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Title

Constraints on Acceleration in Bilingual Development: Evidence from Word Segmentation by Spanish Learning Infants

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Journal

Behavioral Sciences, 14(2)

ISSN

2076-328X

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Publication Date

2024

DOI

10.3390/bs14020108

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Peer reviewed

1 Article

2 Constraints on acceleration in bilingual development: Evidence 3 from word segmentation by Spanish learning infants

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8 **Abstract:** We have previously shown that bilingual Spanish and English learning infants can segment
9 English iambs, two-syllable words with final stress (e.g., guiTAR), earlier than their monolingual peers
10 (Mateu and Sundara 2022). This is consistent with accelerated development in bilinguals, and was attributed
11 to bilingual infants' increased exposure to iambs through Spanish; about 10% of English content words start
12 with an unstressed syllable (Cutler & Carter, 1987), compared to 40% in Spanish (Roark and Demuth 2000).
13 Here we evaluated whether increased exposure to a stress pattern alone is sufficient to account for
14 acceleration in bilingual infants. In English, 90% of content words start with a stressed syllable (e.g.,
15 KINGdom; Cutler and Carter 1987), compared to 60% in Spanish (Pons and Bosch 2010). However, we
16 found no evidence for accelerated segmentation of Spanish trochees by Spanish-English bilingual infants
17 compared to their monolingual Spanish-learning peers. Based on this finding, we argue that merely
18 increased exposure to a linguistic feature in one language does not result in accelerated development in the
19 other. Instead, only the acquisition of infrequent patterns in one language may be accelerated due to the
20 additive effects from the other language.

21 **Keywords:** Spanish; English; bilingualism; word segmentation; acceleration; frequency; noise tolerance;
22 regularization
23

24 1. Introduction

25 Language development depends, at least in part, on lexical knowledge. One of the first
26 challenges that infants face in this domain is segmentation of words from fluent, continuous
27 speech. A number of experimental studies have found that infants use prosodic cues to segment
28 words. For instance, because 90% of English content words begin with a stressed syllable, e.g.,
29 KINGdom [1], monolingual English-learning infants learn to associate stress with word onsets
30 (*Metrical Segmentation Strategy* [2]). As a result, by 8 months they can segment trochees from
31 continuous speech, but they fail to segment iambs, e.g., guiTAR [3,4]. It is not until 10.5 months
32 of age that monolingual English-learning infants segment iambs as well [4]. Converging evidence
33 that infants associate stressed syllables with word onsets comes from infants learning other
34 languages with predominant trochaic patterns, such as German [5] and Dutch [6].

35 In a recent study [7] we have shown that bilingual infants learning Spanish and English
36 successfully segment English iambs at an earlier age than their monolingual English peers. As in
37 Jusczyk et al. [4], we used the Head-turn Preference Procedure to familiarize bilingual 8-month-
38 old infants with two iambic words (e.g., *beret* and *guitar* or *device* and *surprise*) embedded in
39 passages until they accumulated 45s of listening time to each. In the test phase, infants heard four
40 different word lists, two with familiar words, and two with novel words. Results showed that
41 bilingual Spanish-English 8-month-olds listened significantly longer to the familiar words
42 compared to the novel words. Thus, bilingual infants successfully segmented iambs from
43 continuous speech two months before their monolingual English learning peers. That is, bilingual
44 infants showed accelerated development, as defined by Paradis and Genesee [8] – the earlier
45 acquisition of a linguistic property in bilinguals compared to monolinguals.

46 In the linguistic domain, accelerated development in bilinguals' speech production and
47 perception has been reported in only a handful of studies, and therefore the conditions that lead to

30 **Citation:** To be added by editorial staff
31 during production.

32 Academic Editor: Firstname Lastname

33 Received: date

34 Revised: date

35 Accepted: date

36 Published: date



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47

48 accelerated linguistic development are still a matter of debate. The purpose of this study is to
49 evaluate various proposals to determine the conditions under which bilinguals show accelerated
50 development. Below we discuss findings on accelerated development in bilinguals and four non-
51 mutually exclusive hypotheses proposed to account for it: (i) language dominance accounts, (ii)
52 perceptual salience accounts, (iii) domain-general accounts and (iv) frequency accounts. We
53 evaluate the hypotheses against published findings about Spanish-English bilingual infants
54 accelerated segmentation of Spanish iambs [7]. Then, we derive predictions for whether Spanish-
55 English bilingual infants' ability to segment Spanish trochees should be accelerated. In Sections 2
56 and 3 we present data from two new experiments testing Spanish-English bilingual 8-month-olds'
57 segmentation of Spanish trochees. In anticipation of our results, our findings are not consistent
58 with any of the hypotheses that have been proposed to date. In the Discussion, we present a novel
59 account for accelerated development in bilingual infants arguing for a more restricted role of
60 frequency.

62 1.1. Previous proposals to account for acceleration

63 1.1.1. Language dominance accounts

64 A popular proposal when bilingual development diverges from that of monolinguals is that
65 it is due to cross-linguistic transfer [9-16]. Acceleration, then, is a form of positive transfer from
66 the dominant language to the non-dominant language.

67 Despite being a popular construct, there is no consensus on how language dominance
68 should be indexed. In some studies dominance is defined at the individual level, based on the
69 relative amount of input a specific child receives in each language. In others, it is defined at the
70 community level, based on which language is used most often outside the home environment. In
71 some studies dominance is treated as a binary variable (i.e., dominant or non-dominant), in others
72 as a continuous variable indexed by the percent input in one language. Regardless of the way it is
73 measured, dominance does not consistently predict acceleration.

