

Second Language Spanish Vowel Production: An Acoustic Analysis

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Abstract

Findings from a cross-sectional study of the Spanish vowel productions of sixty adult second language learners of Spanish are presented in this article. The data set is based upon digitally recorded readings of an authentic Spanish-language short story. An acoustic examination of F1 and F2 values was carried out on twenty tokens of each vowel, 10 in stressed syllables, 10 in unstressed. The findings show that learners in the early stages of their Spanish study struggle to produce vowels in a native-like way, but the vowels of more advanced learners are similar to those of native speakers. The unstressed vowels of all learners are produced with some degree of centralization, confirming the much theorized influence of English on Spanish vowel productions.

1. Introduction

Non-native vowel quality can lead to a foreign accent for second language (L2) speakers (e.g. Flege 1997, Flege, MacKay & Meador 1999 and Munro 1993), yet relatively little research has been carried out to investigate the acquisition of the Spanish vocalic system by first language (L1) speakers of English. Previous work has relied primarily on impressionistic analysis techniques and focused on beginning and intermediate level learners (Elliot 1997, Hammerly 1982 and Simões 1996); studies that examine the vowel productions of L2 learners of Spanish at different levels of proficiency or that use acoustic methods for analysis are lacking from the literature. By including more advanced groups of learners and employing more precise analysis techniques, a more complete understanding of the interlanguage phonological system of adult L2 learners of Spanish can be developed. Moreover, the much discussed tendency of English learners of Spanish to reduce vowels in atonic syllables (e.g. Stockwell & Bowen 1965) has yet to be explored and quantified. The findings reported in the present paper address the vowel productions of learners at more advanced levels of proficiency, specifically graduating Spanish majors and Ph.D. students, in addition to systematically attending to the question of stress through spectrographic analysis as a means of filling in some of the above mentioned gaps in the research base.

The organization of this paper is as follows: Section 2 reviews work on both Spanish and English vowels as well as the few studies to have investigated the acquisition of Spanish vowels by native English-speaking learners of Spanish. Section 3 outlines the methodology employed to carry out the present study and describes the different subject groups who participated. Results are presented in Section 4; this is followed by a discussion of the findings with respect to previous work in Section 5. And section 6 reviews the conclusions that can be drawn and their importance to the field in addition to proposing directions for future research.

2. Previous Research

2.1 Vowels

2.1.1 An introduction to vowels

Acoustic descriptions of vowels consider the frequencies at which sound waves resonate, describing them in terms of formants. Although three formant measurements are sometimes used to describe vowels across languages, the first and second are the most important for describing Spanish vowels, and we limit the discussion here to these. Many factors influence formant values; however, the primary correlate of the first formant (F1) is tongue height, and the primary correlate of the second formant (F2) is tongue backness. The relationship between F1 value and height is an inverse one: the higher the F1 value, the lower the vowel; conversely, the lower the F1 value, the higher the vowel. Higher F2 values are related to more fronted vowels, and lower F2 values, to more back vowels.

Spectrograms allow for the measurement of formants; formants appear as large concentrations of energy at specific frequencies as shown in Figure 1. Formant charts, such as the one seen for Spanish in Figure 2, in which the formants are measured in Hertz (Hz), are commonly used to depict the location of vowels in the acoustic space. In formant charts, F1 is plotted on the y-axis, and F2 on the x-axis. In order to align formant frequencies with our conception of the vowel space, the axes are placed so that (0,0) is in the upper right hand corner.

2.1.2 The vocalic systems of Spanish and English

Acoustic comparisons of the Spanish and English vocalic systems reveal differences in the two languages, but the differences identified are not consistent across studies. Linguists have identified five vocalic phonemes in Spanish: /i, e, a, o, u/ (e.g. Martínez Celdrán 1995, Navarro Tomás 1957 and Quilis 1999). In English, accounts of the number of phonemes vary, ranging from 9 to 14 (e.g. Bradlow 1995, Delattre 1965 and Ladefoged 2006). Reports point to relatively uniform productions of the five vowels across the many dialects of Spanish (e.g. Barrutia & Schwegler

1993, Morrison & Escudero 2007 and Navarro Tomás 1957); in contrast, differences in vowel productions distinguish regional dialects of English (Ladefoged 2006 and Stockwell & Bowen 1965).

The five Spanish vowels have similar English counterparts, but they are not identical. Some of the most commonly identified differences are as follows:

- Spanish has pure mid vowels while English has diphthongizing vowels: /e/ and /o/ vs. /eɪ/ and /oʊ/.
- Spanish mid vowels are higher and tenser than their lax counterparts in English.
- Spanish /a/ is more front.
- Spanish back vowels, /o/ and /u/ are accompanied by more lip rounding than the corresponding English vowels.

