words			
Duration (ms)	137 (20)	389 (48)	$t(55) = -34.07$, $p < 0.001$*, $d = 6.84$

Average f0 (Hz)	241 (50)	243 (50)	$t(55) = -0.24$, $p = 0.81$, $d = -0.03$
Average Intensity (dB)	76 (3.3)	74 (3)	$t(55) = 3.04$, $p < 0.01$*, $d = 0.44$

We also compared the probability of co-occurrence of syllables preceding and following the Spanish trochaic target words used in Experiment 2 with that of the Spanish iambic target words used in Experiment 3. As indicated in Table 3 (and as can be seen from Tables 1 and 4), target trochaic words were preceded by one of 3 different syllables, whereas target iambic words were preceded by one of 4 different syllables. Both target Spanish trochaic and iambic words were followed by one of 5 or 6 different syllables. The lower backward transitional probabilities for some of the iambic targets indicate that iambic target words in Experiment 3 should be easier to segment than the trochaic target words in Experiments 1 and 2.

4.3 Procedure

We used the same procedure as in Experiment 2, that is, with a familiarization time of 60s.

4.4 Results & Discussion

Again, we confirmed that infants in the two familiarization conditions (*botín/dedal* vs. *corral/tifón*) were comparable on total familiarization times, *t*(18) = -0.76, *p* = 0.46. Figure 1 shows the mean looking time for the familiar (*M* = 8.73s; SD = 2.92) and novel word lists (*M* = 7.69s; SD = 2.76) in the test phase of Experiment 3. Out of the 20 infants tested, 10 listened longer to the familiar words compared to the novel words.

Listening time data from the test phase was analyzed using an lme model with Listening Time as the dependent variable, Trial Type (familiar, novel) as the within-subjects variable and Condition (*botín/dedal*, *corral/tifón*) as the between-subjects variable; and a random intercept for subject. The main effects of Trial Type (*F* = 2.7) as well as Condition (*F* = 3.7) were significant, but their interaction was not (*F* = 0.61).

Consistent with the idea that infants are using syllable co-occurrence patterns to segment both trochees and iambs in Spanish, in another lme model including data from Experiment 2 and 3, with Trial Type (familiar, novel) and Target Type (trochee, iamb) and their interaction as fixed effects, only the main effect of Trial Type was significant (*F* = 8.8). As expected from the results above, there was no significant interaction with Target Type (*F* = 0.06). Infants success at segmenting Spanish iambs is consistent with a *distributional learning* account, but not with a *Metrical Segmentation* account, under which English-learning infants should only segment trochees.

5. Experiment 4: French iambic words

If English-learning infants rely only on syllable co-occurrence patterns to segment Spanish trochees and iambs, they should succeed in segmenting

French iambs as well. However, if English-learning infants are only able to segment bisyllabic words in a language that has lexical stress, they should fail to segment French iambs.

5.1 Participants

Twenty monolingual English-learning infants (8 girls) between the ages of 7.5 and 9.6 months (M = 8.7) participated in the study. Recruitment and subject inclusion criteria were the same as in previous experiments (mean exposure to English = 99%, range = 90-100). Two additional infants were tested but their data was excluded because they failed to complete testing due to fussiness.

5.2 Stimuli

The stimuli used were the same as those used in Polka and Sundara (2011). They were recorded by a native speaker of Canadian French. The passages featured the following iambic words: “beret” hat [bə.ˈʁɛ], “surprise” surprise [syʁ.ˈpʁiz], “devis” device [də.ˈvi], and “guitare” guitar [gi.ˈtaʁ]. Each passage consisted of six sentences with the target word occurring once per sentence, twice at the beginning, twice in the middle, and twice at the end. The speaker was also asked to produce 20-30 repetitions of each bisyllabic word. Passages and words were produced in infant-directed speech. The passages are provided in Table 6, and the acoustic properties of the passages and the lists can be found in Polka and Sundara (2011, pp. 9-

10). As in the case of the Spanish target words, duration was the only reliable cue to distinguish the first and second syllable of the French words embedded in the passages; as expected, the second syllable was significantly longer than the first.

