Can non-native speakers reduce English vowels in a native-like fashion? Evidence from L1-Spanish L2-English bilinguals

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Abstract

This paper investigates the production of English unstressed vowels by two groups of early and late Spanish bilinguals and a control group of native English (NE) monolinguals. Three acoustic measurements were obtained: duration and intensity ratios of unstressed to stressed vowels, normalized vowel formants and Euclidean distances. Both groups of bilinguals showed significantly less differences in duration between stressed and unstressed vowels than the NE monolinguals. Intensity differences depended on whether the stress pattern of the target English words matched the stress pattern of their Spanish cognates. As for vowel quality, the early bilinguals reduced the unstressed vowels, which clustered around the mid-center area of the vowel space, in the same fashion as the NE monolinguals suggesting that vowel reduction might be operating at the phonological level. However, the late bilinguals showed a context-dependent, phonetic-level pattern with vowels that were more peripheral in the vowel space.

1. Introduction

1. 1. Acoustic correlates of word stress in English and Spanish

English and Spanish differ prosodically, whereas English is a stress-timed language with both full and reduced vowels that vary in duration and prominence, Spanish is a syllable-timed language with full vowels only. Both languages also vary in the relative weight of the three acoustic correlates that are known to signal stress, F0, intensity and duration. One of the earliest studies investigating the acoustic correlates of stress was carried out by Fry [1955], who documented that duration and intensity ratios were both cues for judgments of stress in English. Later, Edwards and Beckman [1988] reported that vowel duration was found to be a consistent correlate of stress at the word level, whereas pitch accents were correlates of stress at the sentence level.

Early accounts of Spanish phonology provide conflicting evidence of the role of different acoustic correlates of Spanish lexical stress. For instance, Quilis [1971] claimed that pitch is the most reliable cue of stress in Spanish. This claim was later questioned by Pamies Bertrán [1997], who pointed out that the prosodic context shaped the weight of F0 on Spanish lexical stress and that Quilis' study only targeted words embedded in the same carrier phrase and read in citation form. In a corpus study of utterances in various languages, including Spanish and English, Pamies Bertrán used a normalized metrics (syllabic prominence coefficient) to establish a hierarchy of acoustic correlates of Spanish lexical stress. These coefficients were calculated from transforming into percentages the duration, pitch and intensity ratios of the stressed syllables to their unstressed counterparts. Results indicated that duration and intensity had a heavier weight to signal word stress than pitch, with percentages that ranged from 27% to 46% (duration) and from 27% to 56 % (intensity), as opposed to the minor weight of pitch (13% to 21%). More recently, Ortega-Llebaria and Prieto [2010] examined the role of duration, overall intensity and spectral tilt defined as the 'degree of intensity in the higher frequency regions of the spectrum in relation to intensity in the lower frequency regions' (p. 75) in minimal pairs of the type *deter**mi**no-determi**nó** ('I establish-(s)he established'),* in which the position of the stress signals two different verb tenses. The target words were embedded in declarative and reporting clauses. They found that duration was a strong correlate of stress in Spanish regardless of vowel quality differences and prosodic context. Overall intensity was also used to signal stress differences but it had a minor role. Finally, spectral tilt differences were found to be more related to vowel quality differences than to differences between stressed and unstressed syllables.

It is well known that stress affects vowel quality in many of the world's languages by way of a process called vowel reduction. Acoustically, this process is characterized by a 'shrinking effect' of the vowel space or shift of a vowel towards the center of this space [Lindblom, 1963; Moon and Lindblom, 1994]. It is caused by a decrease of muscular activity and it involves the co-occurrence of various articulatory gestures. These include, (*i*) laxing of vowels, which causes high vowels to become lower and peripheral vowels to become more central, and (*ii*) shortening of temporal duration of muscular activity. Typological studies of unstressed vowel reduction [Barnes , 2006; Bybee, 2001 among others] distinguish between 'phonological vowel reduction' or neutralization of phonological contrasts in unstressed syllables and 'phonetic vowel reduction'a less dramatic process of centralization or raising of non-high vowels. This distinction between phonetic and phonological vowel reduction was also found in earlier studies [Miller, 1981; Fourakis, 1991]. For instance, Fourakis [1991] referred to phonological vowel reduction as a "process whose application causes unstressed vowels to be realized as schwas" (p. 1816). In the case of English, it does not apply to all vowels, since the monophthongs /ɔ/, /u/, and /ʊ/ do not become schwa in unstressed position. At the phonetic level, vowel reduction affects all vowels and it refers to "the tendency for the obtained formant frequencies of a vowel to fall short of the idealized target vowels for that vowel–those values that would be obtained if the vowel were produced in isolation–resulting in an overall shrinkage of the vowel space" [Miller, 1981, p. 42]. Various factors contribute to vowel reduction at the phonetic level, among them, speech rate, contextual assimilation and sentence stress [Fourakis, 1991; Moon and Lindblom, 1994]. For instance, Moon and Lindblom [1994] argue that when a vowel assimilates or becomes articulatorily more similar to its consonant environment and its acoustic properties approach those of the surrounding consonants. This phenomenon is defined as the 'undershoot effect' [Lindblom, 1963; Stevens and House, 1963] or systematic shifts away from 'hypothetical target values'. More recently, Clopper and Pierrehumbert [2008] have documented other lexical and semantic factors that also contribute to the degree of vowel reduction, at the phonetic level, among them, lexical frequency, word density, semantic predictability and word neighborhood.

In Spanish, loss of lexical stress does not involve phonological vowel reduction [Quilis, 1971; Quilis and Esgueva, 1983; Hualde, 2005]. However, more recent research provides evidence of vowel timbre differences between stressed and unstressed vowels at the phonetic level. For instance, in a very detailed account of vowel quality in Spanish and Catalan, Nadeu [2014] found that both vowel quality and vowel duration are sensitive to the absence of lexical stress. Specifically, stressed /a/ was lower in the acoustic vowel space than unstressed /a/ and the unstressed realizations of the Spanish vowels /i, a, o/ were more anterior than their stressed counterparts, although this trend was not consistent across speakers. Similarly, in a study about the acquisition of Spanish vowels by L1-English intermediate learners living in the United States, Cobb and Simonet [2015] reported that a control group of native Spanish speakers raised in Peru and Mexico in Spanish monolingual households but living in the US, exhibited systematic differences in vowel quality between the stressed and unstressed realizations of all Spanish vowels, which were less peripheral in the vowel space than their stressed counterparts. According to the authors, these findings provide supporting evidence of the existence of 'vowel-specific patterns of phonetic, gradient unstressed vowel reduction' in Spanish .

1. 2. Theoretical models in L2 speech learning

Much of the empirical research in L2 perception and production of speech sounds has attempted to test the hypotheses posed by two theoretical models, the Speech Learning Model (SLM for short) proposed by Flege [1995] and the Perceptual Assimilation Model (PAM) proposed by Best [1994] and its extension PAM-L2 [Best and Tyler, 2007]. Both models share the tenet that exposure to the sounds of the ambient language at infancy and early childhood shapes our language experience and determines how we perceive other L2 speech sounds that are acquired later in life in bilingual/multilingual environments. However, the models diverge in the level of analysis of L2 learning, whereas the SLM operates at a phonetic level in that it hypothesizes that successful L2 learning involves reorganizing L1 phonetic categories and establishing new ones, PAM-L2 assumes that the L1 and L2 categories interact at both the phonetic and the phonological levels. Presumably, the L2 learner ends up with a single interlanguage phonological category that serves the two languages and is realized as two single L1 and L2 phonetic categories. The issue of the phonetic and/or phonological level of analysis is relevant to the present study because we have just reported that vowel reduction operates at a higher-order phonological level in English but at a lower fine-grained phonetic level in Spanish. On these grounds, the present study will attempt to shed some light on the phonetic/phonological status of vowel reduction shown by Spanish-English bilinguals. Another point of divergence between both models is the question of time constraints in L2 category learning. While SLM claims that this reorganization of L1-L2 categories remains adaptative over the learner's life span, PAM-L2 predicts that there are time constraints for this perceptual learning to be successful. Specifically, the optimal time would not last much and it would take place in the first stages of L2 acquisition. As L2 learners make progress in the learning ladder and their lexicon expands, they are hypothesized to pay less attention to phonetic detail and shift their attention to higher-order linguistic levels such as morphology or syntax. The relevance of time constraints to the present study lies in how early and late Spanish-English bilinguals will differ in their production of unstressed vowels.