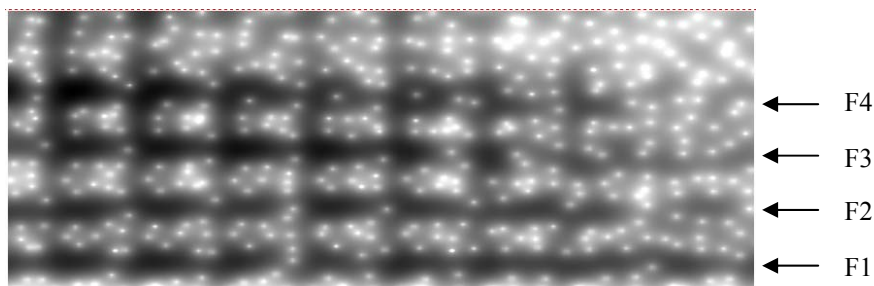


Figure 1. Spectrogram image of a vowel with formants identified

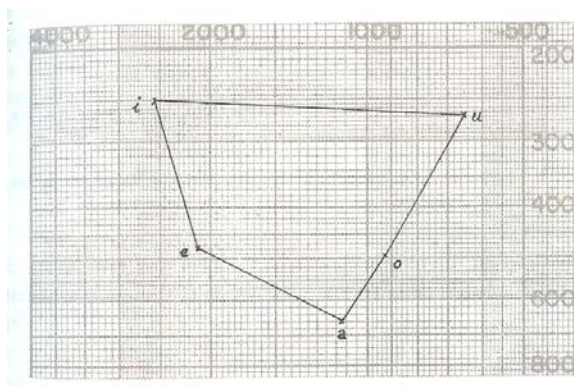


Figure 2. Spanish formant chart (Quilis 1999, p.163)

There are, however, some discrepancies between the findings of different studies. For example, Delattre (1965) found English vowels to occupy more of the front-back acoustic vowel space than Spanish; Bradlow (1995), in contrast, did not find the acoustic vowel spaces of the two languages to be significantly different. Rather, she found all of the English vowels to have more fronted productions. Another inconsistency between these two studies is the positioning of /i/ and /e/ in each language in relation to the other. Delattre (1965) found higher productions of /i/ and /e/ in Spanish while Bradlow (1995) found /i/ and /e/ to be produced higher in English.

One of the most often cited differences in the production of vowels between the two languages is the role of stress. Reduction of unstressed vowels is common in English, whereas in Spanish it is almost non-existent. In a comparative study of reduction in four languages (English, French, German, and Spanish), Delattre (1981) found English to have more reduction than any other language, 17.78%. Spanish represented the other extreme, showing the least amount of reduction, 3.65%.

English vowel reduction generally takes the form of centralization; this is evident in frequency analyses of English vowels. One analysis found [ə] to be the most common phone in adult, conversational speech in English, occurring with a relative frequency of 7.3% (Mines, Hanson & Shoup 1978).¹ In much the same way, Delattre (1965) reported that [ə] was pronounced in 22.99% of vocalic productions, more than any other vocalic phoneme.

Traditional accounts of Spanish vowels acknowledge that there may be some reduction of atonic vowels but that such reduction is generally below the perceptual level (e.g. Navarro Tomás 1957). Several researchers have refuted this notion, observing the devoicing and/or elision of vowels in unstressed syllables in Mexican Spanish (Boyd-Bowman 1952, Canellada de Zamora & Zamora Vicente 1960, Gordon 1980 and Lope Blanch 1963) and Andean Spanish (Delforge 2008, Hundley 1983 and Lipski 1990). Findings from Harmegnies & Poch-Olivé (1992) also point to the possibility of reduction in the articulation of Spanish vowels as they found less stability in spontaneous speech than laboratory speech. More specifically, their findings from one Castilian Spanish speaker point to centralization tendencies and less differentiation between vowels in spontaneous speech.

In the only acoustic study to date of the vowel productions of Spanish-English bilinguals, Willis (2005) finds that the formant values of vowels produced by Spanish-English bilinguals residing in the U.S. Southwest differ from those reported in the literature for other dialects of Spanish, suggesting, like Lipski (1994), that some vocalic variation may exist between different dialects of Spanish. With respect to reduction, the four bilingual informants in Willis' study did not produce the low, central vowel phoneme /a/ in stressed and unstressed positions with any significant differences. What can be concluded from these findings is that some variation in the quality of Spanish vowels may in fact exist across the many dialects of Spanish and

that vowels may be reduced in some contexts, but when compared to English, both dialectal variation and centralization are less in Spanish.

Thus, variation in the number of vowel phonemes, formant frequency or position in the vowel space, diphthongization, and the process of reduction characterize the differences between the English and Spanish vowel systems. Despite what might appear to the naïve ear to be very similar sounds (Stockwell & Bowen 1965), the differences are many.