Table 6. French passages with target words
Guitare passage
Elle a sorti ses belles **guitares**. Trois **guitares** ne seraient pas assez. Il faut d’autres **guitares** pour la fête. Ne faites pas trop attention aux **guitares**. On voit plusieurs **guitares** avant de choisir. Les **guitares** ne sont pas accordées.
Devis passage
Les **devis** reçus sont raisonnables. Elle a d’autres **devis** à envoyer. On doit faire confiance aux **devis**. Il y a trois **devis** posés sur la table. Voilà de bien beaux **devis**. Plusieurs **devis** sont falsifiés.
Beret passage
La mode est aux **bérets** et autres chapeaux. Plusieurs **bérets** sont encore en vente. Ces jolis **bérets** sont à ma soeur. Elle a besoin de trois **bérets**. Il faut mettre les **bérets** sur la table. On va apporter d’autres **bérets**.
Surprise passage
Voici de belles **surprises** pour vous. Il a voulu faire plusieurs **surprises**. D’autres **surprises** risquent encore de se produire. Les **surprises** sont faciles à éviter. Mieux vaut deux que trois **surprises**. Il s’attend aux **surprises** à venir.

As indicated in Table 3, the French iambic targets were preceded by one of 6 different syllables; and they were followed by one of 5 or 6 different syllables. Thus, the transitional probability in passages provided a stronger cue to word boundary for French iambs than for Spanish iambs as well as Spanish trochees used in Experiments 1-3.

5.3 Procedure

Unlike in Polka & Sundara (2011), the familiarization time was extended to 60s (from 45s) like in Experiment 2.

5.4 Results & Discussion

First, we confirmed that infants in the two familiarization conditions (*beret/guitar* vs. *devis/surprise*) were comparable on total familiarization times, $t(18) = -0.76$, $p = 0.09$. Figure 1 shows the mean looking time for the familiar ($M = 9.86$s; SD = 2.19) and novel word lists ($M = 10.14$s; SD = 2.26) in the test phase of Experiment 4. Out of the 20 infants tested, 11 listened longer to the familiar words compared to the novel words.

Listening time data from the test phase was analyzed using an lme model with Listening Time as the dependent variable, Trial Type (familiar, novel) as the within-subjects variable and Condition (*beret/guitar*, *devis/surprise*) as the between-subjects variable; and a random intercept for subject. Only the main effect of Condition was significant ($F = 3.2$); neither the main effect of Trial Type ($F = 0.3$), nor its interaction with Condition was significant ($F = 0.005$). Thus, there was no evidence that English-learning 8-month-olds were able to segment French iambs, despite stronger transitional probability cues to word boundary, even with an extended familiarization period.

In fact, in another lme model comparing infants' performance on Spanish and French iambs, with Trial Type (familiar, novel) and Language (Spanish, French) and their interaction as fixed effects, the interaction of Language and Trial Type was significant ($F = 2.53$), confirming that English-learning infants behaved differently when tested on iambs in the two languages. Additionally, as shown in Figure 1, the main effect of Language was also significant ($F = 6.8$); overall, infants listened longer to French compared to Spanish iambs. These results are inconsistent with a *distributional learning* account – which, based on the transitional probabilities summarized in Table 3 should favor the segmentation of French iambs. Instead, the results are in line with a *lexical stress* account, which predicts English-learning infants' success in segmenting words in languages that share the lexical stress property of English.

6.0 Interim Discussion Part I

In Experiments 1-4 we tested whether English-learning infants' segmentation of bisyllabic words in a non-native language can be explained by one of four hypotheses – the *rhythm* hypothesis, the *distributional learning* account, the *Metrical Segmentation* account, or the *lexical stress* account. Our results show that English-learning 8-month-olds segment bisyllabic words, both trochees and iambs in Spanish, a syllable-timed language, with a long familiarization phase. However, they failed to segment iambs in French, another syllable-timed language, even with a long familiarization phase.