1. 3. Empirical work in L2 suprasegmentals

While a reasonable number of studies have explored the acquisition of segmental features in bilingual populations [Amengual, 2012; Casillas, this volume; Mora and Nadeu, 2012; Simonet, 2010], many researchers agree that the acquisition of L2 suprasegmentals has received much less attention in the literature [Cobb and Simonet, 2015; Chun, 2002; Trofimovich and Baker, 2006]. This might be due to the fact that PAM-L2 and SLM limit their predictions and hypotheses to the acquisition of L2 segmentals. The scarcity of empirical studies on the acquisition of L2 suprasegmentals is striking if we consider that word and sentence stress, rhythm and syllable structure have been found to consistently contribute to the perception of foreign accented-speech.

The cross-linguistic differencences between English and Spanish cues of word stress has a direct impact on bilinguals who learn English as a second language in that prosodic aspects of speech such as stress misplacement, intonation and tempo are known to contribute to the perception of foreign accent and the loss of intelligibility of L2 speech. For instance, Magen [1998] investigated the relative weight of various segmental and suprasegmental factors in the accentedness judgments of English sentences produced by native Spanish speakers. Some of these factors included: insertion of initial epenthetic schwa, vowel reduction, tense-lax vowel pairs, lexical stress and sentence stress. The foreign accent ratings revealed that native English listeners were highly sensitive to word and sentence stress in their perception of accented speech. Similarly, Munro and Derwing, [1999] noted that phonemic errors do not seriously mar intelligibility of L2 speech but prosodic errors have a stronger impact on the loss of intelligibility. Field [2005] manipulated stress placement and vowel quality of English words and presented them to native and non-native English listeners for intelligibility assessment. The manipulations involved three conditions: standard form, stress shift with no change of the weak vowel quality and stress shift with change to full vowel quality. Stress misallocation seriously compromised intelligibility and, more importantly, when stress misplacement was combined with a change to a full vowel, intelligibility decreased substantially, especially among the non-native listeners.

An early study by Flege and Bohn [1989] used glossometry —a technique to measure tongue movements consisting in a light emiting diode (LED) and a pseudopalate with sensor assemblies

[Flege et al., 1986]—, as well as phonetic transcription to investigate the acquisition of English stress by native Spanish speakers. They found that participants implemented the difference between stressed and unstressed vowels in terms of intensity and duration differences in a native-like fashion. Stress placement was not difficult to acquire and it was learned on a word-by-word basis. However, vowel reduction was more difficult to learn.

Gutiérrez-Díez [2001] examined syllable duration in read-aloud passages produced by a group of English native speakers living in the UK and another group of Spanish native speakers who were also advanced learners of English in Spain. The native Spanish group was tested in both languages, that is, they read a passage in Spanish and another one in English. Stressed to unstressed syllable duration ratios for the native Spanish were found to be significantly shorter than the mean duration ratios for the native English group. However, when the duration ratios produced by the native English group were compared with those produced by the Spanish group in the English read-aloud passage, only small significant differences were found between both groups. Interestingly, the target duration ratios attained by the Spanish learners were intermediate between English and Spanish, suggesting that the learners' interlanguage showed an 'attenuated interference or transfer error'.

McAllister, Flege and Piske [2002] investigated the perception and production of Swedish quantity distinctions in a group of Swedish monolinguals and three groups of bilinguals with different L1 backgrounds: L1-Estonian, L1- English and L1-Spanish. The three languages also differ in the phonetic/phonological status of vowel quantity. Whereas Estonian vowels have phonologically-distinct vowel quantity differences, these differences are not phonologically distinct in either English or Spanish. The study tested the validity of a 'feature hypothesis' derived from the SLM, which states that L2 features not used to distinguish a given contrast in the L1 will be difficult to perceive and produce for the L2 learner. The relevant results for the present study are that the phonetic /phonological status of vowel quantity in the L1 predicted successful perception and production of the Swedish vowels. Estonian speakers were the most successful in learning the Swedish quantity contrast, followed next by the English speakers and last by the Spanish speakers. English and Spanish speakers differed from one another because of a difference in the role of duration in both languages. The sound system of English has both long and short vowels and some English vowel pairs such as /i-ɪ/ and /u-ʊ/ contrast in length as well as in vowel quality. However, Spanish does not have short and vowel length distinctions, which accounts for the poorer performance of Spanish speakers relative to their English and Estonian peers.

1. 4. The present study

This study was designed with two major goals in mind. On the one hand, we intended to investigate the role of the L1 (Spanish) phonetic features in the production of the L2 (English) phonetic features, specifically, whether two groups of L1-Spanish L2-English bilinguals varying in length of residence in the United States could implement English word stress in a native-like fashion. On the other hand, we wanted to test the effect of age of arrival (AOA) in the host country on the production of English unstressed vowels.

The Feature Hypothesis [McAllister et al., 2002] proposes that L2 phonetic features not used to signal phonological contrasts in an L1 will be more difficult to perceive than those that are. Further, the difficulty in perceiving phonetic features that are not phonologically meaningful will be reflected in low production accuracy of these features in the L2. In the light of this framework, the following research questions were addressed:

(1) Will L1-Spanish L2-English bilinguals produce English unstressed vowels with unstressed-to-stressed duration and intensity ratios that will fall in the range of the ratios produced by a group of NE controls?

Following the FH, it was hypothesized that Spanish-English bilinguals would have little difficulty implementing differences between unstressed and stressed vowels in terms of duration and intensity ratios. The grounds for this prediction lay on the findings of previous studies reporting that the acoustic cues of Spanish lexical stress include vowel duration and intensity [Ortega-Llebaria and

Prieto, 2010; Ortega-Llebaria et al., 2013; Pamies Bertrán, 1997]. Accordingly, Spanish-English bilinguals are likely to transfer the phonetic features of their L1 (Spanish) to signal syllable prominence in the L2 (English).

(2) Will the Spanish-English bilinguals reduce English unstressed vowels? If so, will this vowel reduction operate at the phonetic level or at the phonological level?

In this case, the FH predicts greater difficulty of L2 feature production because, unlike English, Spanish unstresed vowels are not reduced phonologically. This clear cross-linguistic difference between Spanish and English prosodies will probably have an effect on the L2 productions of Spanish-English bilinguals, who are hypothesized to produce less reduced vowels than the English monolinguals. Based on the findings of recent research in Spanish prosody [Cobb and Simonet, 2015; Nadeu, 2014], we also predict that the bilingual speakers are more likely to show specific context-dependent phonetic patterns of vowel reduction rather than a high-order pattern of vowel reduction working at the phonological level. In other words, it is unlikely that the bilinguals reduce the English unstressed vowels as schwa on a regular basis, this would imply that the unstressed vowels cluster in the center of the vowel space and overlap each other as instances of one single vowel category. Our prediction is that bilinguals are more likely to show a phonetic pattern of vowel reduction, consisting in a less peripheral vowel space with various distinct vowel categories.