74 For instance, Lleó, and colleagues [17, 19] propose that the accelerated rate of development
75 in the production of Spanish codas (e.g., “azul” blue [aθul]) in Spanish-German bilingual
76 children (1;01-2;03) living in Germany, when compared to age-matched Spanish monolinguals, is
77 due to language dominance. German has more codas (63%) compared to Spanish (28%; [18],
78 more on frequency effects below). They argue that the language of the community, in this case
79 German, is dominant and thus plays a role in determining the direction of positive transfer
80 between the two languages of a bilingual child. Further evidence for this proposal comes from
81 Stahnke's [20] data on the acquisition of French determiners in two French-Italian bilingual
82 children – one French-dominant child who lived in Paris and one Italian-dominant child who
83 lived in Rome. The bilingual child living in Rome outperformed the bilingual child living in Paris
84 on the production of French determiners, possibly due to positive transfer from the child's
85 community language, Italian, which has more prosodically prominent determiners than French
86 (more on prosodic salience effects below).

87 However, there are many studies that have failed to confirm the role of dominance in
88 predicting acceleration in developing bilinguals. Italian monolingual children reach adult-like
89 levels of determiner use earlier than their German counterparts, thus positive transfer is expected
90 from Italian to German when Italian is the dominant language at the individual or community
91 level, but not when German is dominant, or when the child receives balanced input [e.g., 21].
92 Kupisch [21] examined the production of determiners by four Italian-German bilingual children
93 living in Germany. The Italian-dominant bilingual child supplied German determiners in
94 obligatory contexts more frequently than monolingual German counterparts, despite living in
95 Germany. This acceleration is not predicted if dominance is evaluated at the level of the
96 community. Additionally, the two balanced bilingual children who received comparable input in
97 the two languages also showed evidence of acceleration in German. This is inconsistent with a
98 role for dominance as an individual level construct because acceleration was observed even when
99 there was no difference in relative input in the two languages. Similarly, and counter to the
100 predictions of dominance-based accounts, Kupisch [22] found that two French-German children
101 showed an accelerated rate of development in the production of German determiners compared to
102 monolingual German children regardless of relative differences in the amount of input they
103 received in each language.

104 In experiments evaluating word segmentation as well, there is no evidence that language
105 dominance indexed at the community or individual level conditions acceleration. The bilingual
106 Spanish-English learning infants tested by Mateu and Sundara [7] were living in Los Angeles,
107 where English is, arguably, the community language, and nevertheless their segmentation of
108 English iambs was accelerated due to experience with Spanish, inconsistent with a prediction
109 based on community standard of dominance (see also [23] for absence of dominance effects on

word segmentation by French-English bilingual infants). Mateu and Sundara also failed to find any relationship between the percentage of Spanish input and segmentation of iambs in English. So, their findings on word segmentation do not support a role for dominance determined at the individual level in predicting acceleration either.

1.1.2. Perceptual salience accounts

It has also been proposed that acceleration is observed only in cases when bilinguals are acquiring linguistic features that are perceptually more salient, and thus more easily learned in one language than the other. As mentioned above, both Italian-German bilingual children and French-German bilingual children outpace their monolingual German peers in their production of German determiners [21, 22]. Kupisch attributes this to several properties of Italian (and French) determiners which make them more perceptually salient, and thus easier to acquire than German determiners. Italian and French determiners are proclitic on the noun, while in German they often form a prosodic unit with the previous word, and are therefore less prosodically prominent. Moreover, the vocalic endings of most Italian DPs harmonize with the vowel in the article, e.g. *una/la ragazza* “a/the girl”, while in German they do not. Kupisch argues that Italian-German and French-German bilingual children benefit from the perceptual salience of determiners in Italian (and French), and as a result of positive transfer, they show an accelerated rate of acquisition of determiners in German compared to their monolingual German peers.

Similarly, Stahnke [20] also finds supporting evidence for the role of perceptual salience in the accelerated production of determiners. French articles are all monosyllabic, whereas in Italian a few are disyllabic, which makes the latter more prosodically prominent. Moreover, Italian has considerably more multisyllabic nouns than French, which according to Lleó and Demuth [24] allows for an earlier prosodification of determiners in Italian than in French. Based on an analysis of a longitudinal corpus with three children, Stahnke shows that one Italian-dominant bilingual child outperformed a monolingual French learning child consistent with acceleration due to the more salient property of determiners in Italian.

The results from Mateu and Sundara [7] on word segmentation, however, cannot be accounted for by appealing to perceptual salience. Spanish iambs cannot be described as more prosodically salient than English iambs. In both languages stress is lexical and is instantiated by lengthening. In fact, stress is arguably more salient in English than in Spanish, since there is a greater difference in duration between stressed and unstressed syllables in English than in Spanish [18, 25] and stressed and unstressed syllables in English additionally differ in vowel quality – unstressed syllables tend to have reduced vowels [26-29]. Therefore, perceptual salience accounts fail to predict positive transfer of stress-based segmentation strategies from Spanish to English.

1.1.3. Domain-general accounts

Acceleration has also been proposed to result from the mere fact that the individual is bilingual. There are many studies showing that bilingualism enhances general (and language-specific) cognitive performance, i.e., executive functioning, e.g., [30-37]. This has been attributed to bilinguals' experience with language inhibition – while speaking one language, bilingual speakers must concurrently suppress the other language, thus exercising executive control. In turn, many researchers have argued that enhanced executive control can result in positive linguistic outcomes [38-46]. Overall though, if bilinguals have an across-the-board enhancement of cognitive performance that is at the root of acceleration, it is difficult to reconcile why acceleration is so seldom documented in the literature.