2.2 Acquisition of Spanish vowels by English speakers

There is a general lack of understanding of what the process of vowel acquisition looks like for native English speakers acquiring Spanish as a second language. The importance of the acquisition of the Spanish vowel system is hinted at in both Elliot (1997) and Simões (1996), but few studies directly address L2 acquisition of the Spanish vowel system. In a classic contrastive analysis, Stockwell & Bowen (1965) predicted that Spanish vowels under weak stress would be the most problematic for native English speakers acquiring the Spanish sound system given the extensive centralization of unstressed vowels in English and the impermissibility of centralization in Spanish. Since then, few research studies have been carried out to investigate the acquisition of this class of sounds. To date, only five studies report findings related to the L2 acquisition of production (Cordero, Munson & Face 2006, Elliot 1997, Hammerly 1982 and Simões 1996) and perception (García de las Bayonas 2004) of Spanish vowels.

In the earliest study to report empirical findings on the L2 acquisition of Spanish vowels, Hammerly (1982) observed vowel errors² to be relatively frequent in the production of first-semester university learners of Spanish. Not only did the first-semester learners transfer the English diphthongs /eɪ/ and /oʊ/ for Spanish monophthongs /e/ and /o/ regularly, they also transferred the allophonic process of vowel centralization. In much the same way, Simões (1996) found vowel reduction or centralization to be one of three recurring incorrect³ patterns in the speech of five intermediate-advanced learners of Spanish.⁴ Elliot (1997) found, however, that with explicit pronunciation instruction, third-semester university learners were able to improve in their pronunciation of vowels, most notably the back vowels /o/ and /u/. Nonetheless, the amount of improvement in vowels as a sound class was less than several other classes, suggesting that it may take longer for native English speakers to acquire the Spanish vowels and that explicit instruction may be necessary. Findings from even more advanced L2 learners of Spanish support this notion. In an analysis of the speech of nine bilingual speech language pathologists (L1 – English, L2 – Spanish), Cordero, Munson, & Face (2006) found minimal differences in the pronunciation of English and Spanish vowels. In other words, differences in formant measurements of Spanish and English vowels were negligible. Despite a trend toward slightly higher F1 values for Spanish vowels, the English and Spanish

F1 values of this group of advanced learners did not differ significantly from one another. In a similar way, these learners tended to produce Spanish vowels with lower F2 values than in English, but the difference only reached significance for /u/.

The pronunciation of Spanish vowels by native English speakers appears to retain a mark of foreign accent, be it in the diphthongization of mid-vowels, the reduction of unstressed vowels, or the production of vowels with English-like acoustic properties. These findings from production studies contrast with those of the only perception study conducted to date. García de las Bayonas (2004) compared the perception of both naturally-produced and synthesized Spanish vowels by native English-speaking learners of Spanish to that of native Spanish speakers. Perception of the naturally-produced Spanish vowels by the L2 learners of Spanish was very accurate, ranging from 94.4% for vowels presented in isolation to 96.8% for those presented within the context of a word.⁵ In much the same way, the formant values of the synthetic vowels accepted by the learners were spread around the same spectral area identified by native speakers. Overall the results of this study indicate that native English speakers are generally accurate in their perception of Spanish vowels.

Accurate production of Spanish vowels appears to pose a challenge to English-speaking learners of Spanish (Cordero, Munson & Face 2006, Hammerly 1982 and Simões 1996) in spite of having established similar perceptual targets (García de las Bayonas 2004). Given the small number of studies conducted to date and the wide variety in subject populations, research questions, and methodologies employed, it is difficult to draw any general conclusions about the acquisition of Spanish vowels by native English speakers. More research is needed that describes in detail the acoustic characteristics of the Spanish vowel productions of native English-speaking learners of Spanish in order to test the validity of impressionistic accounts of theories of L2 vowel acquisition in Spanish. This study sets out to address this issue.

3. Methodology

3.1 Participants

A total of 60 native English speakers and 6 native Spanish speakers participated in this study. All native English-speaking subjects were current L2 learners of Spanish who had no formal Spanish language instruction prior to seventh grade or 12 years of age. Subjects were classified into three groups based upon their level of Spanish instruction: university students enrolled in a fourth-semester Spanish course, graduating Spanish majors, and Ph.D. students in Spanish. There were substantial differences between groups with respect to the amount of time they had been studying Spanish, amount of time spent in a Spanish-speaking country, and time spent using Spanish per week. Learner group descriptions are provided in Table 1.