(3) Will the age of arrival (AOA) in the host country have an effect on the production of English unstressed vowels by Spanish-English bilinguals?

Based on the findings of previous research investigating the effects of experience in L2 speech learning among bilinguals, early bilinguals are predicted to show more native-like implementation of English word stress than their late bilingual peers.

2. Method

2. 1. Participants

Three groups of speakers (N = 31) consisting of a control group of 10 native English monolinguals (NE) with a mean age of 25 years, 11 early Spanish-English bilinguals (ESp) with a mean age of 33 years, and 10 late Spanish-English bilinguals (LSp) with a mean age of 25 years, participated in the study. The number of male and female participants was balanced across the three groups. All the participants reported normal hearing and passed a pure tone hearing screening in both ears from 500 to 4000 Hz at octave intervals prior to the recording session.

The participants in the two bilingual groups were carefully selected to include only experienced speakers who used English on a daily basis, had lived in the U.S. for extended periods of time and had attended colleges and universities there. The early bilinguals' first exposure to English occurred at the age of 3.7 on average and the late bilinguals' first exposure after 21 years of age. When asked about the overall percentage of time they used English, the early bilinguals reported using the target language 84% of the time on average; on their part, the late bilinguals reported using English 75% of the time on average. To measure English language proficiency we used the same standarized tests as Lee et al. [2006]. Two subtests of the Test of Adolescent and Adult Language [Hammill et al., 1994] that focus on receptive vocabulary (TOAL1) and receptive grammar (TOAL2) were administered to the two groups of Spanish-English bilinguals as well as to the English monolinguals. A more detailed account of the linguistic profiles for each group can be found in Table 1. The scores of the TOAL1 and TOAL2 tests obtained by the two bilingual groups were submitted to two independent-samples t-tests. The results showed that both sets of scores were not significantly different from one another: TOAL1 [$t(19) = 1.41$ $p = 0.175$] and TOAL2 [$t(19) = -0.58$ $p = 0.56$].

******Table 1 about here********

2. 2. Speech Materials and procedures

The speech corpus of this study was the same used by Lee et al. [2006]. It consisted of 19 English words (see Table 2), in which stress fell on different syllabic positions (initial, medial, final). The participants were recorded producing the target words, which were presented orthographically within the carrier phrase *I say … this time*. This carrier phrase was used to keep a constant prosodic environment across words. The speech samples were recorded in a sound-proof booth using a DAT tape recorder and later digitized at 22.05 kHz sampling rate.

3. 3. Measurements and analyses

The speech samples were analyzed acoustically with the Praat program [Boersma and Weenik, 2013]. The stressed and unstressed vowel intervals of each word were segmented, labelled and annotated using the TextGrid utility (see Fig. 1). In the words *agenda* and *banana*, both the pre-tonic and post-tonic syllables were considered for the measurements. For the segmentation of the vowel intervals, the principles of acoustic speech segmentation recommended by Turk et al. [2006] were followed. The general strategy was to locate the constriction onsets and releases as well as the dips and rises of amplitude of the surrounding consonants on and spectrographic displays. For instance, in the word *agenda* the boundaries of the /ɛ/ segment were set between the frication noise release of the preceding voiced affricate and the abrupt dip of spectral energy of the following nasal; in *banana*, the boundaries of the pre-tonic /ə/ were set between the offset of the voice bar and the dip of spectral energy of the following nasal; when the surrounding consonants were approximants such as in *kangaroo* or *eleven*, dips of spectral energy and slopes of the F2 and F3 were considered to set the offset and onset boundaries of the vowel segments. Three acoustic measurements were obtained, namely, vowel duration, mean intensity and vowel quality in terms of F1 and F2 frequencies. The values of the three acoustic parameters were automatically extracted by using two Praat scripts designed for this purpose [Lennes, 2011]. The scripts provide the average intensity and duration of the vowel intervals and, the F1, F2 and F3 frequencies measured at the midpoint of each labeled interval. Finally, the duration and intensity raw measurements in a given word were converted to duration and intensity ratios of the unstresed to the stressed vowel.

**********Insert figure 1 about here**************

Further, the vowel formant frequencies were normalized to neutralize sex-linked differences in vocal tract lengths. The vowel normalization method had been previously used in cross-linguistic studies comparing vowels [Yang, 1996] or studies investigating bilingual speech [Guion, 2003; Lee et al., 2006]. This method consists in normalizing all the formant values to one randomly selected speaker of the NE control group on the basis of the F3 frequency of the vowel /æ/ in the words *banana, basket, calendar, giraffe*, and *manage*. The mean F3 of this NE speaker was taken as the norm and was divided by the mean F3 for each bilingual speaker, which gave us a given factor for each bilingual. The raw formant values obtained for each individual speaker were subsequently multiplied by a k factor derived from their own F3. For instance, the unnormalized formant values of /ə/ in the word *compensate* produced by an early bilingual speaker were 238 Hz and 1870 Hz, respectively; the mean F3 of /æ/ was 2585 and the mean F3 of the NE speaker which was taken as the norm was 2499.75. Following the formula given below, the normalized F1 and F2 values of the bilingual speaker become 230 Hz and 1808 Hz, respectively.

$$2499.75/\text{mean F3 } S_i = k_i$$

where 2499.75 = the average F3 of /æ/ for one American English speaker to whom all others are normalized, mean F3 = the mean F3 of /æ/ for a given subject and k_i = k factor for a given subject .

4. Results

Since the target words used in the experiment differed from Spanish in terms of their cognate status and stress pattern, we classified them in two groups depending on whether they were cognates and whether the stress pattern matched the Spanish stress pattern (see Tables 2 and 3). The 'stress-matched' words were all cognates and their stress pattern matched the Spanish stress pattern. This group included the words *agenda, banana, basket, giraffe, manage, medium, potato* and *spaghetti*. The 'non-stress-matched' words included the cognates that did not match the Spanish stress pattern, namely, *agent, calendar, compensate, descent, indicate, introduce, kangaroo machine, origin*, *possess* plus the non-cognate *eleven.* Four separate repeated measures ANOVAs were run to test the main effects of Word and Group as well as the two-way interaction on the duration and intensity ratios of the 'stress-matched' and 'non-stress-matched' words.