These results are problematic for three of the four hypotheses. English-learning infants' failure at segmenting French bisyllabic words is consistent with the *rhythm* hypothesis, but their success in segmenting Spanish bisyllabic words is not. Consistent with the *distributional learning* account, English-learning 8-month-olds succeeded in segmenting Spanish bisyllabic words with a long familiarization duration. However, these infants failed to segment French but not Spanish iambs, despite stronger transitional probability cues to word boundary in French compared to Spanish. And finally, consistent with the *Metrical Segmentation* account, English-learning infants segmented Spanish trochees. However, they also segmented Spanish iambs.

Only the *lexical stress* account is consistent with all the results. English-learning infants' successfully segmented in Spanish, another language that has lexical stress, but not in French, a language that does not have lexical stress. Based on these results, we might also expect that English-learning 8-month-olds will segment English iambs as well given a longer familiarization duration. We have since confirmed this (see Supplementary Material for results from this experiment).

Part II

In the second part of the paper, we investigated the nature of representation of newly segmented Spanish words by English-learning infants. To do so, we familiarized infants with passages containing Spanish trochees or iambs for 60 seconds each, as in Part I. Then, we presented them with word lists containing just the stressed or the unstressed syllable of the target words. By evaluating infants' preference for the stressed (or unstressed) syllable of the familiarized target word, we were able to probe English-learning infants' representation of newly segmented words.

7. Experiment 5: Stressed syllables

Previous research has shown that when familiarized with English trochees for 45s, English-learning 8-month-olds segment the entire word, not the stressed syllable (Jusczyk et al., 1999; see also Kooijman, Junge, Johnson, Hagoort, & Cutler, 2013; Männel & Friederici, 2013). In Experiment 5, we familiarized infants with Spanish passages containing target trochees, and tested them on lists with only the stressed syllables. We also tested the possibility that when familiarized with Spanish iambs, monolingual English-learning 8-month-olds segment just the stressed syllable. This is exactly what English-learning 8-month-olds familiarized with English iambs for 45s do (Jusczyk et al., 1999).

If English-learning 8-month-olds simply segment the stressed syllable in Spanish, we expected them to listen longer to the familiar stressed syllable compared to the novel ones. In fact, in this experiment, a familiarity preference for just the stressed syllable when presented with Spanish trochees (or iambs) would call into question the results from Experiment 2 and 3. Specifically, a familiarity preference for the stressed syllable alone could then explain English-learning 8-month-olds' preference for familiar trochees in Experiment 2 and familiar iambs in Experiment 3.

7.1 Participants

Eighteen monolingual English-learning infants (7 girls) between the ages of 7.4 and 9.7 months (*M* = 8.4) were familiarized with trochaic targets and another 24 (11 girls) between the ages of 7.4 and 9.6 months (*M* = 8.5) were familiarized with iambic targets. Fifteen additional infants were tested but their data was excluded because they failed to complete testing due to fussiness (n = 12), had exposure to a different dialect of English (n = 1), had less than 90% exposure to English (n=1), or had a listening time difference greater than 2*SD* away from the group mean (n=1). Recruitment and subject inclusion criteria were the same as in Experiments 1-3 (mean exposure to English = 99.1%, range = 92-100).

7.2 Stimuli

The passages with the trochaic target words were the same as those used in Experiment 1 and 2, and the ones for the iambic target words were the same as those used in Experiment 3. In the test phase, instead of bisyllabic words, infants were presented with just the stressed syllable of each of the four target words, namely “gan” from “gancho”, “sal” from “salsa”, “ges” from “gesto” and “ven” from “venda” in the trochaic condition; similarly “tín” from “botín”, “dal” from “dedal”, “rral” from “corral” and “fon” from “tifón” in the iambic condition. The strong syllables were edited in PRAAT (Boersma & Weenink, 2013) at zero crossings from the target words produced in isolation for Experiments 1-3.

