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Spanish input accelerates bilingual infants' segmentation of English words

Victoria Mateu [a], Megha Sundara [b,*]

[a] Department of Spanish & Portuguese, University of California Los Angeles, United States of America
[b] Department of Linguistics, University of California Los Angeles, United States of America

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ABSTRACT

We asked whether increased exposure to iambs, two-syllable words with stress on the second syllable (e.g., *guitar*), by way of another language – Spanish – facilitates English learning infants' segmentation of iambs. Spanish has twice as many iambic words (40%) compared to English (20%). Using the Headturn Preference Procedure we tested bilingual Spanish and English learning 8-month-olds' ability to segment English iambs. Monolingual English learning infants succeed at this task only by 11 months. We showed that at 8 months, bilingual Spanish and English learning infants successfully segmented English iambs, and not simply the stressed syllable, unlike their monolingual English learning peers. At the same age, bilingual infants failed to segment Spanish iambs, just like their monolingual Spanish peers. These results cannot be explained by bilingual infants' reliance on transitional probability cues to segment words in both their native languages because statistical cues were comparable in the two languages. Instead, based on their accelerated development, we argue for autonomous but interdependent development of the two languages of bilingual infants.

1. Introduction

Segmentation of continuous speech into words is far from trivial. Perception studies show no systematic cues to word boundaries, such as pauses, in spoken language (Cole & Jakimik, 1978, 1980; Cole, Jakimik, & Cooper, 1980; Klatt, 1980, 1989). Yet infants routinely overcome this challenge before their first year of life (e.g., Jusczyk, Houston, & Newsome, 1999). How do infants learn to segment their native language? The consensus of most researchers is that infants gradually learn to integrate a range of cues.

Research starting from the 1990s demonstrates that, in the earliest stages of development, infants rely on the statistical distribution of syllables for segmentation (Goodsitt, Morgan, & Kuhl, 1993; Pelucchi, Hay, & Saffran, 2009; Saffran, Newport, & Aslin, 1996; Thiessen & Erickson, 2013). For example, word boundaries often occur at relatively low syllable-to-syllable transitional probabilities. Thus, frequently occurring words such as *the baby* are not mistaken for a single word because [ðə] (*the*) occurs before many other syllables, but only a few different syllables follow [beɪ] (*ba*), so infants are likely to segment [beɪbi] (*baby*) from continuous speech.

With increasing age, infants' ability to extract words from fluent speech is affected by their language experience. For instance, English learning 8-month-olds first segment two-syllable words with stress on the first syllable, i.e., trochees (e.g., *hamlet* and *kingdom*) but not two-syllable words with stress on the second syllable, i.e., iambs (e.g., *guitar* and *beret*) (Johnson & Jusczyk, 2001; Jusczyk, Houston, & Newsome, 1999). This is not surprising considering that in conversational English approximately 90% of content words begin with a stressed syllable (Cutler & Carter, 1987). Even considering just two-syllable words in English, approximately 80% start with a stressed syllable (Clopper, 2002). Thus, English learning infants and adults segment words by treating stressed syllables as word onsets (*Metrical Segmentation Strategy*: Cutler & Norris, 1988). These results have been replicated in other predominantly trochaic languages, such as Dutch (Houston, Jusczyk, Kuijpers, Coolen, & Cutler, 2000) and German (Höhle & Weissenborn, 2003). In contrast, monolingual Canadian French learning 8-month-olds can segment iambs (Polka & Sundara, 2012; Polka, Orena, Sundara, & Worrall, 2017, but see Nazzi et al., 2006, for different results with Parisian French learning infants) most likely because in French, when stress is present, disyllabic words have a weak iambic pattern (Delattre, 1966).

Eventually, by about 10.5 months of age, English learning infants segment iambs as well (Jusczyk, Houston, & Newsome, 1999). Results from artificial language experiments suggest that this may be due to increased exposure to iambic words. Specifically, Thiessen and Saffran (2007) showed that even 7-month-old English learning infants, when

* Corresponding author at: UCLA, Department of Linguistics, 3125 Campbell Hall, Los Angeles, CA 90095-1543, United States of America.
E-mail address: megha.sundara@humnet.ucla.edu (M. Sundara).

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pre-exposed to a list of iambic words for two minutes, succeeded at segmenting them. Therefore, altering the distribution of stress patterns in the input by increasing iambs in an experiment facilitates English learning infants' ability to find iambs in continuous speech.

The current study was designed to investigate whether increased exposure to iambs by way of another language could also facilitate English-learning infants' segmentation of iambs. Although by no means a predominant pattern, about 40% of two-syllable words in Spanish are iambs (Alcina Franch & Blecua, 1975; Álvarez, Carreiras, & De Vega, 1992; Guerra, 1983; Quilis, 1981); in fact, about 45% of prosodic words addressed to children in Spanish start with a weak syllable compared to just 10% in English (Roark & Demuth, 2000). Therefore, bilingual Spanish and English learning infants have increased exposure to iambs compared to their monolingual English peers because of their Spanish input. In this paper we tested whether bilingual 8-month-olds exposed to both Spanish and English are able to segment iambs.