3. 1. Duration

Table 2 shows the mean duration ratios and standard deviations obtained by each of the Spanish early and late bilinguals and the English monolinguals tallied across the stress-matched and non-stress-matched words. A given value closer to 1, indicates little difference between stressed and unstressed vowel durations. Conversely, values closer to 0 indicate greater duration differences between stressed and unstressed vowels. Although the duration ratios exhibit a certain degree of variability as a function of word, the general tendency is that both groups of bilinguals produced unstressed vowels that were insufficiently shorter relative to their unstressed counterparts (see Figs. 2a and 2b). In contrast, English monolinguals produced unstressed vowels that were considerably shorter than their stressed counterparts. In order to test whether these group differences were significant, the mean unstressed-to stressed duration ratios obtained for the two groups of Spanish-English bilinguals and the English monolinguals were submitted to two repeated measures ANOVAs –one for the stress-matched cognates and another one for the non-stress-matched– with Word (8 stress-matched, 11 non-stress-matched) as the within-subjects factor and Group (3) as the between-subjects factor. The stress pattern did not affect the duration ratios, since similar results were obtained regardless of whether the words matched the stress pattern of the Spanish cognates. The ANOVA yielded ~~a~~ significant effects of Group [stress-matched words $F(2, 28) = 20.44$, $p < 0.001$; non-stress-matched words $F(2, 28) = 23.65$, $p < 0.001$], ~~a~~ significant effects of Word [stress-matched $F(7, 196) = 23.99$, $p < 0.001$; non-stress-matched $F(10, 280) = 25.75$, $p < 0.001$] and ~~a~~ significant two-way interactions [stress-matched $F(14, 196) = 2.52$, $p < 0.005$; non-stress-matched $F(20, 280) = 2.7$, $p < 0.001$]. Pairwise comparisons with *Tukey*'s DHS post-hoc tests revealed that both the early and late bilinguals' duration ratios differed from the English monolinguals' ratios [$p < 0.001$ for both 'stress-matched' and 'non-stress-matched' words], but none of the two bilingual groups' duration ratios diferred from one another [stress-matched $p = 0.840$, non-stress-matched $p = 0.969$]. The significant interactions showed that duration ratios varied considerably as a function of word, even among the English monolinguals. These analyses seem to indicate that the Spanish-English bilinguals did not implement duration differences between unstressed and stressed vowels in a native-like fashion. They produced shorter vowels in unstressed position but this vowel length reduction was insufficient to reach native-like standards.

***************Table 2 about here****

**************Figs. 2 a and 2 b about here**************

3. 2. Intensity

The mean intensity ratios and standard deviations of the unstressed to stressed English vowels produced by the two bilingual groups and the native English monolinguals are shown in Table 3. As with the duration ratios, values closer to 1 are indicative of little intensity differences between stressed and unstressed vowels, whereas values closer to 0 indicate greater intensity differences. As shown by the results of the repeated measures ANOVAs, different trends were found depending on whether the target words matched the Spanish stress patterns (see Figs. 3a and 3b). When the stress-matched words were analyzed, the ANOVA yielded a significant main effect of Group, [$F(2, 28) = 5.01$, $p < 0.05$], a significant main effect of Word, [$F(7, 196) = 10.75$, $p < 0.001$] and a significant two-way interaction [$F(14, 196) = 2.57$, $p < 0.005$]. Pair-wise comparisons using *Tukey*'s post-hoc analyses indicated that the unstressed-to-stressed intensity ratios of the vowels produced by the early and late bilinguals were significantly higher than the ratios produced by the English monolinguals [$p < 0.05$]. The early and late bilingual groups did not significantly differ from one another [$p = 0.972$]. Again, the significant interaction indicates that the intensity ratios varied across words even among the English monolinguals.

However, the intensity ratios of the non-stress-matched words followed different trends. The ANOVA yielded a significant effect of Word [$F(10, 280) = 12.20$, $p < 0.001$], but neither the main effect of Group [$F(2,28) = 2.86$ $p = 0.07$] or the two-way interaction [$F(20, 280) = 1.38$, $p = 0.12$] were significant. These results show that early and late bilinguals' implementation of unstressed-to stressed intensity ratios depended on whether the stress pattern of the English target words matched the pattern of their Spanish cognates. Apparently, Spanish-English bilinguals produced more native-like intensity ratios if the stress patterns of the target words did not match the stress patterns of the Spanish cognates.

*************Table 3 about here************

****************Fig. 3 about here*****************

3. 3. Vowel quality

The mean normalized formant frequencies and standard deviations of the 21 unstressed vowels obtained for each group of participants are tallied in Table 4. Two repeated measures two-way ANOVAs were run to test the main effects of Group (3), Word (21) and the two-way interaction on the F1 and F2 frequencies of the unstressed vowels. In the case of the F1 frequencies, both the main effects of Group, [$F(2,28) = 11.52$, $p < 0.001$], Word [$F(20, 560) = 14.8$, $p < 0.001$] and the two-way interaction [$F(40, 560) = 2.79$, $p < 0.001$] were significant. Pairwise comparisons with *Tukey*'s post-hoc analyses showed that both groups of bilinguals produced the English unstressed vowels with F1 frequencies which were significantly higher than the English monolinguals' F1 frequencies. As for the F2 frequencies, the main effect of Word and the two-way interaction were also significant, [$F(20, 560) = 27.91$, $p < 0.001$] and [$F(40, 560) = 4.1$, $p < 0.001$] but the main effect of Group was not significant, [$F(2,28) = 1.78$, $p = 0.187$]. These results suggest that the bilinguals' production of the English unstressed vowels along the F2 dimension was easier than along the F1 dimension. It is known that F1 varies mostly with tongue height and F2 with tongue advancement [Kent and Read, 1992 among others]. It follows that, if early and late bilinguals produced unstressed English vowels that were lower in the vowel space relative to the English targets, they were probably transferring the acoustic propertierties of Spanish /a/, a low central vowel with F2 values close to English /ə/ but with higher F1 values than English /ə/ [Martínez Celdrán and Fernández Planas, 2007].

***************Table 4 about here***********

Figure 4 shows the acoustic vowel spaces of the vowels produced by the English monolinguals (a), the early Spanish-English bilinguals (b), and the late Spanish-English bilinguals (c) averaged across spellings and speakers. Each symbol represents the unstressed vowels on the basis of their orthographic representation. Overall, the early bilinguals show a more native-like pattern of vowel reduction since the vowel points exhibit little dispersion and tend to converge towards the center of the vowel space. However, the late bilinguals show a more Spanish-like pattern with vowel tokens that are more peripheral and dispersed in the vowel space than the early bilinguals' vowels.

*************Fig. 4 about here*****************

The degree of vowel reduction for the two bilingual groups relative to the NE control group was measured numerically in terms of Euclidean distances (ED). The method used for the calculation of the ED followed the same procedure as prior studies in L2 speech [Lee et al., 2006; Chen et al., 2012], which, in turn, is similar to the method proposed by Lindblom [1986]. The Euclidean distances were computed for each individual speaker on the basis of these five vowel pairs as represented in spelling /i-u/, /i-e/, /e-a/, /a-o/ and /o-u/. As shown in the equation below, F1i and F2i are the average formant values obtained by each speaker for the first vowel point of the pairing in Hz, whereas F1ii and F2ii are the average formant values obtained by each individual speaker for the second vowel point of each pair.

$$ED = \sqrt{(F1i - F1ii)^2 + (F2i - F2ii)^2}$$

Table 5 shows the mean EDs between the two vowel points of each pair averaged across speakers. Overall, the higher standard deviations of the late bilinguals' data are indicative of a greater dispersion of the vowels relative to the early bilinguals or the English monolinguals, who exhibited less variability. The mean Euclidean distances obtained by each individual speaker for the five vowel pairs were submitted to five one-way ANOVAs to test the main effect of Group. No significant effects were found for the /i-u/ and /i-e/ EDs, [$F(2,28) = 0.031$, $p = 0.969$] and [$F(2, 28) = 0.349$, $p = 0.709$]. However, the ANOVA yielded significant effects of Group for the /e-a/, /a-o/ and /o-u/ pairs, [$F(2, 28) = 10.48$, $p < 0.001$, $F(2, 28) = 11.09$, $p < 0.001$ and $F(2, 27) = 5.64$, $p < 0.01$]. Pairwise comparisons with Tukey's post-hoc analyses showed that only the late bilingual's EDs for these three vowel pairs were significantly longer than the early bilinguals' and monolinguals' EDs [/e-a/ $p < 0.001$, /a-o/ $p < 0.001$, /o-u/ $p < 0.01$]. These results suggest that the early bilinguals showed native-like patterns of vowel reduction. However, the late bilinguals showed difficulty reducing some unstressed English vowels and this difficulty seemed to be strongly dependent on spelling.