Although there is some overlap between the three groups, there are also clear distinctions. Generally, Ph.D. students have been studying Spanish longer than graduating majors who have been studying Spanish longer than fourth-semester Spanish students. Similarly, Ph.D. students on average have spent much more time abroad than either of the two groups. Fourth-semester students have spent very limited time in Spanish-speaking countries, and those who have, have typically traveled for leisure, not language study. The amount of time using Spanish outside of work/study each week appears to be the most variable feature and the specific numbers may not be reliable as many learners had trouble estimating these amounts. Nonetheless it seems clear that more advanced learners use Spanish more often on a weekly basis. Although no standardized proficiency measures were employed, there are notable differences that differentiate the three groups of Spanish students.

| Level | No. of subjects | Years of Spanish study | | Time spent in a Spanish-speaking country (in months) | | Time spent using Spanish per week (in hours)* | |
|--------------------------|-----------------|------------------------|---------|------------------------------------------------------|---------|-----------------------------------------------|---------|
| | | range | average | range | average | range | average |
| Fourth-semester | 20 | 2-7 | 5.15 | 0-1 | 0.4125 | 0-6 | 2.05 |
| Graduating Spanish major | 20 | 5-16 | 7.95 | 0-16 | 6.16 | 0-27 | 8.11 |
| Ph.D. | 20 | 7-26 | 12.83 | 2-60 | 14.175 | 1-54 | 35.18** |

*Using Spanish was broken into four activities: speaking Spanish with native or fluent speakers of Spanish, listening to Spanish language television, movies, or music, reading for pleasure, and writing for purposes other than coursework. The value listed in this column is the sum of the amount of time reported for each of the four activities.

**This average is based on 17 responses. Three Ph.D. students did not respond to this question.

Table 1. Learner group characteristics

In addition to the 60 L2 learners of Spanish, 6 native speakers of Spanish also participated in this study. These six native speakers are from three different areas of the Spanish-speaking world: 3 from Spain, 2 from Mexico, and 1 from Colombia. All of these individuals are university instructors of Spanish and are also proficient in English. The number of years studying English ranges from 8-20 and the amount of time spent living in the U.S. ranges from 5 ½ years to 20 years. Each of these subjects uses Spanish weekly as part of their job and/or studies in addition to using

it for pleasure to watch TV or movies, speak with other native or fluent Spanish speakers, and read Spanish-language texts.

Using comparison data from bilingual peers is critical as the linguistic repertoire of a bilingual is not equivalent to that of two monolinguals (e.g. Grøsjen 1989). As a result, there has been a call in recent years to not compare L2 learner data to that of monolingual native speakers, but rather to use bilingual peers as a comparison group (e.g. Ortega 2006, 2007). This may be of utmost consequence as previous phonological studies have shown that the productions of bilinguals are not always identical to those of monolinguals (e.g. Flege & Hillenbrand 1984 and Willis 2005). Data from this comparison group is critical in light of the above arguments and given the relative absence of work examining bilinguals' production of L1 vowels (Bohn & Flege 1992). Moreover, given the range of formant values reported in the literature, having a native speaker control group whose vowels have been produced in the same linguistic context, on the same task, and analyzed in the same way allows for more accurate comparisons.

3.2 Tasks

Subjects were asked to complete two tasks. The first was a background questionnaire used to gather biographical data on each of the subjects and their experiences learning Spanish. The second task was an oral reading of a Spanish short story. The short story, *Aniversario* by Luis Romero, was an authentic text taken from a literature anthology used in third-year university courses. The story was modified slightly in order to have enough instances of specific Spanish segments in specific linguistic contexts; modifications generally took the form of changing names or the addition of emotional interjections, such as "*Dios guarde su alma.*" or "*¡Basta ya!*" Subjects were asked to read the story aloud at a normal pace while being recorded using a Marantz digital recorder.

3.3 Data analysis

The same one hundred vowel tokens, 20 tokens of each of the 5 Spanish vowels, were analyzed for each participant with all vowels tokens occurring between consonants. Of the 20 tokens for each vowel, 10 were in stressed syllables and 10 were in unstressed syllables; tokens were also balanced across open and closed syllables.

Each vowel token was first extracted from the connected speech stream using Adobe Audition v.1.0 digital audio editing software, and then F1 and F2 were measured at the center point of the vowel by an LPC formant-tracking algorithm (script) in Praat v.4.5.16 signal-processing software. Random hand-checking was done to verify accuracy of the script, and all statistical outliers were hand-checked and corrected as needed. Tokens were excluded from analysis if the targeted vowel

was not produced (e.g. *in*í*ciado* > *inciado*), if it was converted to a diphthong (e.g. *acudió* > *acuido*), if a different vowel was substituted (e.g. *lugar* > *legar*), or if it was produced with weak energy (almost no sound) with no measurable formants. A total of 152 learner vowel tokens and 18 native speaker tokens were excluded from analysis for these reasons.