7.3 Procedure

We used the same procedure as in Experiment 2, with the four word lists substituted by the isolated stressed syllables.

7.4 Results & Discussion

Using *t*-tests we again confirmed that infants in the two familiarization conditions for the trochaic condition (*gancho/salsa* vs. *gesto/venda*) were comparable on total familiarization times, $t(16) = 0.38$, $p = 0.71$. Figure 2 shows the mean looking time for the familiar ($M = 6.7$s; $SD = 2.2$) and novel word lists ($M = 7.7$s; $SD = 2.7$) in the test phase of Experiment 5. Out of the 18 infants tested, 14 listened longer to the novel syllables compared to the familiar syllables.

Listening Time in the test phase was analyzed using an lme model with Trial Type (familiar, novel) and Condition (*gancho/salsa*, *gesto/venda*) and their interaction as the fixed effects. Only the effect of Trial Type was significant (F = 6.63), not Condition (F = 0.54) or Condition × Trial Type (F = 0.7). However, in contrast to Experiment 2, English-learning 8-month-olds listened significantly longer to novel stressed syllables when compared to familiar Spanish stressed syllables.

Next, we compared Experiment 2 and 4 using another lme model with Trial Type (familiar, novel), Condition (*gancho.salsa, gesto.venda*) and Target Type (bisyllable, stressed syllable) and their interactions as fixed effects. The interaction of Trial Type and Target Type was significant (F = 14.4). These results indicate that English-learning 8-month-olds behaved differently while presented with Spanish trochees (Experiment 2) or Spanish stressed syllables alone (Experiment 5) in the test phase; infants listened longer to familiar trochees, whereas they listened longer to the novel stressed syllables. Thus, monolingual English-learning 8-month-olds success in segmenting Spanish trochees in Experiment 2 cannot be attributed to a match just in the stressed syllable.

Next, we ran parallel analysis for infants tested in the iambic condition. First, using t-tests we confirmed that infants in the two familiarization conditions (*botín/dedal vs. corral/tifón*) were comparable on total familiarization times, $t(22)$ = 2.07, p = 0.39. Figure 2 shows the mean looking time for the familiar (M = 7.9s; SD = 2.04) and novel word lists (M = 8.8s; SD = 1.83) in the test phase of Experiment 5. Out of the 24 infants tested, 18 listened longer to the novel syllables compared to the familiar syllables. Again, in an lme model with Trial Type (familiar, novel) and

Condition (*botín/dedal, corral/tifón*) and their interaction as fixed effects, only the main effect of Trial Type was significant (*F* = 4.97), but not Condition (*F* = 0.77) or the interaction of Trial Type and Condition (*F* = 0.12). Just like in the trochaic condition, English-learning 8-month-olds listened significantly longer to novel stressed syllables when compared to familiar Spanish stressed syllables.

We also compared the results of Experiment 3 and Experiment 5 in an lme model with Listening Time as the dependent variable, Trial Type (familiar, novel), Condition (*botín*/*dedal*, *corral*/*tifón*) and Target Type (bisyllable, stressed syllable) and their interactions as fixed effects. The interaction of Trial Type and Target Type was significant (*F* = 7.18). These results indicate that English-learning 8-month-olds behaved differently while presented with Spanish iambs (Experiment 3) or just the stressed syllable offset (Experiment 5) during the test phase. Infants listened significantly longer to familiar Spanish iambs; in contrast, they listened significantly longer to the novel stressed offset syllables. Thus, again, infants' success at segmenting Spanish iambs cannot be attributed to a match just in the stressed syllable.