*******Table 5 about here*********

5. Discussion and conclusions

The present study investigated the production of English stress accent by two groups of Spanish-English bilinguals varying in L2 experience, defined in AOA in the U.S. More specifically, intensity and duration ratios along with vowel quality of the stressed vs. unstressed vowels were measured. In the light of the Feature Hypothesis [McCallister et al., 2002], we first addressed the question of whether phonetic features that are used in the L1 to signal word stress (i. e. the duration and intensity ratios of unstressed to stressed vowels) are easier to acquire than those features that are not used in the L1 (i. e. vowel reduction). The summary of the results shown in Table 6 indicates that both early and late bilinguals could not implement duration and intensity differences between stressed and unstressed vowels in a native-like fashion. Instead, they produced English unstressed vowels with shorter durations and lower intensity than their stressed counterparts. However, the unstressed-to-stressed duration and intensity ratios obtained by the two groups of bilinguals were significantly smaller than the duration ratios obtained by the English monolinguals. These findings are in line with earlier studies examining duration and intensity differences between stressed and unstressed vowels by bilingual speakers [Flege and Bohn, 1989; Gutiérrez-Díez, 2001; Lee et al. 2006] and they suggest that both groups of bilinguals had some difficulty implementing sufficient duration and intensity differences between English stressed and unstressed vowels. Overall, these results are not supportive of the FH because both groups were predicted to implement unstressed-to-stressed duration and intensity differences with relative ease considering that both English and Spanish use these two acoustic cues to signal word stress.

*******Table 6 about here******

Following the FH, the second research question addressed the issue of whether Spanish-English bilinguals would show phonological patterns of vowel reduction just like their English monolingual peers or whether they would transfer the phonetic patterns of their L1 and exhibit a more context-dependent pattern of vowel reduction. When examining the mean F1 and F2 frequencies, both bilingual groups produced unstressed vowels with significantly higher F1 frequencies than the English monolinguals. However, the bilinguals' F2 frequencies did not significantly differ from the English monolinguals' frequencies. This finding could be accounted for in terms of the acoustic similarity between Spanish /a/ and English /ə/. As central vowels, both have similar F2 frequencies, but F1 frequencies are different because Spanish /a/ is a low vowel and has higher F1 frequencies than English /ə/, which is located in the mid position of the vowel space.

The comparison of the Euclidean distances between the vowel pairs /i-u/, /i-e/, /e-a/, /a-o/ and /o-u/, indicated that early and late bilinguals followed different trends. The EDs of the five vowel pairs obtained by the early bilinguals did not significantly differ from the EDs obtained by the English monolinguals. This was not the case of the late bilinguals, who seemed to have difficulties reducing the unstressed vowels as represented in the pairs /e-a/, /a-o/ and /o-u/, showing a more context-dependent pattern of vowel reduction. The early bilinguals were more native-like and produced more centralized vowels than the late bilinguals, who exhibited a more peripheral vowel space.

The third research question involved the possible impact of age-related effects in the acquisition of English word stress. The results just reported suggest that age of acquisition has a strong impact on the bilinguals' reduction of unstressed English vowels. The early bilinguals' unstressed vowels were more central than the late bilinguals' and the EDs of the five vowel pairs did not significantly differ from the native English monolinguals', suggesting a more native-like production pattern of these vowels and successful implementation of English prosody in terms of unstressed vowel reduction. These findings support previous work in L2 suprasegmentals in that first language prosodic knowledge may affect second language prosodic knowledge even among early bilinguals [Dupoux et al., 2010; Guion, 2006; Lee et al., 2006] and might be indicative that the early bilinguals acquired vowel reduction patterns operating at a higher phonological level. This involved reducing the target English vowels on a regular basis, regardless of spelling. Conversely, late bilinguals reduction of vowels seemed to rely heavily on spelling, which suggests that the late bilinguals might have transferred the more context-dependent vowel reduction pattern found in Spanish.

We speculate that other factors might have influenced the different degree of vowel reduction between early and late bilinguals. First of all, a possible effect of the task must be considered. The target words were presented in written form, therefore some spellings might have triggered vowel reduction and others might have inhibited it. Orthographic transparency has been found to influence non-native speech production [Erdener and Burnham, 2005; Rafat, 2010]. Spanish is considered a transparent language in that the pronunciation of a given vowel or consonant is quite close to its spelling. However, English is considered an opaque language because a given sound may be represented with different spellings. It follows that, influenced by Spanish, the late learners might have shown a tendency to produce some of the unstressed syllables with full vowels, thus transferring the orthographic features of their first language. Nevertheless, this interpretation must be taken in caution, because the different spellings were not balanced across words.

The significant Word x Group interactions found suggest that bilinguals' implementation of English word stress was strongly influenced by lexical factors. Some of the target words triggered more native-like production of unstressed vowels than others, most of the target words had cognates in Spanish and this might have had an inhibitory effect to reduce unstressed vowels in a native-like fashion. This cognate-status effect has been reported in vowel production by Catalan-Spanish bilinguals and it is influenced by language dominance [Mora and Nadeu, 2012]. The Catalan vowel inventory includes the vowels /e/ and /ɛ/, whereas Spanish has only /e /. This would explain why the Spanish-dominant bilinguals produced instances of Catalan /ɛ/ that resembled Spanish /e/ and this effect was stronger in cognate words than in non-cognates. In contrast, Catalan-dominant bilinguals production of /ɛ/ was not affected by the cognate-status effect, which suggests that the Spanish-dominant bilinguals' production of Catalan /ɛ/ was influenced by the lexical status of the Catalan word with respect to Spanish. Production of /ɛ/ in non-cognates was easier because bilinguals could not transfer the pronunciation of a word that does not exist in Spanish. Conversely, production of /ɛ/ in cognates probably triggered transfer of Spanish /e/. Similarly, Amengual [2012] found that Spanish heritage speakers (English-dominant) produced more English-like VOTs in cognates than in non-cognates. The target words used in the present study did not allow for an analysis of the effect of cognate status because almost all the target words were cognates. Nevertheless, the different trends found in the intensity ratios of the 'stress-match' and 'non-stress-match' words suggested that, in line with the studies just reported, bilinguals produced more Spanish-like intensity ratios in the words that matched the Spanish stress pattern than in the words that did not match the Spanish stress pattern. This might indicate that the transfer of the phonetic features of the L1 to the L2 is most likely to occur when lexical items overlap phonologically and orthographically.

The variability of vowel reduction patterns among the late bilinguals further attests that, in line with prior work on acquisition of English stress by Spanish bilinguals [Flege and Bohn, 1989; Guion, 2006; Guion et al., 2004], English stress patterns may have been learned on a word-by-word basis and later extended to phonologically similar words. This would support the exemplar theory [see Solé, this volume for a review], which assumes that words may be discrete entities just like phonemes and, as such, a set of overlapping categories of similar words build up the memory of the speakers of a language [Port, 2007 among others]. This memory includes not only prototypes and abstractions, but also details about the orthographic and phonetic description of the target words. Apparently, the database of exemplars (words) shapes a speaker's choice of pronunciation decisions, since speakers modify their pronunciations to be more similar to what they hear others say [Goldinger, 1998; Pierrehumbert, 2001]. The different patterns shown by the two bilingual groups suggest that the late bilinguals might be less likely than the early bilinguals to abstract the English stress patterns across the lexicon. This might be due to the fact that the early bilinguals had been exposed to more native exemplars of reduced English word categories because they attended school in the US and learned the English pronunciation rules at an earlier age. Nevertheless, more research is needed to investigate how lexical and phonological categories interact in the bilingual brain and whether the establisment of lexical representations is a prerequisite for the establishment of phonological categories.