Statistical analyses were conducted using SPSS v.14.0 software to determine whether differences in formant values were significant. One-Way Analysis of Variance (ANOVA) tests were carried out to compare the means of the four subject populations – fourth semester learners, graduating Spanish majors, Ph.D. students, and native speakers. Post-hoc tests included Least Significant Differences (LSD) for paired comparisons of the groups. Independent Samples t-tests were used to compare stressed and unstressed productions within each learner group. For all statistical tests, the probability level (p-value) for significance was set at 0.01.

4. Results

Results are presented according to learner level, with mean formant frequencies for each vowel presented first, followed by further analysis of vowel productions by syllable stress. At the end of each section, results from native speaker data are reported, serving as a point of comparison.

4.1 Formant values of individual vowel phonemes

A total of 5,848 learner vowel tokens were analyzed as part of this analysis. Fourth-semester university students of Spanish produced 1,929 vowel tokens to be considered for analysis whereas graduating Spanish majors produced 1,966 tokens, and Ph.D. students, 1,953. First and second formant frequencies are reported in Tables 1, 4, 7, 10, and 13 in Appendix A with accompanying statistical analyses; the formant values are represented here graphically in Figure 3 in the form of a vowel chart. Findings for each individual vowel phoneme will first be reported individually and then general trends will be presented.

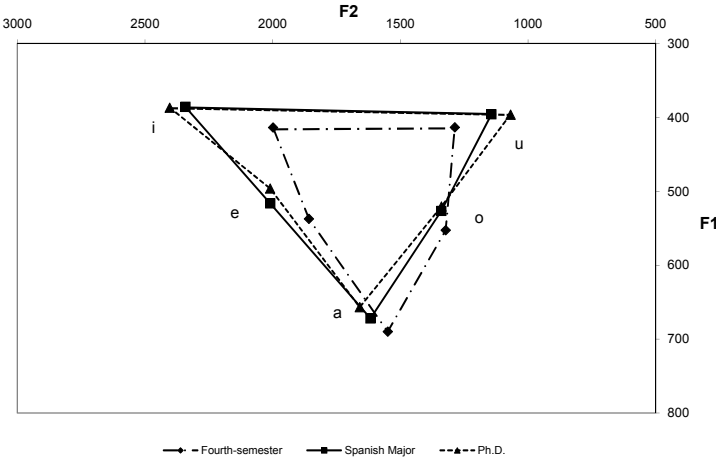


Figure 3. Formant values by level

4.1.1 Learner productions of individual vowel phonemes

Learner groups show some variability in their production of the high, front vowel /i/. Both the graduating Spanish major and Ph.D. student groups produce /i/ with lower F1 frequencies and higher F2 frequencies than the fourth-semester learner group. This suggests a more fronted, higher tongue position on the part of the two more advanced learner groups. While differences between the fourth-semester group and both of the more advanced learner groups for both F1 and F2 are statistically significant at the $p<0.01$ level, the differences between the two advanced groups are not.

Findings for the mid, front vowel are similar in that graduating Spanish majors and Ph.D. students produce /e/ with lower F1 values and higher F2 values than fourth-semester learners, reflecting a more fronted, higher tongue position by the two advanced learner groups. Again, differences between fourth-semester learners and the two advanced groups are statistically significant for both F1 and F2; unlike the findings from /i/, however, Ph.D. learners produce /e/ with a significantly lower F1 value than graduating Spanish majors. Ph.D. students and graduating Spanish majors do not differ in a statistically significant way in their F2 values.

With respect to /a/, a similar trend is observed. The F1 value of fourth-semester learners is higher than that of graduating Spanish majors and Ph.D. learners, and conversely their F2 value is lower. Differences between fourth-semester learners and graduating Spanish majors are statistically significant only for F2 whereas differences between fourth-semester learners and Ph.D. students are significant for

both F1 and F2. Moreover, the formant values of graduating Spanish majors and Ph.D. students show statistically significant differences for F2.

The findings for the two back vowels differ from those of the front and central vowels. The trend of lower F1 frequency values at more advanced levels holds for the mid, back vowel /o/. Differences in F1 values are significant only between fourth-semester learners and each of the more advanced learner groups. There is no pattern in the values of F2 between the learner groups. While graduating Spanish majors produce /o/ with a lower F2 than fourth-semester learners, Ph.D. students produce /o/ with a higher F2 than both groups. None of the differences between groups are statistically significant, suggesting that the differences between the groups are not meaningful and that the groups produce /o/ with F2 values in a similar range.

The F1 values of the high, back vowel /u/ follow the same trend as the F1 values for each of the other vowels: as learner level increases, the F1 decreases. This reflects a higher tongue position in the mouth at the more advanced levels. Differences are significant only between fourth-semester learners and graduating Spanish majors and fourth-semester learners and Ph.D. students. With respect to F2 values of the learners' productions of /u/, a new pattern is observed. As learner level increases, the F2 value decreases, signaling a more back tongue production. This difference is significant not only between fourth-semester learners and each of the two more advanced levels, but also between graduating Spanish majors and Ph.D. students.