If bilingual Spanish-English 8-month-olds are able to segment English iambs it would provide evidence for accelerated development in bilingual infants compared to their monolingual peers. Acceleration in bilingual acquisition is rare but has been reported in several single-case studies evaluating speech production by older bilingual children. This includes studies documenting bilingual toddlers' phonological (Almeida, Rose, & Freitas, 2012; Lleó, Kuchenbrandt, Kehoe, & Trujillo, 2003), as well as morphosyntactic development (Hsin, 2011; Kupisch, 2007; Liceras, Fernández Fuertes, & Alba de la Fuente, 2011). In young infants, the evidence for acceleration comes from one investigation of Welsh and English learning bilinguals; bilingual Welsh-English infants showed a significant preference for familiar over unfamiliar Welsh words at 11 months in contrast to monolingual Welsh infants who showed a preference only at 12 months (Vihman, Thierry, Lum, Keren-Portnoy, & Martin, 2007).

There are two reasons why bilinguals might successfully segment iambs earlier than monolinguals. Acceleration of the developmental timeline, as defined by Paradis and Genesee (1996), is one possible outcome of interdependent bilingual development, specifically, a cross-linguistic interaction between the grammatical representation of the two languages of a bilingual. For example, Lleó et al. (2003) attribute the earlier production of coda consonants (e.g., "tren" train [tren]) by German and Spanish learning bilingual children compared to their monolingual Spanish peers to the facilitatory effect of the significantly higher frequency of coda consonants in German.

In contrast, Müller (2017) claims that accelerated development is a spurious result of bilinguals applying simpler, more efficient, non-linguistic computations when faced with surface similarities in their two languages (see also Meisel, 1994, 2007). She argues that cross-linguistic effects are always due to interference and manifest as delays in development. For instance, bilingual children learning German and a Romance language like Spanish, Italian, or French correctly place finite verbs in second position in German unlike their monolingual German peers, who erroneously place these verbs in final position (Clahsen, Eisenbeiss, & Penke, 1996). Note that the canonical word order of Romance languages is Subject-Verb-Object, so finite verbs are most often placed in second position. In German, verb placement is variable – finite verbs move to second position in matrix clauses but remain in their final, base-generated position in subordinate clauses. Thus, bilingual children correctly place finite verbs in German earlier than their monolingual peers. However, about half the bilingual children who skipped the verb-final stage go on to exhibit difficulties learning finite verb placement in German subordinate clauses (Müller & Patuto, 2009). Thus, what appeared to be accelerated development in German earlier on, Müller argues, is instead a result of bilingual children relying on surface similarities in verb placement across *both* languages.

Spanish and English also share many surface similarities involving how stress is used and instantiated that are of relevance to word segmentation. In both languages stress is used at the word level. However, the exact distribution of stress differs across the languages as mentioned previously; in English most words start with a stressed syllable whereas stress placement is more variable in Spanish. Further, stress is cued in both languages by duration differences; stressed syllables are longer than unstressed syllables, although to a smaller extent in Spanish (Delattre, 1965; Ortega-Llebaria & Prieto, 2011). Finally, despite differences in the instantiation of stress across the two languages, monolingual English learning infants can discriminate between word-initial and word-final stress even among Spanish disyllabic words (Skoruppa, Cristia, Peperkamp, & Seidl, 2011) and can segment words in Spanish, albeit with an extended familiarization phase, further attesting to their surface similarity (Sundara & Mateu, 2018). Note that monolingual English learning infants do so despite the fact that stressed and unstressed syllables in English additionally differ in vowel quality such that only English unstressed syllables have reduced vowels, further distinguishing the two languages (see Ortega-Llebaria & Prieto, 2007, 2011 for a review).

These surface similarities between Spanish and English hide substantive underlying differences. Crucially, they have been described as belonging to different rhythm classes. Spanish is considered a prototypical syllable-timed language, whereas English is considered stress-timed (Abercrombie, 1967; Dauer, 1983; Pike, 1967; Ramus, Nespor, & Mehler, 1999). Categorization of languages into rhythm classes is by no means uncontroversial (for reviews see Arvaniti, 2009; White & Mattys, 2007); however, rhythm differences have been found to predict speech perception behavior.

Because of these rhythm differences, newborns are able to discriminate Spanish from English since birth (Moon, Panneton-Cooper, & Fifer, 1993), even in the absence of experience with either language (Nazzi, Bertoncini, & Mehler, 1998). By 5 months of age, monolingual English and bilingual Spanish and English learning infants alike are able to discriminate between the two languages (Bahrick & Pickens, 1988). Thus, these rhythm differences ensure that bilingual infants are able to distinguish their two languages from each other when they belong to different rhythmic classes, as is the case for Spanish and English.

Additionally, native speakers of languages with different rhythms are thought to rely on different units for word segmentation (see Cutler, 2005 for a review). English speakers have been proposed to rely on stress (Cutler & Norris, 1988) whereas Spanish speakers have been proposed to rely on syllables (Bosch, Figueras, Teixidó, & Ramon-Casas, 2013; Soto-Faraco, Sebastián-Gallés, & Cutler, 2001). Further, it has been thought that word segmentation abilities do not easily transfer across languages from different rhythm classes, i.e., infants and adults learning stress-timed languages like English and Dutch have documented difficulties segmenting words in a syllable-timed language, like French, Italian, or Spanish (e.g., Cutler, Mehler, Norris, & Segui, 1986, 1992; Murty, Otake & Cutler, 2007; Polka et al., 2017; but see also Pelucchi et al., 2009a, b; Sundara & Mateu, 2018).