Instead, given that infants presented with the bisyllabic sequence (Experiments 2 & 3) or just the stressed syllable (Experiment 5) in the test phase were of a comparable age and had similar amounts of exposure to the familiarization passages, the switch in the direction of preference suggests that English-learning infants encoded the stressed syllable in the newly segmented Spanish trochees and iambs in greater detail than the bisyllabic sequence. In the infant preference literature, familiarity preferences emerge when infants begin to encode a stimulus to construct an initial representation; a shift in preference towards novel stimuli is observed when representations become more robust (Roder, Bushnell, & Sasseville, 2000; Solokov, 1963).

In sum, in Experiments 2, 3 and 5, when familiarized with bisyllabic sequences, English-learning infants segmented the whole sequence, but simultaneously represented a portion of these words — the stressed syllable, in more detail.

8. Experiment 6: Unstressed syllables

In Experiment 5 we saw that English-learning infants encoded Spanish stressed syllables in bisyllabic sequences in great detail whether they were onsets of trochees or offsets of iambs. In Experiment 6, we again familiarized English-learning 8-month-olds with Spanish bisyllabic sequences, but this time we tested them on lists with only the unstressed syllables.

8.1 Participants

Twenty monolingual English-learning infants (12 girls) between the ages of 7.5 and 9.7 months (M = 8.6) participated in the trochee unstressed syllable experiment, and twenty monolingual English-learning infants (7 girls) between the ages of 7.6 and 9.5 months (M = 8.32) participated in the iamb unstressed syllable experiment. Seven additional infants were tested but their data was excluded because they failed to complete testing due to fussiness (n = 3), or having less than 90% of exposure to English (n = 3). Recruitment and subject inclusion criteria were the same as in Experiments 1-4 (mean exposure to English = 99.6%, range = 94-100).

8.2 Stimuli

The passages for the Spanish trochaic targets were the same as those used in Experiments 1 and 2, and the ones for the Spanish iambic targets were the same as those used for Experiment 3. In the test phase, instead of listening to the target words, infants were presented with just the unstressed syllable of each of the four target words, namely “cho” from “gancho”, “sa” from “salsa”, “to” from “gesto” and “da” from “venda” in the Spanish trochaic condition; and similarly “bo” from “botín”, “de” from “dedal”, “co” from “corral” and “ti” from “tifón” in the Spanish iambic condition. The weak syllables were edited in PRAAT (Boersma & Weenink, 2013) at zero crossings from the target words produced in isolation for Experiments 1-3.

8.3 Procedure

We used the same procedure as in Experiment 4, with the four strong syllable lists substituted by 4 lists of weak syllables.

8.4 Results & Discussion

Using *t*-tests we again confirmed that infants in the two familiarization conditions of the trochee unstressed syllable experiment (*gancho/salsa vs. gesto/venda*) were comparable on total familiarization times, $t(18) = 0.66$, $p = 0.52$. Figure 2 shows the mean looking time for the familiar (M = 7.7s; SD = 2.5) and novel word lists (M = 7.8s; SD = 2.8) in the test phase of Experiment 5. Out of the 20 infants tested, 10 listened longer to the novel syllables compared to the familiar syllables.

Listening time in the test phase was analyzed in an lme model with Trial Type (familiar, novel) and Condition (*gancho/salsa, gesto/venda*) and their interaction as fixed effects. Additionally, a random intercept was included for each subject to model baseline differences in listening time. Neither the effect of Trial Type, Condition nor their interaction was significant (Fs < 0.5).