4.1.2 Summary of learner productions

Learners at the two more advanced levels (i.e. graduating Spanish majors and Ph.D. students) produce vowels with lower F1 frequency values; this is evident in Figure 3 by the general upward shift in the vowel space for these two learner groups. Also evident in the vowel chart are the higher F2 values of front and central vowels (i.e. /i, e, a/) produced by graduating Spanish majors and Ph.D. students in comparison to those of fourth-semester learners. The back vowels do not follow the same trend; differences in F2 values for /o/ are not significant, and the more advanced learner groups produce the high, back vowel /u/ with lower F2 values, or a more back position in the vowel space.

The vowel space of fourth-semester learners is reduced in comparison to that of graduating Spanish majors and Ph.D. students, whose vowel spaces resemble one another. Statistical analyses confirm these visual observations in that fourth-semester learners differ from graduating Spanish majors in 8 of the 10 comparisons and from Ph.D. students in 9 of 10. Graduating Spanish majors and Ph.D. students produce statistically significant differences in formant values in only 3 of the 10 comparisons.

In summary, graduating Spanish majors and Ph.D. students produce vowels with formants at similar frequencies; the vowel productions of these two advanced learner groups reflect a larger vowel space on the part of these two groups in comparison to that of more novice learners, those in their fourth-semester of Spanish language study. More specifically, the advanced groups show more fronted pronunciations of front and central vowels and a more back production of the high, back vowel. These two groups also produce vowels higher in the vowel space than the fourth-semester students.

4.1.3 Native speaker productions of individual vowel phonemes

While L2 learner language has been shown to be a systematic and rule-governed system (e.g. Corder 1971), analyzing learner productions in relation to native speaker productions facilitates observations about target-like use and identification of whether learners are moving toward or away from the target system. Consequently, six L1 speakers of Spanish read the same text as learners and the native speaker vowel productions were analyzed in the same way in order to be able to compare groups on the same task. The actual formant values of the six native speaker controls are included alongside the learner data in Appendix A. Figure 4 combines the vowel spaces of each of the three learner groups with that of the native speaker control subjects, determined by mean formant values.

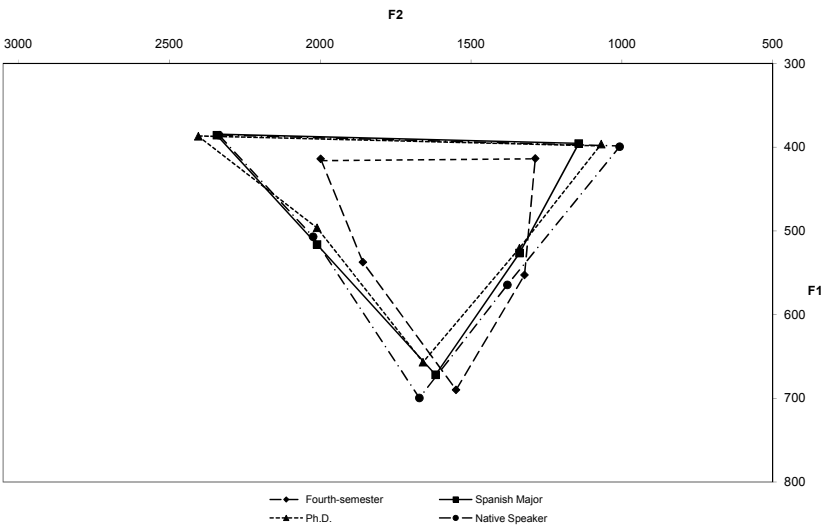


Figure 4. Formant values of learner groups and native speakers

The vowel space delineated by the mean formant values of each of the five vowel phonemes for native speakers resembles that of graduating Spanish majors and Ph.D. students. This is supported by statistical analyses in that no statistically significant differences were found between these two advanced learner groups and native speakers for F1 and F2 values of /i/ or /e/, nor were there any for F2 values of /a/ and /o/ and F1 values of /u/. Differences between native speakers and both graduating Spanish majors and Ph.D. students were significant for the /o/ F1 values; moreover, there were significant differences found between native speakers and graduating Spanish majors in the F2 values of /u/ and between native speakers and Ph.D. students in the F1 values of /a/.

These findings suggest that learners move toward native-speaker values for both F1 and F2 as they advance in their study of the Spanish language, specifically between the fourth-semester of study to the final semester of formal language study at the university level. Few changes, however, are observed between graduating majors and Ph.D. students with respect to vowel formant frequencies; both groups produce formants with values similar to those of native speakers.

4.2 Vowel production according to syllable stress

Equal numbers of stressed and unstressed vowels were analyzed as part of this study in order to investigate the effect of stress on the Spanish vowel productions of native English speakers. Findings for each group of subjects will be presented in isolation first, followed by a comparison of the groups and general observations.