Given the surface similarity in Spanish and English, bilingual infants could then use a simpler domain-general learning mechanism, statistical learning, that is not specific to humans (see Santolin & Saffran, 2018 for a review), to successfully segment words in both languages. In fact, recent research documents a bilingual advantage in statistical learning with artificial languages in both adults (e.g., Toro, Sinnett, & Soto-Faraco, 2005; Weiss, Gerfen, & Mitchel, 2009) and infants (Antovich & Graf Estes, 2018; de Bree et al., 2017; Kovács & Mehler, 2009; Singh et al., 2015). Thus, a faster rate of development in word segmentation could emerge in bilingual infants from their reliance on statistical learning, at which they are presumed to have an advantage.

If being bilingual itself confers better statistical learning abilities, we should expect evidence of word segmentation in bilinguals earlier than monolinguals regardless of the specific combinations of languages being learned. The limited research on word segmentation, however, provides no evidence that bilingual infants segment natural language stimuli earlier than monolinguals. Bilingual Spanish and Catalan learning 6- to 8-month-olds (Bosch et al., 2013), English and Mandarin learning 7- to 11-month-olds (Singh & Foong, 2012) and French and English learning

8-month-olds (Orena & Polka, 2019; Polka et al., 2017) have all been shown to segment words at the same age as their monolingual peers. However, we cannot rule out the possibility that bilingual infants segment words even earlier than monolingual peers without testing younger bilingual infants in these languages. Therefore, whether bilingual exposure by itself predicts a faster rate of development of word segmentation abilities per se remains an open question.

2. Experiment 1

In Experiment 1, we tested Spanish and English learning bilingual 8-month-olds' ability to segment English iambs. We selected iambs because it has been previously established that monolingual English learning 8-month-olds fail to segment them (e.g., Jusczyk, Houston, & Newsome, 1999; Thiessen & Saffran, 2007). We further reasoned that given surface similarities in Spanish and English – that is, the presence of lexical stress, and given greater exposure to iambic words because of learning Spanish, bilingual infants learning both languages should successfully segment iambs at 8 months. If bilingual infants successfully segment English iambs at 8 months, that is, earlier than their monolingual peers, this would be evidence for accelerated development in bilinguals. These results would be consistent with either interdependent development of their two languages or the use of domain-general statistical learning, at which they may be presumed to have an advantage. In Experiment 3 we disambiguate the two predictions.

2.1. Materials and methods

2.1.1. Subjects

Thirty-eight English-and-Spanish learning 8-month-olds ($M = 8.74$, range = 7.6–9.5) who had between 20 and 80% exposure to Spanish participated in the study. Twenty additional infants were excluded due to fussiness ($N = 9$) or having less than 20% exposure to either Spanish ($N = 6$) or English ($N = 5$). The sample size was calculated based on the effect size of word segmentation experiments with natural language stimuli using the Headturn Preference Procedure. A recent meta-analysis on word segmentation using this procedure reports effect sizes ranging from 0.16 to 0.5 (Cohen's d) with a median sample size of 20 (Bergmann et al., 2018). The average effect size for word segmentation experiments tested using this procedure in our lab is 0.31. The estimated sample size based on this effect size for an interaction in a linear mixed effect model with 80% power is between 30 and 40 infants per condition (Green & Macleod, 2016). Due to the COVID-19 pandemic we have between 34 and 39 infants (not 40) in each of the 4 experiments reported here.

All infants were recruited from Los Angeles and its surrounding areas. Based on detailed parental questionnaires which allowed us to calculate the number of hours per week that the infant heard one language over the other (Sundara & Scutellaro, 2011), the exposure to Spanish ranged from 20.6 to 75.8% ($M = 47.22\%$, $SD = 17.58$). None of the subjects had a history of cognitive impairment or an ear infection on the day of testing.

2.1.2. Stimuli

We re-recorded Jusczyk, Houston, & Newsome, (1999) iambic stimuli – *beret*, *guitar*, *device*, and *surprise* passages and lists as produced by another native American English female speaker. Each passage contained 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 also recorded repetitions of the four target words in isolation. Passages and lists were produced in infant-directed speech. To characterize the acoustic properties of the stimuli we segmented the two syllables of each target word in the passages and the lists using Praat (Boersma & Weenink, 2013). Duration, average fundamental frequency (f0), and average intensity measurements were calculated. These measures are presented in Table 1. As expected, the second syllable of the iambs was significantly longer than the first one. As in Jusczyk, Houston, & Newsome, (1999) neither pitch nor intensity consistently distinguished the two syllables in lists and passages; pitch did not significantly distinguish the two syllables in either context, whereas intensity was significantly different only in lists (see Table 1, reporting on paired t-tests with Bonferroni's correction $(0.05/3 = 0.02)$).

Table 1
Acoustic characteristics of the two syllables of the English iambic targets from passages and lists, the standard deviations are reported in parentheses.