Instead, Müller [47] argues that sometimes bilinguals rely on domain-general mechanisms in response to superficial similarities in their two languages, and this is mischaracterized as acceleration (see also [48, 49]). For example, bilingual learners of German in combination with a Romance language, such as Italian or French, tend to correctly place finite verbs in second position in German [51]. This is in contrast to age-matched monolingual German children who erroneously place finite verbs in final position [50]. On the surface this looks like acceleration. However, Romance languages typically follow a Subject-Verb-Object order, so verbs often appear in second position. In German, the placement of the verb is variable – finite verbs move to second position in matrix clauses but they remain *in situ*, in final position in embedded clauses. Müller contends that bilingual children succeed earlier simply by drawing on surface-level word order parallels in their two languages. Consistent with this account, although bilingual children correctly place finite verbs in second position in German earlier than their monolingual peers, approximately half of the bilingual children who skip the non-target-like verb-final stage face challenges with verb placement in German embedded clauses [51].

170 Two similar proposals (*NLM-e model* [52]; *Perceptual Wedge Hypothesis* [53]) have also
171 been posited to account for bilingual infants' putatively advanced abilities in speech perception.
172 Specifically, bilingual infants continue to show neural responses to non-native speech sound
173 distinctions when their monolingual peers have stopped responding to them. The bilinguals'
174 responses in these cases have been shown to reflect their reliance on auditory perceptual
175 sensitivities, rather than specific language experience as demonstrated by their monolingual peers
176 [53-56], which suggests that bilingual experience may promote extended flexibility or openness
177 to learning native and non-native contrasts because of their extended reliance on auditory
178 perceptual sensitivities.

179 Mateu and Sundara [7], however, present evidence against the proposal that the earlier
180 segmentation of English iambs by bilingual Spanish-English infants is due to their reliance on
181 domain-general mechanisms, specifically their ability to leverage transitional probabilities to
182 identify word boundaries. Bilingual adults [57, 58] as well as infants [59-62] have been
183 demonstrated to have an advantage when using transitional probabilities to find words in artificial
184 languages. However, Mateu and Sundara show that bilingual infants failed to segment Spanish
185 iambs, given comparable statistical cues. Thus, there is no evidence that bilingual 8-month-olds
186 rely solely on transitional probabilities to segment words in their native languages, or that this is
187 the reason for their earlier segmentation of English iambs.
188

189 1.1.4. Frequency effects

190 Often a necessary condition in proposals about acceleration is more evidence for a linguistic
191 feature in one language compared to the other. This hypothesis is sometimes referred to as
192 *additiveness* [63] and is supported by the widest range of studies: those investigating
193 phonological and morphosyntactic production in bilingual children as well as based on word
194 segmentation by bilingual infants.

195 Recall that Lleó et al. [17] found that bilingual Spanish-German children produce codas in
196 Spanish before their monolingual counterparts. As mentioned previously, codas are more frequent
197 in German than in Spanish, and therefore, bilingual Spanish-German children hear, and
198 consequently, produce more codas than their monolingual Spanish counterparts. Similarly,
199 Tamburelli, Sanoudaki, Jones, and Sowinska [64] found acceleration in the acquisition of
200 complex consonant clusters in Polish-English bilinguals – Polish-English bilinguals outperform
201 English monolinguals (7;0-8;11) when producing /s/ + obstruent clusters in English non-words.
202 Thus, exposure to Polish, a language with more complex onsets, facilitates the acquisition of
203 English, a language with fewer complex onsets.

204 A frequency account could also explain some of the results on production of determiners.
205 Kupisch [65] found that overall, the number of bare nouns, i.e., nouns that are not preceded by a
206 determiner are highest in German (18%), lower in Italian (12%) and lowest in French (6%).
207 Possibly as a result of exposure to languages where production of determiners is obligatory more
208 often, Italian-German and French-German bilingual children produce more determiners in
209 German compared to monolingual German children [21, 22]. A frequency-based account,
210 however, cannot explain why two Italian-French bilingual children showed positive transfer from
211 Italian to French [20], indicating that differences in frequency alone are inadequate to capture all
212 cases of acceleration.

213 Additiveness effects have been found in the domain of morphosyntactic acquisition as well.
214 Specifically, it has been reported that English *wh*-questions are acquired earlier in Spanish-
215 English bilinguals than in English monolinguals [66]. Hsin [66] claims that the facilitating effect
216 of Spanish on English *wh*-question production stems at least in part from the frequent exposure
217 to, and early mastery of, other operations utilizing the C-domain in Spanish. For example,
218 whereas object topicalization, a construction that involves movement to CP, appears in 1.35% of
219 all finite clauses in Spanish, [67], it only appears in 0.00134% of English finite clauses [68] (see
220 also [69]), i.e., topicalizations are 1,000 times more frequent in Spanish than in English.

221 Lastly, Mateu and Sundara [7] also attribute the acceleration effects found in segmentation
222 of English iambs to the effects of additiveness. In Spanish, stress placement in words is more
223 variable than in English. Approximately 40% of prosodic words in Spanish child-directed speech
224 start with a weak syllable, compared to only 10% in English [70]. Therefore, Spanish-English
225 bilingual infants hear more iambs compared to their monolingual English peers because of their
226 input in Spanish. The authors argue that because of their greater experience with iambs, Spanish-
227 English bilingual infants are able to associate stressed syllables with offsets as well at an earlier
228 developmental point than their monolingual peers.