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Table 1. Characteristics of the two groups of Spanish bilinguals and one group of English monolinguals.

Group		**Minimum**	**Maximum**	***M***	***SD***
Early Spanish	Age	19	40	25.7	6.6
	AOA	2.5	6	3.7	1.2
	LOR	16	33	23.4	5.6
	EDU	14	18	16	
	L2 use	60	95	84.5	11.1
	TOAL1	13	32	24.6	6.1
	TOAL2	14	32	22.1	6.3
Late Spanish	Age	21	48	33.2	9
	AOA	15	33	21.5	5.3
	LOR	5	27	12.9	8.8
	EDU	13	20	16	
	L2 use	30	100	75	23.7
	TOAL1	13	30	21	5.1
	TOAL2	15	33	23.8	6.7
Native English	Age	20	31	24.9	4.2
	AOA			NA	
	LOR			NA	
	EDU	13	16	16	
	L2 use			NA	
	TOAL1	25	34	29.8	2.8
	TOAL2	13	33	28.4	5.8

Table 2. Mean duration ratios and standard deviations (in parentheses) of English reduced vowels produced by two groups of Spanish early and late bilinguals (ESp and LSp) and a group of Native English (NE) monolinguals.

Word	**Stress- match**	**NE**	**ESp**	**LSp**
***a**génda*	Yes	0.642 (0.253)	0.835 (0.188)	0.744 (0.122)
*ág**e**nt*	No	0.435 (0.231)	0.474 (0.163)	0,568 (0.219)
*b**a**nána*	Yes	0.313 (0.124)	0.287 (0.108)	0.528 (0.189)
*básk**e**t*	Yes	0.363 (0.210)	0.472 (0.198)	0.512 (0.197)
*cál**e**ndar*	No	0.569 (0.224)	0.640 (0.231)	0.781 (0.243)
*cómp**e**nsate*	No	0.355 (0.145)	0.786 (0.366)	0.931 (0.262)
*d**e**scént*	No	0.421 (0.147)	0.664 (0.395)	0.608 (0.295)
***e**léven*	No	0.459 (0.143)	0.884 (0.295)	0.610 (0.203)
*g**i**ráffe*	Yes	0.259 (0.091)	0.636 (0.286)	0.443 (0.138)
*índ**i**cate*	No	0.490 (0.099)	0.679 (0.223)	0.795 (0.382)
*intr**o**dúce*	No	0.277 (0.092)	0.393 (0.126)	0.369 (0.117)
*kang**a**róo*	No	0.287 (0.052)	0.393 (0.171)	0.526 (0.228)
*m**a**chíne*	No	0.284 (0.105)	0.512 (0.244)	0.461 (0.064)
*mán**a**ge*	Yes	0.564 (0.063)	0.597 (0.171)	0.805 (0.203)
*médi**u**m*	Yes	0.561 (0.202)	0.717 (0.185)	0.690 (0.176)
*ór**i**gin*	No	0.992 (0.018)	1.015 (0.039)	1.008 (0.085)
*p**os**séss*	No	0.444 (0.160)	0.508 (0.109)	0.360 (0.153)
*p**o**táto*	Yes	0.236 (0.161)	0.398 (0.149)	0.298 (0.116)
*sp**a**ghétti*	Yes	0.255 (0.123)	0.498 (0.150)	0.549 (0.161)

Table 3. Mean intensity ratios and standard deviations (in parentheses) of English reduced vowels produced by a group of Native English (NE) monolinguals and two groups of Spanish early and late bilinguals (ESp and LSp).

Word	**Stress-match**	**NE**	**ESp**	**LSp**
***a**génda*	Yes	0.642 (0.253)	0.835 (0.188)	0.744 (0.222)
*ág**e**nt*	No	0.435 (0.231)	0.474 (0.163)	0.568 (0.307)
*b**a**nána*	Yes	0.313 (0.124)	0.287 (0.108)	0.528 (0.189)
*básk**e**t*	Yes	0.363 (0.210)	0.472 (0.198)	0.512 (0.197)
*cál**e**ndar*	No	0.569 (0.224)	0.640 (0.231)	0.781 (0.243)
*cómp**e**nsate*	No	0.355 (0.145)	0.786 (0.366)	0.931 (0.262)
*d**e**scént*	No	0.421 (0.147)	0.664 (0.395)	0.608 (0.295)
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*g**i**ráffe*	Yes	0.259 (0.091)	0.636 (0.286)	0.443 (0.138)
*índ**i**cate*	No	0.490 (0.099)	0.679 (0.223)	0.795 (0.382)
*intr**o**dúce*	No	0.277 (0.092)	0.393 (0.126)	0.369 (0.117)
*kang**a**róo*	No	0.287 (0.052)	0.393 (0.171)	0.526 (0.228)
*m**a**chíne*	No	0.284 (0.105)	0.512 (0.244)	0.461 (0.064)
*mán**a**ge*	Yes	0.564 (0.063)	0.597 (0.171)	0.805 (0.203)
*méd**iu**m*	Yes	0.561 (0.202)	0.717 (0.185)	0.690 (0.176)
*ór**i**gin*	No	0.992 (0.018)	1.015 (0.039)	1.017 (0.085)
*p**o**sséss*	No	0.444 (0.160)	0.508 (0.109)	0.360 (0.153)
*p**o**táto*	Yes	0.236 (0.161)	0.398 (0.149)	0.298 (0.116)
*sp**a**ghétti*	Yes	0.255 (0.123)	0.498 (0.157)	0.549 (0.139)

Table 4. Mean and F1 and F2 normalized frequencies of English reduced vowels averaged across words. SDs are in parentheses. Note that *agenda_1* and *banana_1* correspond to the pretonic vowel, likewise *agenda_2* and *banana_2* correspond to the postonic vowel.

	NE		**ESp**		**LSp**	
	F1	F2	F1	F2	F1	F2
***a**génda_1*	400 (76)	1690 (112)	497 (76)	1792 (140)	544 (102)	1698 (103)
*agénd**a**_2*	501 (86)	1519 (76)	536 (98)	1551 (151)	597 (85)	1542 (97)
*ág**e**nt*	383 (130)	1658 (112)	517 (236)	1818 (289)	456 (83)	1864 (299)
*b**a**nána_1*	410 (136)	1599 (119)	513 (45)	1702 (164)	583 (85)	1553 (150)
*banán**a**_2*	539 (163)	1530 (208)	593 (145)	1533 (199)	650 (99)	1583 (101)
*básk**e**t*	444 (65)	1772 (119)	451 (39)	1933 (153)	453 (67)	1853 (101)
*cál**e**ndar*	500 (82)	1353 (120)	606 (72)	1373 (148)	516 (94)	1492 (192)
*cómp**e**nsate*	379 (158)	1502 (139)	414 (90)	1731 (229)	462 (64)	1514 (204)
*d**e**scént*	353 (78)	1759 (153)	637 (83)	1693 (88)	600 (89)	1695 (96)
***e**léven*	443 (83)	1313 (507)	508 (145)	1568 (370)	494 (287)	1912 (301)
*g**i**ráffe*	392 (23)	1340 (160)	437 (31)	1485 (161)	385 (36)	1672 (82)
*índ**i**cate*	318 (68)	2066 (172)	387 (45)	2078 (235)	333 (34)	2074 (304)
*intr**o**dúce*	338 (129)	1757 (140)	353 (40)	1850 (171)	349 (31)	1549 (287)
*kang**a**róo*	374 (60)	1203 (94)	427 (67)	1379 (297)	407 (44)	1216 (155)
*m**a**chíne*	450 (188)	1636 (412)	396 (69)	1767 (245)	532 (112)	1674 (205)
*mán**a**ge*	448 (93)	1764 (141)	513 (95)	1824 (370)	475 (81)	1830 (186)
*médi**u**m*	393 (102)	1619 (339)	518 (134)	1744 (293)	467 (112)	1610 (232)
*ór**i**gin*	395 (60)	1636 (116)	432 (42)	1716 (119)	356 (54)	1943 (231)
*p**o**sséss*	340 (58)	1887 (118)	355 (52)	1577 (156)	465 (59)	1185 (96)
*p**o**táto*	366 (80)	1577 (146)	444 (136)	1567 (352)	441 (40)	1299 (209)
*sp**a**ghétti*	267 (42)	1983 (148)	438 (157)	1828 (219)	516 (76)	1650 (204)