Measures	First syllable	Second syllable	Statistical comparison
Passage words			
Duration (ms)	127 (40)	446 (110)	$t(23) = 14.29$, $p < 0.001$*, $d = 3.85$
Average f0 (Hz)	232 (55)	220 (63)	$t(23) = -1.53$, $p = 0.14$, $d = 0.19$
Average Intensity (dB)	69.8 (3.9)	71.4 (4.8)	$t(23) = 1.69$, $p = 0.10$, $d = 0.36$
List words			
Duration (ms)	107 (45)	669 (113)	$t(59) = 48.45$, $p < 0.001$*, $d = 6.55$
Average f0 (Hz)	287 (67)	293 (70)	$t(59) = 0.49$, $p = 0.62$, $d = 0.084$
Average Intensity (dB)	65.6 (3.9)	74.6 (2.1)	$t(59) = 15.2$, $p < 0.001$*, $d = 2.87$

Transitional probabilities were calculated as well. Iambs all had a backward transitional probability of 0.17, that is, they were preceded by 6 different syllables; and a forward transitional probability ranging from 0.17 to 0.33, i.e. they were followed by one of 3–6 different syllables. The transitional probability between the first and second syllable was 1 for all target words.

2.1.3. Procedure

We implemented the Headturn Preference Procedure as described in Jusczyk, Houston, & Newsome, (1999). Infants sat on their caregiver's lap in the center of a three-sided pegboard booth. At the beginning of each trial, the light in the center panel flashed attracting the infant's gaze toward it. Then, a light on either the left or the right side flashed, prompting the child to look towards that direction. When the infant started to look at the flashing light, a passage or list was played through a loudspeaker located just behind the light. If the infant looked away from the panel for more than 2 s, the speech stimuli stopped playing and a new trial began. The infant's looking/listening time to each passage and list was recorded by the experimenter seated outside the pegboard booth. The flashing light and speech was played on the left or right sides at random. The parent and experimenter wore headphones and listened to music to prevent influencing the infant's behavior.

Because we were interested in bilingual infants' ability to segment words from running speech, we first familiarized them with passages featuring two different iambic target words (*beret*, *guitar* or *device*, *surprise*). Like in Jusczyk, Houston, & Newsome, 1999, after infants accumulated 45 s of listening time to each passage they were presented all four isolated words lists – two familiar and two novel – in three blocks for a total of 12 trials. Listening time to familiar and novel words were compared statistically.

2.2. Analyses

Listening time data were analyzed using linear mixed effects models in the *R* programming environment (R Core Team, 2020; v. 3.6.3) using *lme4* (Bates, Mächler, Bolker, & Walker, 2015) and *lmerTest* (Kuznetsova, Brockhoff, & Christensen, 2017) to obtain p-values. Fixed effects included Block (1,2,3) and Condition (*beret.guitar* vs *device.surprise*) as between-subjects variables and Trial Type (familiar vs novel) as a within-subjects variable, and all interactions. We also included random intercepts for subjects to model baseline differences in listening time, and random slopes for Trial Type for each subject to allow for differences in extent of preference for familiar or novel trials. Random slopes were eliminated before random intercepts, if the model failed to converge. We report results from the highest-level random effect structure that converged (Barr, Levy, Scheepers, & Tily, 2013). Planned comparisons, if warranted, were done using the *emmeans* package (Lenth, Singmann, Love, Buerkner, & Herve, 2020) in *R*. To evaluate the effect of the relative percentage of Spanish heard, all analyses on bilingual infants were also repeated with Percent Spanish as a fixed effect, and all its interactions with Block, Condition and Trial-type. Percent Spanish did not interact with the Trial type – the main variable of interest, in any combination, so we do not report these results separately.

2.3. Results & discussion

Only the main effect of Block [$F(2, 415) = 5.33$, $p = 0.005$] and Trial Type [$F(1, 415) = 7.0$, $p = 0.008$] were significant. As is typical in infant experiments, overall listening times reduced in successive blocks, with a significant decline between Block 1 and both Block 2 [$t(372) = 2.8$, $p = 0.02$] and Block 3 [$t(372) = 2.9$, $p = 0.01$]. Crucially, as shown in Fig. 1, the bilingual infants listened significantly longer to familiar compared to novel English iambs. Thus, the bilingual 8-month-olds were able to segment English iambs.

3. Experiment 2

When familiarized with English iambs, monolingual English learning 8-month-olds succeeded only in segmenting the stressed syllable, not the whole disyllabic word (Jusczyk, Houston, & Newsome, 1999). So, Experiment 2 was designed to determine whether bilingual infants were segmenting the complete iambic target and or just the stressed syllable. In this experiment, we again familiarized infants with passages containing iambs, but tested them only on the stressed syllable. If bilingual infants were segmenting just the stressed syllable and not the whole iamb in Experiment 1, we expected them to show a familiarity preference for the stressed syllable alone in Experiment 2.

3.1. Materials and methods

3.1.1. Subjects

Thirty-nine Spanish and English learning 8-month-olds ($M = 8.79$, range $= 7.9$–9.5) who had between 20 and 80% exposure to Spanish participated in the study. Fifteen additional infants were excluded due to fussiness ($N = 4$), being exposed to a third language more than 5% of the time ($N = 2$), or having less than 20% exposure to either Spanish ($N = 3$) or English ($N = 6$). Recruitment criteria were the same as for Experiment 1. Based on parental reports, the average exposure to Spanish ranged from 20% to 80% ($M = 49.09\%$, $SD = 18.76$).