4.2.1 Fourth-semester learners

Formant frequencies for stressed and unstressed vowels produced by fourth-semester learners are reported in Tables 1 and 2 in Appendix B; they are also presented visually in the form of a vowel chart in Figure 5. The vowel chart in Figure 5 shows that the vowel space of unstressed Spanish vowels for this particular group of learners falls within that of stressed vowels, showing some degree of differentiation in vowel production according to stress. The differences between the stressed and unstressed production of each vowel phoneme are not statistically significant for the majority of the phonemes. More specifically, fourth-semester learners produce only /a/ with statistically significant differences for both F1 and F2; stressed and unstressed productions of /e/ and /u/ do differ statistically with respect to F2 values. Taken together, there is greater “reduction” toward the center of the vowel space with respect to tongue backness than tongue height by these fourth-semester learners.

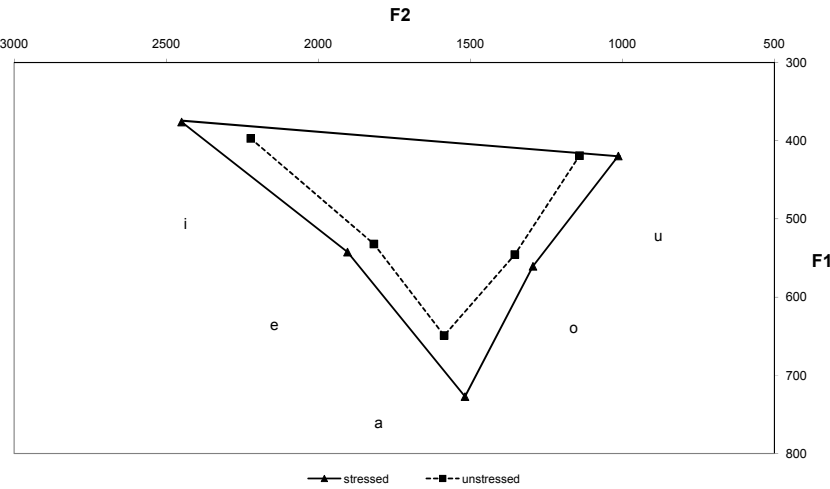


Figure 5. Fourth-semester learner formant values, stressed vs. unstressed

4.2.2 Graduating Spanish majors

In Figure 6, formant values of stressed and unstressed productions of the five Spanish vowels are displayed graphically; the data are also available in numeric format in Tables 3 and 4 in Appendix B. As with the fourth-semester learners, the unstressed vowel space of the graduating Spanish majors falls inside the vowel space of stressed vowels, suggesting that this group of learners does produce stressed and unstressed variants differently. Graduating Spanish majors as a group produce both /a/ and /i/ with statistically different F1 and F2 values; moreover, they also produce /e/ and /u/ with statistically different F2 frequencies. Thus, there is again more movement toward the center of the vowel space on the front-back (F2) dimension than the high-low (F1) dimension.

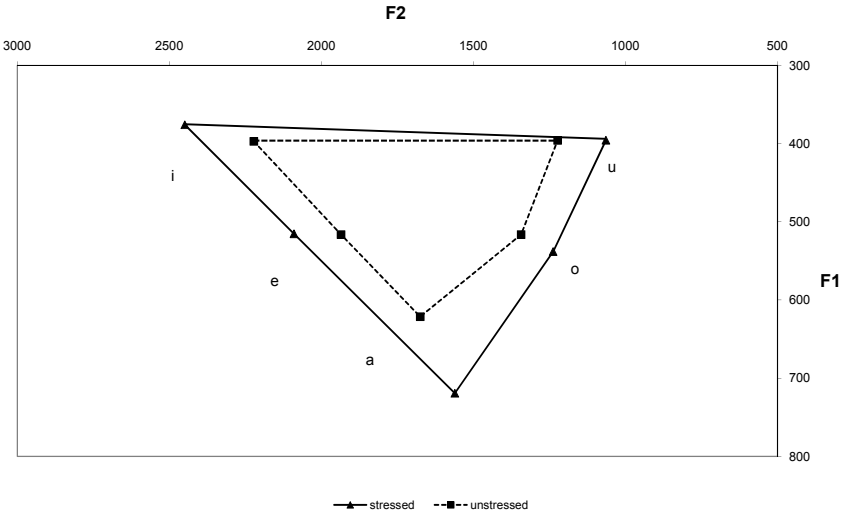


Figure 6. Graduating Spanish major formant values, stressed vs. unstressed

4.2.3 Ph.D. students

Ph.D. students produce Spanish vowels with patterns similar to those of the other two learner groups in that the unstressed vowel space is contained within the vowel space demarcated by stressed vowels. This is shown graphically in Figure 7 and in numeric format in Tables 5 and 6 in Appendix B. Differences in the stressed and unstressed productions of this learner group are statistically significant for both F1 and F2 with respect to /a/, for F1 with respect to /o/, and for F2 with respect to /e/, /i/, and /u/. This advanced learner group thus shows centralization on the front-back dimension for four of the five vowels and on the high-low dimension for only two.