229 1.3. The current study

In two experiments, we evaluated whether 8-month-old bilingual Spanish-English learning infants segment Spanish trochees earlier than their monolingual peers. Thus far, the word segmentation abilities of Spanish learning infants have been examined in two studies. Based on these studies we know that monolingual Spanish infants can segment monosyllabic words embedded in passages by 6 months [71]. However, we do not know when monolingual Spanish learning infants segment disyllabic words. In Mateu and Sundara [7], we tested Spanish monolingual and Spanish-English bilingual infants' ability to segment Spanish iambs; neither group succeeded. Therefore, if at all Spanish monolingual 8-month-olds are able to segment disyllabic words remains unclear. In both experiments we present data on monolingual Spanish-learning 8-month-olds as well to address this question. Crucially, if bilingual infants succeed at segmenting Spanish trochees when Spanish monolingual infants fail, the result would provide evidence of accelerated bilingual development.

All four hypotheses discussed above predict accelerated segmentation of Spanish trochees by Spanish-English bilingual infants. We tested all infants in Los Angeles, where English, arguably, is the community language. And we know from previous research that English-learning infants segment English trochees by 8-months [4]. So based on their English experience Spanish-English learning bilingual 8-month-olds should be able to segment Spanish trochees as well. Thus, based on a community construct of dominance, we expected accelerated segmentation of Spanish trochees. We also evaluated the dominance account at the individual level, where bilingual infants' acceleration is expected to be commensurate with percent of English input. In a salience-based account as well bilingual infants' segmentation of Spanish trochees is predicted to be accelerated because, as mentioned above, stress cues are more perceptually salient in English than in Spanish. Similarly, we expected to see acceleration based on the enhanced executive functioning hypothesis as well; bilingual infants are better able to track transitional probabilities than their monolingual peers. Finally, in English, 90% of content words start with a stressed syllable [1], compared to 60% in Spanish [72]. As a result of more exposure to trochees in English, following the additiveness account as well, we expected to see acceleration in Spanish-English bilingual infants.

2. Experiment 1

In Experiment 1, we familiarized Spanish-English bilingual 8-month-olds and their monolingual Spanish peers with Spanish trochees embedded in passages, then tested them on the Spanish trochees produced in isolation. Because we wanted to maximize the chances of success, all target words were of the form CVC.CV since in Spanish, 95% of words of this syllable shape are trochees [72], and Spanish learning infants have been shown to be sensitive to syllable weight when detecting stress at around 9-months [72]. Additionally, we have previously shown that monolingual English-learning 8-month-olds are able to segment these Spanish trochees, when given an extended familiarization phase of 60 seconds [73]. Thus, we know that these Spanish trochees can be segmented from passages by infants at 8-months.

2.1. Materials and Methods

2.1.1. Participants

We based our sample size on a meta-analysis of 285 experiments from 68 publications on infant word segmentation abilities [74]. The mean age of infants tested in the meta-analysis was 8-months (range = 6-25 months). The median sample size was 20 (range = 4-64 participants), with an aggregate effect size (Cohen's d) of 0.16 ($SE = 0.03$). We therefore aimed for at least 20 participants in each group.

The final sample included data from 29 Spanish-English bilingual 8-month-olds ($M = 8.49$, range = 7.5-9.7). Only infants who were exposed to Spanish between 20% and 80% of the time were included so we could compare their performance to the group of bilingual infants tested on English iambs in Mateu and Sundara [7]. Based on detailed language questionnaires, we calculated the number of hours per week each infant heard the two languages [75]. Exposure to Spanish ranged from 22.7 to 76.6% ($M = 47.5%$). Based on parental report none of the participants had a history of cognitive impairment or an ear infection on the day of testing. Four more bilingual infants were tested but excluded because they failed to complete the task due to fussiness. Additionally, 30 monolingual Spanish learning 8-month-olds ($M = 8.38$, range = 7.5-9.5) who had at least 80% of exposure to Spanish ($M = 95.1%$, range = 80.9-100%) were included in the study as a control group. Thus, the language profile of monolingual Spanish infants in this experiment was also similar to the group of monolingual infants in Mateu and Sundara [7]. Four more monolingual infants were tested but excluded due to fussiness. All infants were recruited from Los Angeles county, and none of them were tested in the experiments reported in [7].

2.1.2. Stimuli

The same Spanish stimuli used in Sundara and Mateu [73] were employed in this study. The four CVC.CV trochaic words were “gancho” *hook* [ˈgan.tʃo], “salsa” *sauce* [ˈsal.sa], “gesto” *gesture* [ˈhes.to], and “venda” *bandage* [ˈben.da]. 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 lists consisted of repetitions of the target words in isolation. Both passages and lists were recorded by a female native speaker of Mexican Spanish who was asked to read the sentences and words in infant-directed speech.

The acoustic properties of the stimuli are described in detail in Sundara and Mateu [73] and summarized here. As in the case of the English and Spanish iambic stimuli in Mateu and Sundara [7], duration was the only reliable cue to distinguish the first and second syllable in the passages and the lists of the Spanish trochees; the first stressed syllable (passages, 300ms; lists, 343ms) was significantly longer than the second, unstressed one (passages, 220ms; lists, 267ms). Pitch and intensity were not reliably different in either passages or lists. As reported in [73], the target trochaic words had a backward transitional probability of 0.33, meaning they were preceded by one of three different syllables, and a mean forward transitional probability of 0.18, they were followed by one of five or six different syllables. The English iambs employed in Mateu and Sundara [7] had comparable transitional probabilities, with slightly strong (i.e., lower) backward TP (0.17) and slightly weaker (i.e., higher) forward TP (0.23).