3.1.2. Stimuli, procedure & analysis

Same as in Experiment 1, except in the test phase, infants were presented with just the stressed syllable of the iamb – *ret*, *prise*, *vice* and *tar*. The final model that converged had a random intercept for subject.

3.2. Results & discussion

In Experiment 2 the only significant effect was that of Block [$F(2, 416) = 21.9$, $p < 0.001$], again because listening times were overall greater in Block 1 compared to Block 2 [$t(408) = 4.9$, $p < 0.0001$] and Block 3 [$t(408) = 6.3$, $p < 0.0001$]. Neither the main effect of Trial Type nor its interaction with Block ($p > 0.4$) was significant. So, there was no evidence to indicate that bilingual 8-month-olds segment just the stressed syllable of English iambs.

4. Experiment 3

In Experiment 3, we tested bilingual Spanish and English learning 8-month-olds' ability to segment Spanish iambs. If bilingual infants succeed at segmenting English iambs by relying on a domain-general

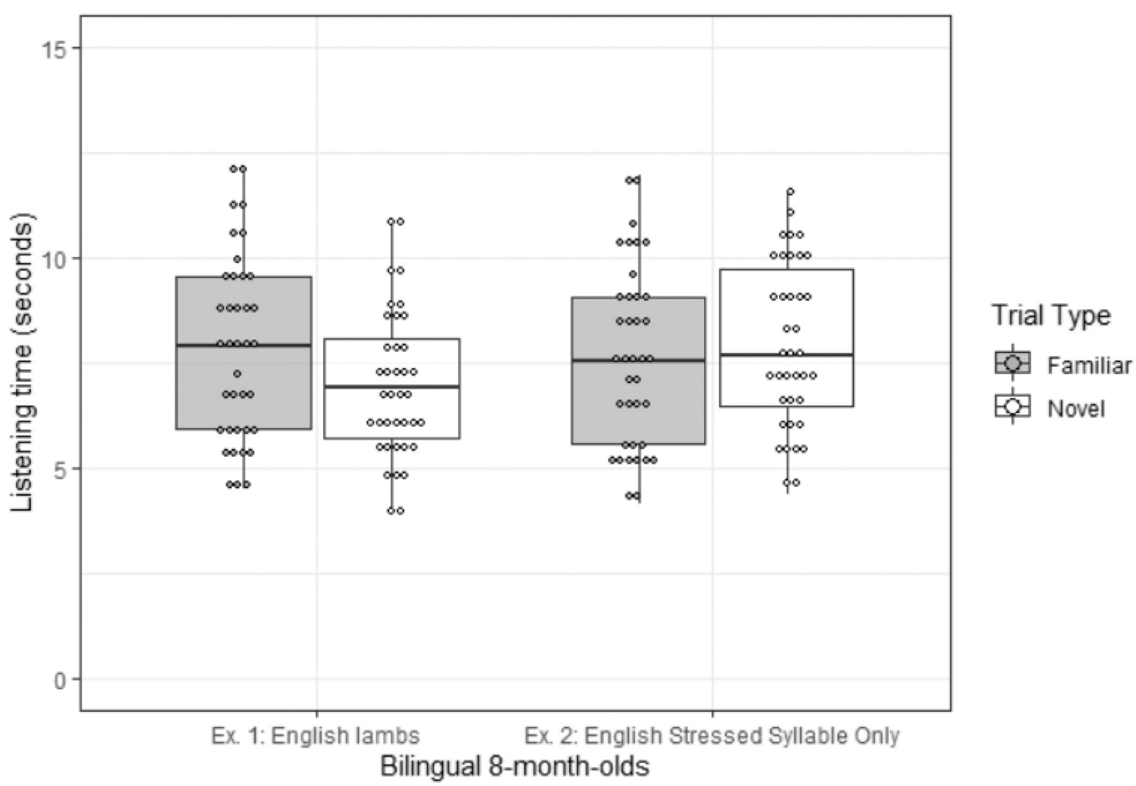

Fig. 1. Box plots of mean listening time to the familiar and the novel trials when bilingual 8-month-olds were tested on English iambs (Experiment 1), or just the stressed syllable of English iambs (Experiment 2); individual subject data are overlaid.

sensitivity to transitional probabilities, then, given comparable transitional probability cues, they should also succeed at segmenting iambs in Spanish.

4.1. Materials and methods

4.1.1. Subjects

Thirty-four Spanish and English learning 8-month-olds (M = 8.39, range = 7.4–9.6) who had between 20 and 80% exposure to Spanish participated in the study. Twenty-one additional infants were excluded due to fussiness (N = 8), having more than 5% exposure to a third language (N = 1), or having less than 20% exposure to English (N = 3) or Spanish (N = 9). Recruitment criteria were the same as for Experiment 1. Based on parental reports, the average exposure to Spanish ranged from 21.3–77.9% (M = 47%, SD = 18).