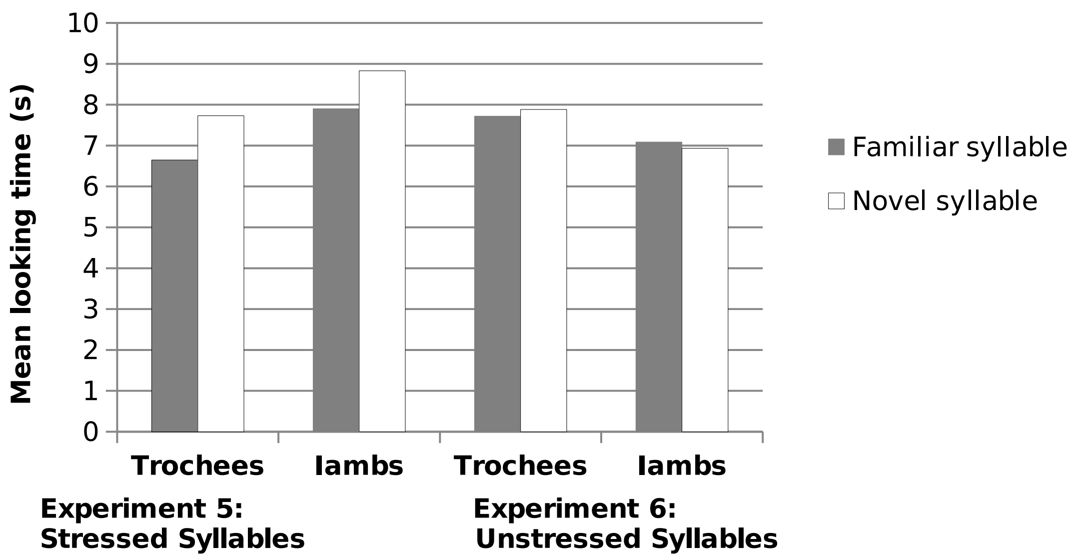

Figure 2. Monolingual English-learning 8-month-olds' mean listening times (+/- *SE*) to familiar and novel syllable constituents of Spanish words. Infants

tested in all conditions were familiarized with bisyllabic targets embedded in passages for 60s.

English-learning infants did not show a preference for just the weak syllable of the familiarized Spanish iambic words either. As expected, *t*-tests confirmed that infants in the two familiarization conditions of the iamb unstressed syllable experiment (*botín*/*dedal* vs. *corral*/*tifón*) were comparable on total familiarization times, $t(18) = -0.29$, $p = 0.78$. Figure 2 shows the mean looking time for the familiar (M = 7.1s; SD = 2.89) and novel word lists (M = 6.93s; SD = 2.86) in the test phase of Experiment 5. Out of the 20 infants tested, 9 listened longer to the novel syllables compared to the familiar syllables.

Listening Time in the test phase was analyzed using an lme model, again with Trial Type (familiar, novel), Condition (*botín*/*dedal* vs. *corral*/*tifón*) and their interaction as fixed effects. We also included a random intercept by subject. There was no significant effect of Trial Type (F =0.09) or Condition (F = 1.22). The interaction of Trial Type and Condition was significant (F =3.87), but a post-hoc comparison using *lsmeans* package in *R* showed that the effect of Trial Type was in opposite directions for the *botín*/*dedal* vs. *corral*/*tifón* condition, although neither was significant.

Next, two lme models confirmed that infants behaved differently in Experiments 5 and 6. That is, infants matched the stressed syllable but not the unstressed syllable to the familiarized bisyllabic sequence (significant interaction of Trial Type and Syllable Type, for trochees, *F* = 2.18, for iambs, *F* = 2.8).

9.0 Interim Discussion Part II

The results from Experiments 5 and 6 show that English-learning infants' segmentation of bisyllabic sequences in Experiments 2 and 3 cannot be attributed to their recognition of the syllable constituents alone. Instead, monolingual English-learning 8-month-olds represent the stressed syllables of bisyllabic words in greater detail than the bisyllabic sequences.

They do so despite differences in the acoustic instantiation of stress in a non-native language. Recall that in Spanish stressed and unstressed syllables differ primarily in duration, albeit to a lesser extent than in English (Delattre, 1965; Ortega-Llebaria, & Prieto, 2011). Additionally, unlike in English where vowel quality differences are the primary distinguishing factor between stressed and unstressed syllables, in Spanish these syllables do not differ in vowel quality (Beckman & Edwards, 1994; Campbell & Beckman, 1997; Morrill, 2012; Patel et al., 2012). Thus, vowel quality differences are not necessary, and the small duration differences seen in Spanish are sufficient for English-learning infants to detect stressed syllables.