2.1.3. Procedure and Design

The Headturn Preference Procedure (HPP) as described in Jusczyk, Houston, and Newsome [4] was used to test segmentation of Spanish trochees from fluent speech. Infants sat on their caregiver’s lap in the center of a three-sided booth with three lights at the center of each panel. The two side panels also had a loudspeaker mounted behind the light. At the beginning of each trial, the light on the center panel flashed, attracting the infant’s gaze. When the infant oriented to the center panel’s flashing light, the center light stopped flashing and one of the lights on the side panels began to flash. When the infant turned their head and looked towards the side light, an auditory stimulus started to play. The audio presentation continued until the infant looked away from the flashing light for more than two consecutive seconds or when the trial ended (max duration = 17s).

The experiment consisted of two phases. In the familiarization phase, half the infants heard two passages with either *gancho* and *salsa* or *gesto* and *venda*. Once an infant accumulated 45s of listening time to each passage, the test phase started. In the test phase, infants were presented with four separate word lists (two familiar and two novel) in three blocks (12 trials total). The experimenter was seated outside the booth and observed 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-canceling headphones and listened to music with lyrics to eliminate potential biases. Testing lasted approximately 5-7 minutes.

2.2. Analyses

Listening times to the familiar and novel trials in the test phase were modeled with Bayesian linear mixed effects in the *R* programming environment [76] using the package *brms* [77]. In Bayesian statistics, the goal of modeling is to estimate parameters (i.e., β coefficients) that define the relationship between variables of interest – in this case, the relationship between Group (also Condition, Block), and trial type, on the dependent variable, Listening Time. The outcome is a probability distribution that indicates the plausibility of different values of the parameters of interest. A strength of this approach is that it can quantify support for the null hypothesis, unlike in frequentist analyses. Moreover, Bayesian methods do not require large sample sizes to produce accurate results, as they do not depend on asymptotic properties of estimators. This can be especially useful in infant studies which often rely on small sample sizes due to the considerable time, cost and effort required to collect data from infants.

The model was estimated using NUTS sampling with 4 chains of 8000 iterations and a warmup of 1000. For the population level effects, we set a default normal prior with a mean of 0 and a standard deviation of 1. We chose a weakly informative prior because we believed the coefficients to be small at best. For the intercept of the model, we set a prior with a weakly informative mean of 0 and a standard deviation equal to the standard deviation of infants’ listening time in milliseconds (SD = 4634), allowing the intercept to vary widely. For the residual standard deviation σ of the model, we chose a mean of 1 and a standard deviation of 0.5. For the full analysis code, see [OSF page](#).

Fixed effects included Group (Bilingual, Monolingual) and Condition (gancho.salsa, gesto.venda) as between-subjects variables and Block (1, 2, 3) and Trial Type (familiar, novel) as within-subjects variables, and all interactions. We also included random intercepts for subjects to model baseline differences in listening time (full model: ListeningTime ~ Group * Block * Condition * TrialType + (1 | subject)). Because percent of English input did not contribute to the model fit when examining the bilingual data, we do not report analysis with percent English as a variable. Planned comparisons were performed with the *emmeans* package [78].

Below we report the median estimated coefficient of each variable of interest (β) and its 95% Credible Interval (CI). The narrower the CI, the more precise the estimate of the effect. The effect is considered credible when the CI does not include 0. When the CI included 0, we report the probability of direction (pd); the pd varies between 50 and 100, and summarizes the percentage of estimated coefficients that have the same direction as the median coefficient β . If the pd is around 50, we can be confident that the independent variable does not contribute to model fit. Our estimations for all population-level effects converged (Rhats = 1.00 for all parameters).

2.3. Results

Overall, the bayesian analysis showed that both Spanish-English bilingual infants and their Spanish monolingual peers segmented Spanish trochees in Block 3; that is, we found no evidence for acceleration. Listening time data in each of the three blocks for bilingual Spanish-English and monolingual Spanish infants is presented in Figure 1. There was a credible three-way interaction between Trial Type, our variable of interest, with Block and Group ($\beta = 2.13$, [0.16, 4.09]). Post-hoc comparisons revealed that both bilingual ($\beta = 4.398$, [1.24, 7.49]) and monolingual infants ($\beta = 6.927$, [2.63, 11.28]) listened credibly longer at familiar words compared to novel words in Block 3. Listening times in no other blocks were credibly different. The interaction stemmed from a larger estimate in the monolingual group. Crucially, there was no main effect of Group ($\beta = 0.00$, [-1.96, 1.97], pd = 50.00%) nor an interaction of Trial Type by Group ($\beta = 0.21$, [-1.75, 2.17], pd = 58.39%). Because both estimates are centered around 0 with a pd less than 60%, we can be confident that there were no consistent differences between the Groups. The Full model results are reported on the project OSF page.