4.1.2. Stimuli and procedure

We used the same Spanish iambic stimuli as in Sundara and Mateu (2018). The four target words were: "botín" loot [boˈtin], "dedal" thimble [deˈdal], "corral" corral [koˈral], and "tifón" typhoon [tiˈfon]. 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. The speaker was also asked to produce repetitions of each iamb. Passages and words were produced in infant-directed speech by a female native speaker of Mexican Spanish. The acoustic properties of the stimuli are described in Sundara and Mateu (2018: 110). As in the case of our English stimuli, duration was the only reliable cue to distinguish the first and second syllable of the Spanish iambs in the passages and the lists; with the second stressed syllable (*passages*, 318 ms; *lists*, 389 ms) being longer than the first one (*passages*, 148 ms; *lists*, 137 ms).

As reported in Sundara and Mateu (2018), Spanish iambs had a backward transitional probability ranging from 0.25 to 0.33, i.e., they were preceded by one of 3–4 different syllables; and a forward transitional probability ranging from 0.17 to 0.2, i.e. they were followed by one of 5–6 different syllables. Thus, English iambs had somewhat stronger (that is, lower) backward transitional probability cues whereas the Spanish iambs had somewhat stronger forward transitional probability cues. The transitional probability between the first and second syllables of the target words was on average 0.92 (range = 0.83–1). Half of the infants were familiarized with *botín* and *dedal*, and the other half with *corral* and *tifón*.

4.1.3. Analyses

Analyses were identical to those in Experiment 1. The final model included a random intercept for subject and a random slope for Trial Type by subject.

4.2. Results & discussion

As we can see from Fig. 2, bilingual 8-month-olds' listening time to novel Spanish iambs was numerically greater than their listening time to familiar Spanish iambs. However, neither the main effect of Trial Type, nor any of its interactions were significant ($p > 0.2$). The only significant effect was the main effect of Block and the interaction of Block by Condition [$F(2, 370) = 5.7$, $p = 0.004$], this was driven by the fact that the Block effect differed across the two conditions.

In order to compare the bilingual 8-month-olds' segmentation of English (Experiment 1) and Spanish iambs (Experiment 3), we ran another mixed effect model with listening time as the dependent variable, and Language (Spanish, English), Block, and Trial Type, and all their interactions as fixed effects; the model also included the random intercept for subject and the random slopes for subject by Trial Type. The Language × Trial Type interaction was significant [$F(1, 788) = 5.1$, $p = 0.02$] confirming that bilingual infants behaved differently when tested on English iambs in Experiment 1 and Spanish iambs in Experiment 3.

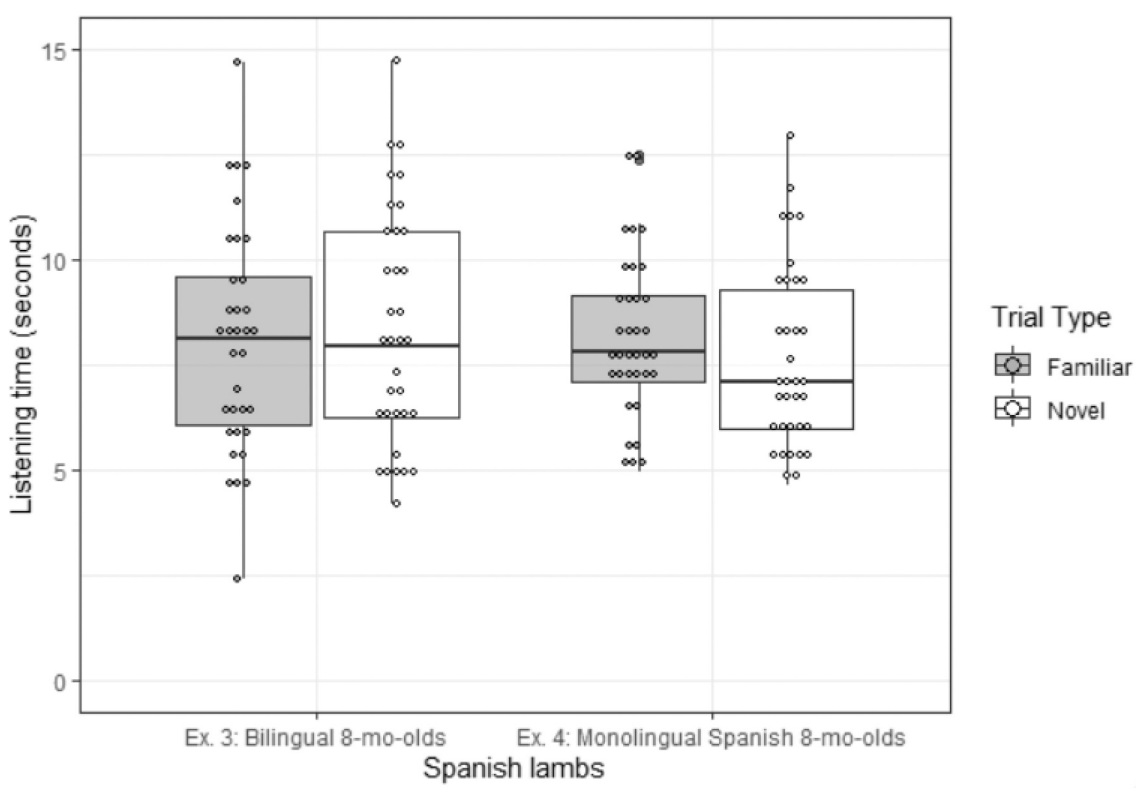

Fig. 2. Box plot of mean listening times to the familiar and the novel Spanish iambs for bilingual (Experiment 3) and monolingual Spanish learning 8-month-olds (Experiment 4); individual subject data are overlaid.