Table 5. Euclidean distances in Hz between two vowel points averaged across speakers. SDs are in parentheses.

	i-u	**i-e**	**e-a**	**a-o**	**o-u**
NE	201 (111)	215 (65)	453 (44)	144 (55)	195 (80)
ESp	208 (108)	199 (75)	494 (47)	161 (42.74)	312 (106)
LSp	219 (223)	234 (134)	570 (78)	286 (109.28)	376 (155)

Table 6. Summary of the results for the two Spanish-English bilingual groups' production of the three phonetic features distinguisihing English stressed and unstressed vowels.

		Early Bilinguals	Late Bilinguals
	Spanish	Native-like	Native-like
Intensity	Yes	No	No
Duration	Yes	No	No
Reduction	No	Yes	No

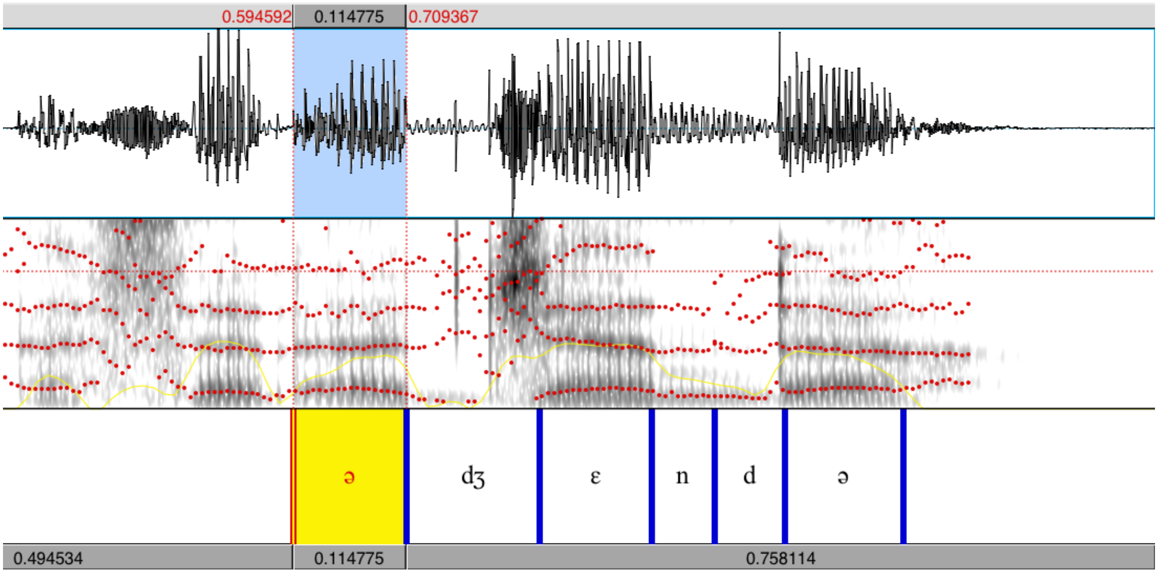
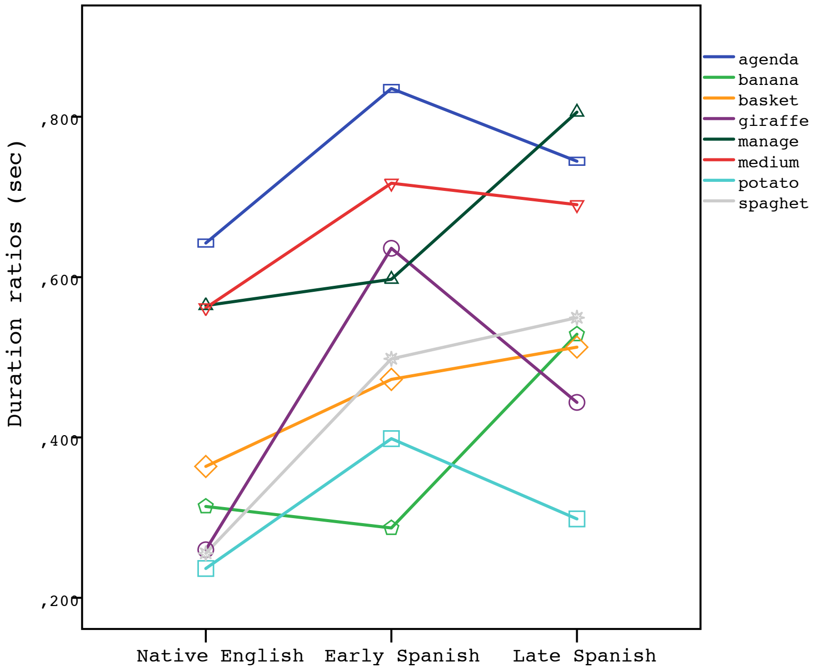


Figure 1. Speech sample and Textgrid with annotated vowel intervals.


Duration ratios (sec)
,800
,600
,400
,200
Native English
Early Spanish
Late Spanish
agenda
banana
basket
giraffe
manage
medium
potato
spaghet