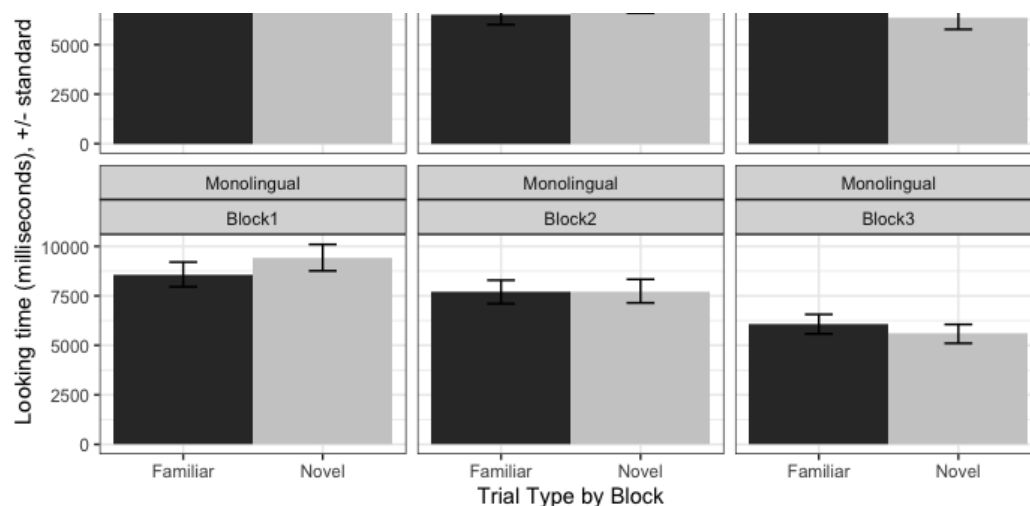


Figure 1. Listening times broken down by Block from Experiment 1 where we tested segmentation of Spanish trochees by bilingual Spanish-English learning infants (upper panel) and monolingual Spanish-learning infants (lower panel).

3. Experiment 2

Experiment 2 was designed to confirm that both monolingual and bilingual infants were segmenting the complete trochaic target word, and not only the stressed syllable (based on Jusczyk, Houston, & Newsome's [4] argument applied to segmentation of English iambs). In this experiment, we familiarized infants with the same passages containing the Spanish trochees, but

in the test phase they were presented with lists of the stressed syllables alone. If monolingual or bilingual infants in Experiment 1 were only segmenting the stressed syllable and not the entire trochee, we expected them to listen longer to the stressed syllable alone in this experiment. If monolingual infants only segment the stressed syllable whereas bilinguals segment the whole disyllabic word, this would also be evidence for acceleration. The opposite pattern where bilingual infants segment only the stressed syllable whereas monolinguals segment the whole disyllabic word, would be evidence of a delay.

3.1. Materials and Methods

3.1.1. Participants

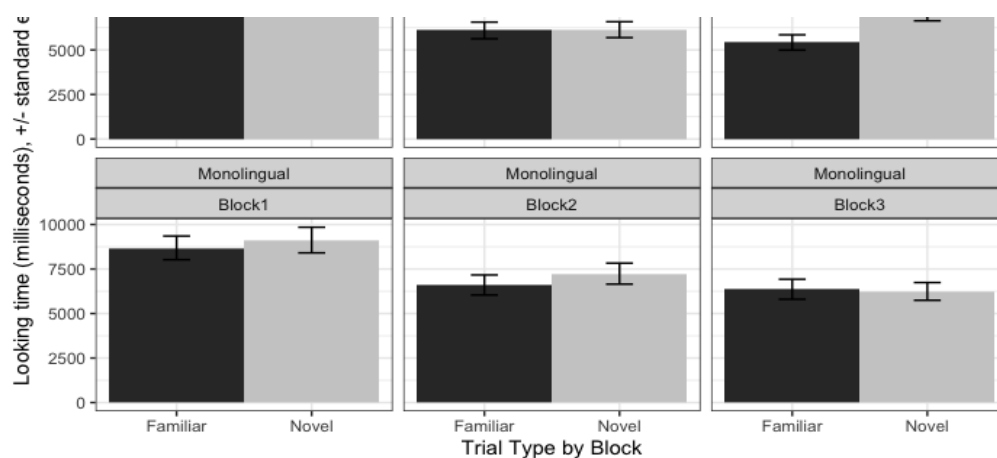
All inclusion criteria were identical to that in Experiment 1. In the final sample, data from 24 bilingual Spanish-English learning 8-month-olds ($M = 8.37$, range = 7.6-9.5) who had an average exposure to Spanish of 44.3% (range = 20% to 73.1%) were included. Eight more bilingual infants were tested but their data was excluded because they did not complete testing due to fussiness. Additionally, 28 monolingual Spanish learning 8-month-olds ($M = 8.6$, range = 7.5-9.5) who had more than 80% of exposure to Spanish ($M = 94.8\%$, range = 81-100%) were included in the study as the control group. One more monolingual infant was tested but excluded due to fussiness. None of the infants participated in Experiment 1 or in the experiments reported in [7].

3.2. Stimuli, Procedure and Design, and Analysis

The stimuli, procedure, design, and analysis (see OSF page) were the same as in Experiment 1, except that infants were presented with just the stressed syllable of the trochaic word – *gan*, *sal*, *ges*, and *ven* – in the test phase. Again, percent of English exposure was not a significant predictor in the model, so we do not report analysis with percent of English as a variable.