5. Experiment 4

In Experiments 1 and 2, we showed that bilingual Spanish-English learning 8-month-olds segment English iambs, and not just the strong syllable. These results provide evidence in support of accelerated segmentation of English iambs by Spanish and English learning bilingual infants. However, in Experiment 3, bilingual infants failed to segment Spanish iambs even with comparable transitional probability cues. Thus, bilingual infants' success cannot be attributed to their relying on a more efficient, domain general mechanism like transitional probabilities to segment words in both languages. Instead, the acceleration is likely a result of cross-linguistic interaction between the representation of the two languages.

In Experiment 4 we tested monolingual Spanish learning 8-month-olds to ascertain that bilingual infants were not delayed in their segmentation of Spanish iambs in comparison to their monolingual Spanish peers. To date, word segmentation abilities of Spanish learning infants have been investigated in one study (Bosch et al., 2013). Bosch et al. familiarized Spanish monolingual infants with two monosyllabic words embedded in passages till each infant accumulated 45 s of listening time, following which infants were presented two familiar and two novel isolated words. At 6 months, monolingual infants listened significantly longer to familiar monosyllabic words whereas at 8 months, they listened significantly longer to novel monosyllabic words – a preference thought to be associated with easier tasks (Hunter & Ames, 1988). Whether Spanish learning monolingual infants are able to segment disyllabic words remains unclear. If monolingual Spanish learning infants also fail to segment Spanish iambs, we would have no evidence of a delay in segmentation of Spanish iambs by bilingual infants.

5.1. Materials and methods

5.1.1. Subjects

Thirty-five Spanish learning 8-month-olds (M = 8.43, range = 7.6–9.5) who had at least 90% exposure to Spanish participated in the study. Seven additional infants were excluded due to fussiness ($N = 4$), being exposed to a second language more than 5% of the time ($N = 1$), or parental interference (N = 2). All infants were recruited from Los Angeles and its surrounding areas. Based on parental reports, the average exposure to Spanish ranged from 90% to 100% (M = 96.94%, SD = 3.3).

5.1.2. Stimuli, procedure & analysis

Same as in Experiment 3. The final model that converged had a random intercept for subject.

5.2. Results & discussion

In Experiment 4 as well neither the main effect nor any interaction with Trial Type was significant ($p > 0.2$). The only significant effect was that of Block [$F(2, 383) = 10.7$, $p < 0.0001$], with listening times in Block 1 being significantly greater than in Block 2 [$t(375) = 2.9$, $p = 0.009$] or Block 3 [$t(375) = 4.5$, $p < 0.0001$]. Thus, just like their bilingual peers, monolingual Spanish learning 8-month-olds showed no evidence of segmenting Spanish iambs (Fig. 2). These results are in contrast to the developmental pattern reported for monosyllabic words (Bosch et al., 2013); there was no evidence that monolingual Spanish learning 8-month-olds can segment Spanish iambs. Because there was no evidence that monolingual Spanish learning 8-month-olds segmented Spanish iambs, bilingual 8-month-olds' failure to segment Spanish iambs cannot be attributed to a delay.

6. General discussion

In Experiments 1 and 2 we showed that bilingual Spanish and English learning 8-month-olds successfully segmented English iambs, and not just the stressed syllable. Bilingual infants' success in Experiment 1 and 2 is in contrast with the performance of monolingual English 8-month-olds, who instead of segmenting English iambs, segment just the stressed syllable (Jusczyk, Houston, & Newsome, 1999). Monolingual English learning infants successfully segment English iambs, and not just the stressed syllable only by 10.5 months. Thus, Spanish and English learning bilingual infants' segmentation of English iambs is accelerated in comparison to their monolingual English learning peers.

Crucially, our findings are incompatible with Müller's (2017) proposal that acceleration is due to bilingual infants relying on a more efficient, non-linguistic computation that is shared across their two languages (see Endress & Hauser, 2010; Johnson & Seidl, 2008; Sohail & Johnson, 2016, for alternate domain general mechanisms influencing word segmentation). If bilingual infants were using the same strategy to segment words in both languages, such as relying on transitional probability alone, then given comparable transitional probability cues they should have succeeded in segmenting both English and Spanish iambs. However, in Experiment 3, we showed that bilingual infants failed to segment Spanish iambs.

Bilingual infants' success at segmenting English iambs cannot be attributed to language dominance either. It has been argued that bilinguals may sometimes transfer knowledge from their dominant language to their non-dominant language, which may lead to acceleration (or delay) of development in their non-dominant language (Gawlitzek-Maiwald & Tracy, 1996; Lleó & Rakow, 2006; Paradis, 2001). First, we found no evidence that monolingual Spanish infants can segment Spanish iambs (Experiment 4). So, it is difficult to argue that bilingual infants transferred their word segmentation skills from Spanish. Second, recall that we tested bilingual infants with a wide range of exposure to Spanish, all the way from 20% to 80%; however, bilingual infants' success at segmenting English iambs was independent of the extent of exposure to Spanish.