English-learning infants matching of the Spanish bisyllabic sequence to both the bisyllabic sequence itself (with a familiarity preference) as well as the stressed syllable (with a novelty preference) may be unexpected. Recall that when familiarized with English bisyllabic sequences, English-learning infants segment the whole trochaic unit, or the stressed syllable in the case of iambs, but never both (English: e.g., Echols et al., 1997; Jusczyk et al., 1999; Morgan & Saffran, 1995). Dutch infants as well segment either bisyllabic words or constituent syllables in their native language (Kooijman, Hagoort & Cutler, 2005; 2009).

It is possible that this is merely the result of the longer familiarization duration in our experiments. In the original Jusczyk et al. experiment, where English-learning infants were familiarized with English trochees for 45s, but tested on the strong syllable, they showed a trend towards recognizing the strong syllable. Whether extending the familiarization time to 60s would allow English-learning infants to match the stressed syllable as well to English trochees remains to be determined.

More intriguing is the possibility that the small duration difference between stressed and unstressed syllables in Spanish is especially salient to English-learning infants due to the minimal variability in the duration of syllables in syllable-timed languages like Spanish. This is in contrast to the large variability in syllable durations typically seen in stress-timed languages like English (Ling et al., 2000; Ramus et al., 1999; White & Mattys, 2007). The increased perceptual salience of the duration difference might potentially explain why English-learning infants represented stressed syllables in Spanish in greater detail, as indicated by the novelty preference. Under such an account, the difficulty of adult English learners of Spanish in detecting Spanish stress can be attributed not to their inability to detect small duration differences, but to their shift in attention to vowel quality differences that cue stress because of their experience with English (Ortega-Llebaria et al., 2013; Holt & Lotto, 2006; Mayo et al., 2011; Llanos, Dimitrieva, Shultz, & Francis, 2013; Iverson et al., 2003).

10. General Discussion

In 6 experiments we tested English-learning 8-month-olds' ability to segment words in a non-native language. We did so for two reasons. First, we wanted to identify the conditions under which infants can segment words in a non-native language. Second, if successful, we wanted to evaluate their representation of newly segmented non-native words. Answers to both these questions contribute to our understanding of the bases of bi/multilingual acquisition in infancy.

In Table 7 the results of all 6 experiments are summarized. We showed that monolingual English-learning 8-month-olds were able to segment Spanish trochaic words when familiarized with Spanish passages for 60s but not 45s (Exp. 1-2). Additionally, they segmented Spanish, but not French iambs when provided the same extended familiarization duration (Exp. 3-4). These results provide evidence against the *rhythm hypothesis*. Specifically, the unfamiliar rhythm of the target language, in this case, Spanish, did not block word segmentation by English-learning 8-month-olds. The fact that English-learning infants segment Spanish but not French iambs also indicates that infants are not just using statistical cues to find words, and so accounts that rely on *distributional learning* alone must be ruled out. Finally, our results are also not consistent with a *Metrical Segmentation* account in which English-learning infants only successfully segment trochaic words. Instead, English-learning infants detect stressed syllables at the word level (*lexical stress*) and thereby succeed in segmenting words, even in a rhythmically-different language like Spanish.

Table 7. Summary of results for Experiments 1-6. In all experiments infants were familiarized with bisyllabic targets embedded in passages, and tested on isolated words or syllables. Whether infants demonstrated a preference in the test phase is presented in the final column.