3.3. Results and Discussion

Again, using Bayesian analysis, we found no evidence that either bilingual Spanish-English learning infants or their monolingual Spanish peers were segmenting the stressed syllable alone. Listening time data in each of the three blocks for both groups is presented in Figure 2. Neither the effect of Trial Type nor any interactions with Trial Type were credible. Note that although the listening times of bilingual infants in Block 3 for novel words are numerically greater than that for familiar words the difference was not statistically reliable as shown by a CI centered close to 0 ($\beta = 0.268$, [-2.81, 3.32]). Full model results are reported on the project OSF page. In the absence of a difference between the bilingual and monolingual groups, we have no evidence for acceleration – or delay – in bilingual Spanish-English acquiring infants. That is, in Experiment 2 as well bilingual Spanish-English 8-month-olds behaved like monolingual Spanish-learning 8-month-olds.



428 **Figure 2.** Listening times broken down by Block from Experiment 2 where we tested the
429 segmentation of the stressed syllable of Spanish trochees by bilingual Spanish-English learning
430 infants (upper panel) and monolingual Spanish-learning infants (lower panel).

431 4. General Discussion

432 In this study we sought to identify the conditions under which bilingual development is
433 accelerated. In Experiment 1, we tested bilingual Spanish-English 8-month-olds and their
434 monolingual Spanish peers on their ability to segment Spanish trochees. Our results showed an
435 identical pattern of results for monolingual and bilingual infants – longer listening times to the
436 familiar words in the third block. Further, the performance of bilingual infants was not correlated
437 with the extent of English input. Results from Experiment 2 further confirmed that neither group
438 was simply extracting the stressed syllable out of the trochee, providing further evidence that
439 there was no difference in the performance of bilingual Spanish-English and monolingual Spanish
440 infants. Thus, infants in both groups behaved similarly – they did not segment the stressed
441 syllable in Experiment 2, but successfully segmented the whole trochee in Block 3 in Experiment
442 1. We first discuss the evidence for successful segmentation of Spanish trochees by Spanish-
443 learning bilinguals and monolinguals, then revisit the four hypotheses predicting acceleration in
444 bilingual infants.

445 Recall that although there is evidence that monolingual Spanish learning infants can
446 segment Spanish monosyllabic words [71], it is unclear whether they can segment disyllabic
447 words. Mateu and Sundara [7] did not find evidence that Spanish learning 8-month-olds, whether
448 monolingual or bilinguals, segment Spanish iambs. We present the first evidence that Spanish
449 learning 8-month-olds are able to segment Spanish trochees. Monolingual infants listened
450 credibly longer to previously familiarized Spanish trochees in Experiment 1, and not to the
451 stressed syllable alone in Experiment 2. Note however, that we saw evidence for credible
452 segmentation of Spanish trochees in Block 3 alone (Experiment 1). We are now testing
453 monolingual Spanish learning infants to delineate the developmental trajectory of word
454 segmentation in Spanish.

455 Crucially for our research question, Spanish-English bilingual infants as well just like the
456 monolingual Spanish learning infants, credibly segmented Spanish trochees in Block 3.
457 Therefore, contra the predictions of all four hypotheses, we saw no evidence of accelerated
458 segmentation of Spanish trochees in bilingual infants. Our results are clearly incompatible with
459 language dominance accounts. In dominance-based accounts bilinguals transfer knowledge from
460 their dominant language, which can lead to accelerated development in their non-dominant
461 language (e.g., [14,19]). We included bilingual infants with exposure to English ranging from
462 20% to 80%, and yet bilingual infants' success at segmenting Spanish trochees was not predicted
463 by percent of exposure to English. Further, recall that all Spanish learning infants were tested in
464 Los Angeles, where the language of the community is English. So dominance, whether defined
465 using a continuous measure at the individual level, or in a categorical way based on the
466 community language, did not predict acceleration.

467 The findings presented here are also inconsistent with proposals where the acquisition of
468 more perceptually prominent linguistic elements results in accelerated sensitivity to the less
469 prominent feature. Stress is arguably more salient in English than in Spanish. Thus, exposure to
470 English stress should have accelerated Spanish learning infants' segmentation of Spanish
471 trochees; but that was not the case. Mateu and Sundara's previous finding that Spanish-English
472 learning infants' ability to segment English iambs is accelerated, is also inconsistent with a
473 perceptual salience based account; stress is not as salient in Spanish as in English and
474 nevertheless it is exposure to Spanish that accelerated segmentation of English iambs.

475 Proposals that claim that acceleration is due to bilingual infants relying on a more efficient,
476 non-linguistic computation also fail to account for either the findings reported here or the ones
477 previously reported in Mateu and Sundara [7]. If bilingualism itself confers an advantage due to
478 better statistical learning abilities, then Spanish-English learning bilinguals should show
479 accelerated word segmentation abilities when tested on Spanish trochees (this study) and Spanish
480 iambs (previously tested in Mateu & Sundara [7]) as well, analogous to their accelerated ability to
481 segment English iambs. Recall that the transitional probability cues are comparable for all three
482 sets of stimuli. However, bilingual 8-month-olds failed to segment Spanish iambs, just like
483 monolingual Spanish infants, showing no evidence for acceleration in Mateu & Sundara [7]. In
484 the present study, again, there were no differences in the performance of the two groups: bilingual
485 Spanish-English learning infants as well as monolingual Spanish learning infants demonstrated
486 segmentation of Spanish trochees in Block 3.