Instead, we argue that our findings of accelerated segmentation of English iambs by Spanish-English learning bilingual infants stem from cross-linguistic influence, when the target feature is present in both languages (à la 'additiveness' in Lleó, 2016). Specifically, bilingual infants transfer knowledge from one language that contains more (consistent) evidence for a particular feature to the one with less evidence for it (see similar arguments in Hsin, 2011; Kupisch, 2007; Liceras et al., 2011).

We believe it is the presence of lexical stress in both Spanish and English that makes acceleration possible. Lexical stress is perceptually salient – 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; Goyet, de Schonen, & Nazzi, 2010; Höhle, Bijeljac-Babic, Herold, Weissenborn, & Nazzi, 2009; Jusczyk & Thompson, 1978; Sansavini, Bertoncini, & Giovanelli, 1997; Skoruppa et al., 2009). In fact, learning even one language with lexical stress promotes discrimination of lexical stress patterns independent of the extent of exposure to that language (Abboub, Bijeljac-Babic, Serres, & Nazzi, 2015; Bijeljac-Babic, Höhle, & Nazzi, 2016; Bijeljac-Babic, Serres, Höhle, & Nazzi, 2012). Thus, exposure to a higher percentage of initial unstressed syllables in Spanish causes bilingual infants to cease to use stress as a principal indicator of word onsets alone in English, a stage that monolingual English learning infants do not reach until they are 10.5-months-old (Jusczyk, Houston, & Newsome, 1999) – or after they are heavily exposed to iambic word lists (Thiessen & Saffran, 2007).

In our study cross-linguistic transfer resulted in accelerated segmentation of English iambs by Spanish and English learning bilingual infants compared to monolingual English learning infants. Typically, cross-linguistic transfer is associated with a delay in bilingual development. However, we did not find any evidence that acceleration in segmenting English iambs comes at the expense of a delay in segmenting Spanish ones. There was no evidence that either bilingual infants or their monolingual Spanish learning peers were able to segment Spanish iambs.

Because of cross-linguistic transfer effects bilingual and monolingual infants may have different developmental outcomes even when both groups use similar mechanisms. Like monolingual infants, bilingual infants as well integrate domain-general cues like transitional probabilities, with language-specific cues – in this case stress, to segment English iambs. Like monolingual infants, bilingual infants also use transitional probabilities, as well as the few words in isolation that they hear to segment a cohort of possible words, and subsequently learn the placement of lexical stress by aggregating over this cohort (Thiessen & Erickson, 2013). As a result, monolingual English, Dutch, and German learning 8-month-olds align stressed syllables with word onsets (*English*, Jusczyk, Houston, & Newsome, 1999; ***Dutch,*** Houston et al., 2000; ***German,*** Höhle & Weissenborn, 2003) yet monolingual French learning 8-month-olds may align them with offsets (Polka et al., 2017; Polka & Sundara, 2012). Older monolingual English learning infants, eventually move away from primarily relying on strong syllables to indicate word onsets and start drawing on other sources of information, such as allophonic (e.g., Jusczyk, Hohne, & Bauman, 1999), phonotactic (e.g., Mattys, Jusczyk, Luce, & Morgan, 1999), or distributional cues (e.g., Saffran et al., 1996), as well as phonological phrase boundaries (Christophe, Gout, Peperkamp, & Morgan, 2003), or bootstrapping from known words (e.g., *Mommy/Mama*, baby's own name, Bortfeld, Morgan, Golinkoff, & Rathbun, 2005; functional elements such as 'the', Shi, Cutler, Werker, & Cruickshank, 2006) to segment words that begin with weak syllables. Exposure to Spanish, a language with significantly more iambs than English, provides bilingual infants with enough distributional evidence to stop relying on stress to cue word onsets alone earlier than their monolingual peers.

Finally, given bilingual infants failure to segment Spanish iambs we must also conclude that word segmentation strategies are not shared across languages. The two systems are thus autonomous, yet interdependent, and bilingual infants must develop different sensitivities to each segmentation cue based on the target language. In Spanish, stress cues are subtler and not as reliable as in English; further, there is also some suggestion that there are fewer and/or less useful sources of information about potential word boundaries in Spanish (e.g., Fleck, 2008). All of this could make it harder for Spanish learning infants to develop a bias to align stress with word onsets (or offsets). Our results from Experiment 4 attest that monolingual Spanish 8-month-olds do not align stress with word offsets. The developmental timeline of when monolingual (or bilingual) Spanish-learning infants segment Spanish words remains to be determined.

7. Conclusion

In four experiments we showed that unlike their monolingual English learning peers, bilingual Spanish and English learning 8-month-olds successfully segment English iambs. We argue that the increased exposure to iambs via Spanish leads bilingual infants to abandon their robust reliance on stress to indicate word onsets in English, a developmental milestone that is only achieved by older – 10.5-month-old monolingual English infants. This means Spanish and English learning bilingual infants represent iambs in their English lexicon significantly earlier than their monolingual English counterparts. We conclude that bilingual acquisition can be accelerated from the earliest stages of development.

Supplementary material

Deidentified data are available from the OSF page for this project: https://osf.io/xdvre/?view_only=821404ef380849b088db4eb5cbe065ff

Declaration of Competing Interest

None.

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