Experiment	Familiarization passages	Familiarization Time	Test stimuli in lists	Preference
1	Spanish trochees	45s	Spanish trochees	None
2	Spanish trochees	60s	Spanish trochees	Familiarity
3	Spanish iambs	60s	Spanish iambs	Familiarity
4	French iambs	60s	French iambs	None
5a	Spanish trochees	60s	Stressed syllable only	Novelty
5b	Spanish iambs	60s	Stressed syllable only	Novelty
6a	Spanish trochees	60s	Unstressed syllable only	None
6b	Spanish iambs	60s	Unstressed	None

	syllable only

Infants’ early sensitivity to lexical stress is well-attested, not just when learning English, but also cross-linguistically (Echols, Crowhurst, & Childers, 1997; Friederici, Friedrich, & Christophe, 2007; Höhle, Bijeljac-Babic, Herold, & Weissenborn, & Nazzi, 2009; Jusczyk & Thomspon, 1978; Sansavini, Bertoncini, & Giovanelli, 1997). This early sensitivity to lexical stress has been shown to shift to favor language-specific properties over the first year of life (Goyet et al., 2010; Jusczyk, Cutler, & Redanz, 1993; Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993; Pons & Bosch, 2010; Skoruppa et al., 2009). As a consequence of experience with their native language, English-learning 8.5-month-olds prefer to listen to trochees over iambs (Echols et al., 1997; Jusczyk, Cutler, & Redanz, 1993; Turk et al., 1995) and are able to segment English trochees, but not iambs (Jusczyk et al., 1999) at least with a 45s familiarization duration.

Together with the extant research, our results reveal that young English-learning infants ability to segment in a non-native language is more graded than the *rhythm* hypothesis would indicate. Infants are able to transfer word segmentation skills to a rhythmically similar language – Dutch, with the greatest ease. However, word segmentation does not pose the same challenge in all rhythmically different languages. English-learning infants can segment in non-native languages with lexical stress, like Spanish and Italian, with somewhat longer familiarization durations. English-learning infants' success in segmenting both trochees and iambs in Spanish is consistent with their using *distributional* cues, as opposed to *Metrical Segmentation*. Most challenging are languages like French, with no lexical stress. However, recall that around 8-months, English-learning infants are able to segment words in artificial language experiments with no stress cues whatsoever, relying just on transitional probabilities when supported by a much longer familiarization phase of 2 minutes. So, we believe that given a sufficiently long familiarization phase, English-learning infants should also succeed in segmenting words in French. These results highlight the plasticity of word segmentation skills in young infants.

In Experiments 5 and 6, we probed English-learning infants' representation of newly segmented Spanish bisyllabic words – both trochees and iambs. We found that infants matched the stressed but not the unstressed syllable to the bisyllabic sequences. Further, given that English-learning infants demonstrated a novelty preference for the stressed syllable, we can conclude that their representation of the stressed syllable of the bisyllabic sequence is more detailed than that of the whole bisyllabic sequence.

In Spanish, stressed and unstressed syllables differ in duration, but not pitch or intensity, or vowel quality. In contrast, English stressed and unstressed syllables primarily differ in vowel quality with additional differences in duration, pitch, as well as intensity. English-learning 8-mo-olds' success at representing the stressed syllable in Spanish indicates that duration differences are sufficient to signal stress for these infants. In this way, English-learning 8-month-olds behaved like Spanish-learning infants (see also Skoruppa et al., 2009; Skoruppa, Cristià, Peperkamp, & Seidl, 2011). We argue that these results show that vowel quality differences are not necessary to signal stress for English-learning 8-month-olds. Whether these infants might be able to use vowel quality differences, if they were present, remains to be determined.

To summarize, we showed that 8-month-old monolingual English-learning infants are successful in segmenting Spanish trochees and iambs, but not French iambs. Given that Spanish is rhythmically different from English our results show that non-native rhythm does not block word segmentation in infants. Additionally, given that infants had the same, if not more statistical cues to word boundaries in French than in Spanish, our results also rule out accounts that rely on *distributional learning* alone. Finally, English-learning infants' ability to segment both trochees and iambs in Spanish suggests that these infants are not just relying on *Metrical Segmentation*. Instead, infants' ability to use transitional probability cues to word segmentation in a non-native language is facilitated by the availability of stress cues at the word level.

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Supplementary Material

Archived data from this paper is available at
<http://www.phonetics.ucla.edu/>