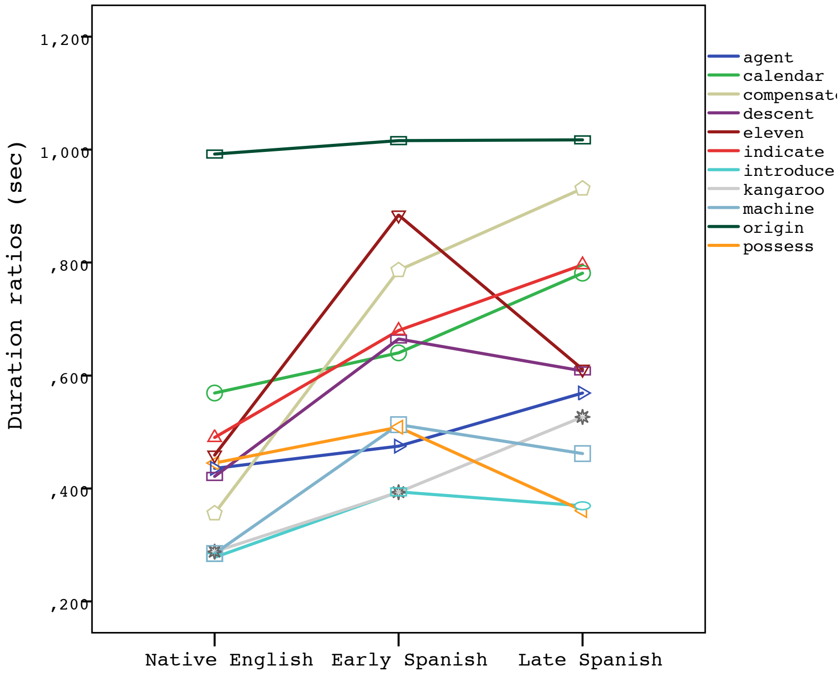
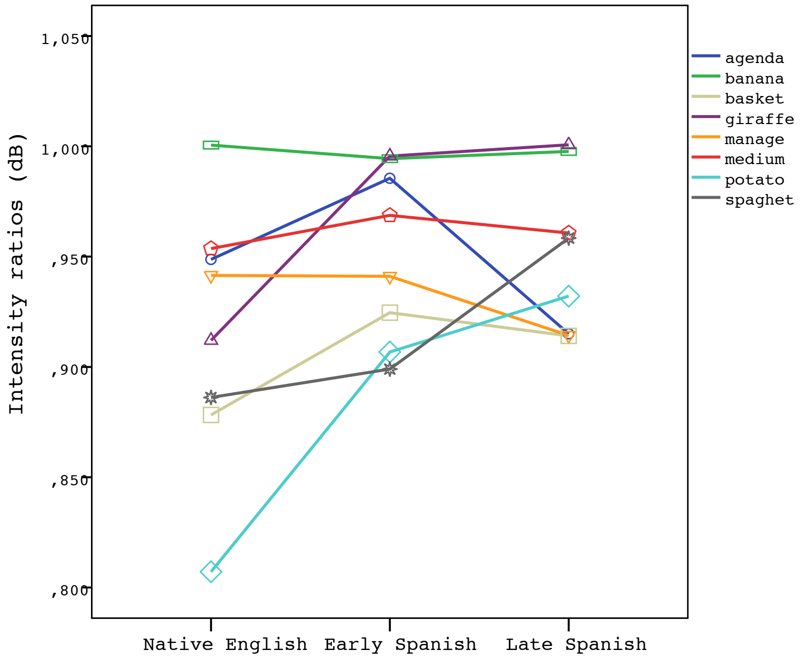

Duration ratios (sec)
1,200
1,000
,800
,600
,400
,200
Native English
Early Spanish
Late Spanish
agent
calendar
compensat
descent
eleven
indicate
introduce
kangaroo
machine
origin
possess

Figure 2. Mean duration ratios of unstressed-to-stressed vowels for the English words that matched the Spanish stress patterns (top) and the words that did not match the Spanish stress patterns (bottom). The lines represent the mean values per word obtained by the native English monolinguals and the early and late Spanish-English bilinguals.



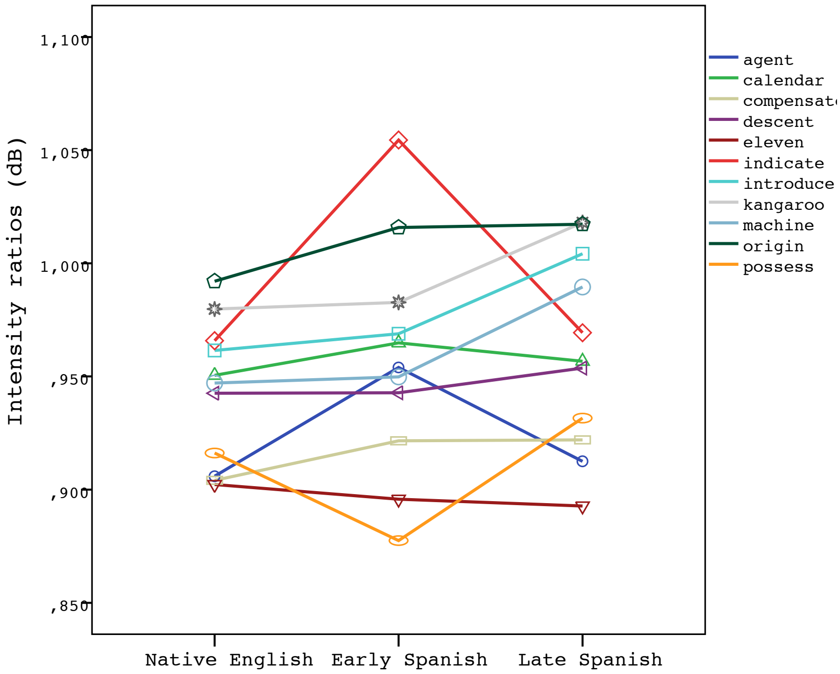


Figure 3. Mean intensity ratios of unstressed-to-stressed vowels for the English words that matched the Spanish stress patterns (top) and the words that did not match the Spanish stress patterns (bottom). The lines represent the mean values per word obtained by the native English monolinguals and the early and late Spanish-English bilinguals.

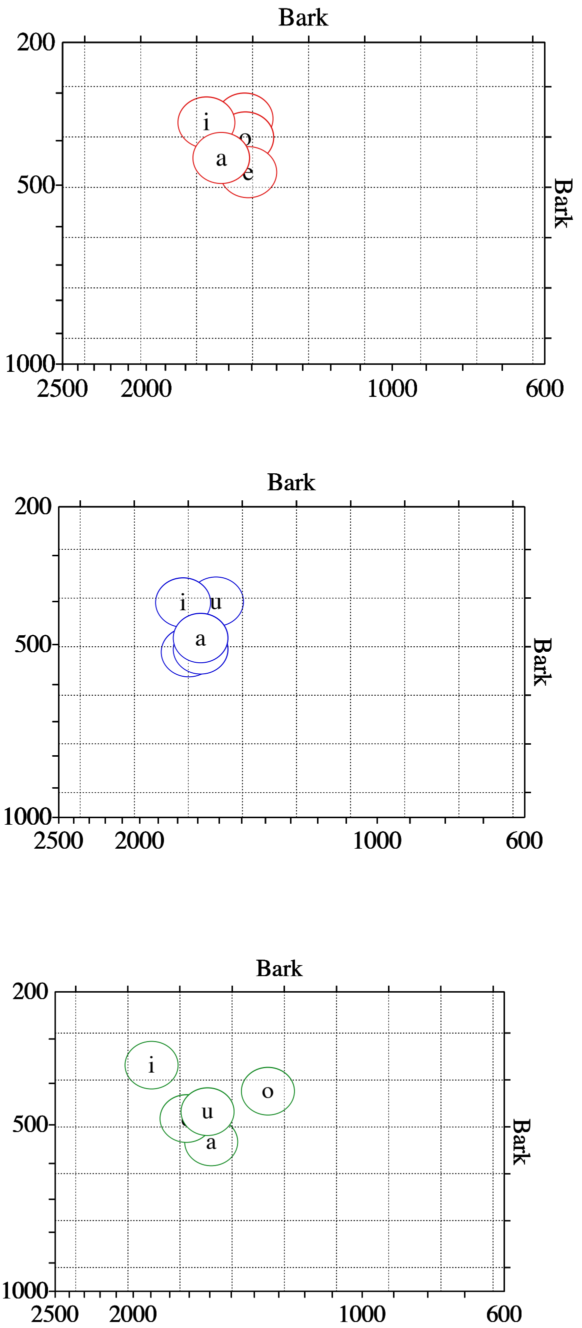


Figure 4. Normalized F1 and F2 mean frequencies of the unstressed vowels averaged across speakers by orthographic representation for the native English monolinguals (red), the early Spanish-English bilinguals (blue) and the late Spanish-English bilinguals (green)