487 An addictiveness-based account also fails to account for our findings. We have argued
488 previously in [7] that the determining factor in predicting accelerated segmentation of English

489 iambs by bilingual infants was addictiveness (i.e. frequency effects). In English, only 10% of
490 words start with a stressed syllable, whereas in Spanish the proportion is greater, 40% [70]. Thus,
491 because of their Spanish experience, bilingual infants hear many more iambs than monolingual
492 infants, which positively influences their ability to segment those from fluent speech in English.
493 Consistent with the addictiveness account, we expected to see accelerated segmentation of Spanish
494 trochees by bilingual infants in the current study because in English 90% of content words start
495 with a stressed syllable [1], compared to 60% in Spanish [72]. However, this was not the case.
496 That is, the greater frequency of a linguistic feature in one language does not inevitably lead to
497 acceleration in the other language.

498 Instead, we propose that the findings of acceleration in segmenting English iambs, but not
499 Spanish trochees, is owing to the fact that iambs are highly infrequent in English (10%), whereas
500 trochees are not as rare in Spanish (40%). We know that infrequent patterns are underlearned
501 cross-linguistically, early in acquisition, e.g., [79-82]. In artificial language experiments in the lab
502 as well, learners are often biased to “sharpen” statistical distributions in their input, pushing them
503 to prefer probabilities closer to 0 or 1, thus producing near-categorical learning outcomes [83-85].
504 This is especially true for children [86,87]. That is, young learners often fail to acquire infrequent
505 patterns early in acquisition. This may be because they fail to encode infrequent patterns due to
506 memory limitations [84]. Or because they regularize variability in the input [83,86] (see also
507 [88,89]). Or because they filter infrequent patterns out as noise [82,90].

508 Whatever the cause, we see its effects during the development of word segmentation
509 abilities in monolingual English learning infants. English-learning 8-month-olds associate
510 stressed syllables with word onsets, consistent with English input where 90% of the words start
511 with a stressed syllable. At the same age they temporarily fail to segment English iambs like
512 *guitar* and *surprise* [4], which constitute only 10% of English input [2].

513 No such underlearning is likely to be observed for the segmentation of Spanish trochees,
514 because trochees constitute 60% of Spanish input. Therefore, only bilingual Spanish-English
515 learning infants’ segmentation of English iambs (not Spanish trochees) benefits from the additive
516 effect of input from the other language.

517 Extrapolating from these results to bilingual acquisition we conclude that acceleration will
518 not necessarily be observed when one language simply has more evidence for a pattern than the
519 other. Instead, we expect it to emerge when one language has minimal evidence for a pattern and
520 the other has substantially more instances of this pattern. Because of the addictiveness of evidence
521 from one language for the infrequent pattern, learners do not regularize, fail to encode, or filter
522 out the infrequent pattern in the other.

523 In this paper we focused our attention towards identifying conditions for accelerated
524 development in word segmentation by Spanish and English learning bilingual infants. We
525 propose that it is only the learning of infrequent patterns in one language that may benefit from
526 increased experience with the same pattern in another language. In addition to making falsifiable
527 empirical predictions, our proposal restricts the cases – whether phonological or morpho-syntactic
528 – where development may be accelerated. This is necessary because accelerated development in
529 bilinguals is not common, so we need to be able to pinpoint fruitful areas of research if we want a
530 window into language representation in bilingual learners. Another strength of this proposal is
531 that it relies on bilingual infants using the same core mechanisms as monolingual infants in
532 service of learning both their native languages. What we did not do in this paper is investigate the
533 interaction between the various accounts proposed to account for acceleration, although we do
534 state in the introduction that the four proposed accounts are not mutually exclusive. To fully
535 understand cross-linguistic interaction in developing bilinguals, future research exploring the
536 acquisition of linguistic features where these proposals intersect is necessary.

537 5. Conclusions

538 In sum, when bilingual learning children exhibit an accelerated rate of linguistic
539 development compared to monolingual children, we can gain a better understanding of language
540 representation in bilinguals, if we are able to rule out explanations originating in imbalanced
541 input, or bilinguals’ reliance on domain-general mechanisms. In two experiments we showed that
542 just like their monolingual Spanish learning peers, bilingual Spanish-English learning 8-month-
543 olds successfully segment Spanish trochees, and not just the stressed syllable. These results
544 cannot be explained by language dominance, accounts appealing to perceptual salience or
545 bilingual infants reliance on domain-general abilities. They also cannot be attributed merely to
546 increased exposure to a pattern in one language compared to another. That is, increased exposure
547 to a linguistic feature does not automatically result in accelerated development. We argue that
548 only the acquisition of infrequent patterns in one language can be accelerated from the additive
549 effects of exposure to the other language. As a result, bilingual Spanish-English learning infants

segment infrequent English iambs, but not the more frequent Spanish trochees, earlier than their monolingual peers.

Author Contributions: Conceptualization, V.M. and M.S.; methodology, V.M. and M.S.; formal analysis, V.M. and M.S.; investigation, V.M. and M.S.; resources, M.S.; data curation, V.M. and M.S.; writing—original draft preparation, V.M. and M.S.; writing—review and editing, V.M. and M.S.; visualization, V.M. and M.S.; project administration, M.S.; funding acquisition, M.S.. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by two UCLA COR Faculty research grants and NSF BCS-2028034 to M.S.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of University of California, Los Angeles (#10-001562; 10 Dec 2010 - to date).

Informed Consent Statement: Informed consent was obtained from caregivers of each infant participant involved in the study.

Data Availability Statement: Deidentified data are available from the OSF page for this project: <https://osf.io/rncmq/>

Acknowledgments: We would like to thank Dulce Montoya for recording the stimuli, Chad Vicenik, Robyn Orfitelli, Rosalva Mejía, Anya Mancillas, Hadley Stork, and Guadalupe Ramírez for help with recruiting and testing infants.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

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. Quitate 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.*

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