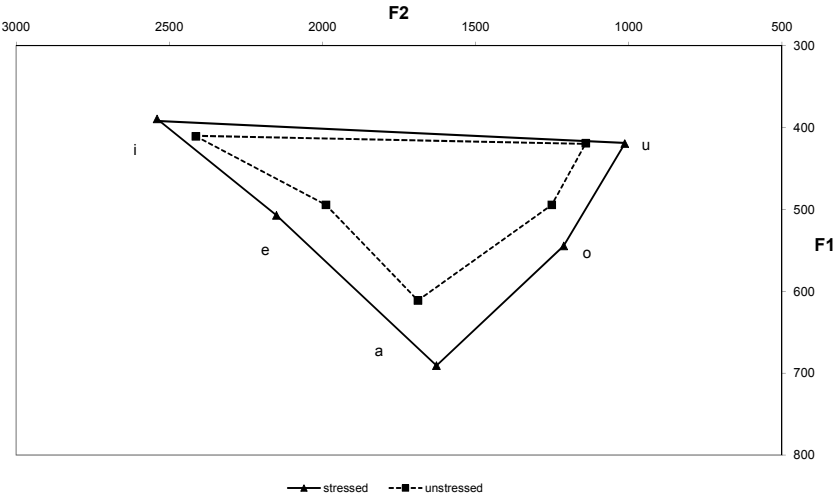


Figure 7. Ph.D. students formant values, stressed vs. unstressed

4.2.4 Native speakers

As mentioned in the introduction, it is generally accepted in the Spanish phonological literature that Spanish unstressed vowels evidence little centralization (e.g. Delattre 1981, Navarro Tomás 1957 and Willis 2005). Findings from this study as presented here in Figure 8 and in Tables 7 and 8 in Appendix B suggest that this particular group of native Spanish speakers, bilingual in English, do show some centralization in the pronunciation of unstressed vowels as compared to stressed vowels. This is seen by the unstressed vowel space being encompassed by the stressed vowel space as shown in Figure 8. The differences in production are, however, minimal as they are only statistically significant with respect to the F2 frequencies of /e/ and /u/. No significant differences were found for this group of native speaker for /a/, /i/, or /o/.

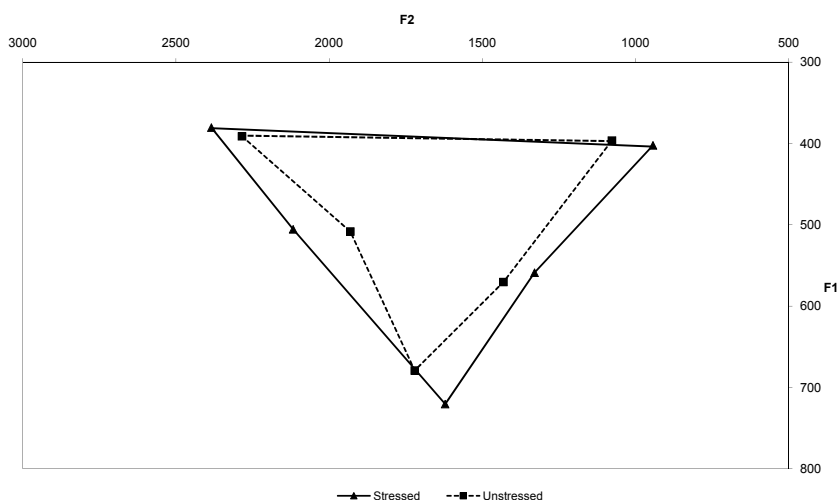


Figure 8. Native speaker formant values, stressed vs. unstressed

4.2.5 Comparisons between groups

All four subject groups show the greatest difference in stressed and unstressed productions with respect to F2 frequency values; in other words, each group, native speakers included, pronounces unstressed vowels more toward the center of the vowel space on the front-back dimension. Learner groups do, however, appear to “reduce” unstressed vowels more in that they produce more phonemes with statistically significant F2 differences than native speakers; /e/, /a/, and /u/ show centralization in F2 values for all three learner groups while only /e/ and /u/ differ in the productions of native speakers. Moreover, graduating Spanish majors and Ph.D. students also produce unstressed /i/ with more central F2 values.

The low, central phoneme /a/ shows the most consistent and possibly greatest reduction among all three learner groups in that unstressed productions show more centralized F1 and F2 values. Native speakers, on the other hand, do not show any reduction as a result of syllable stress in this particular phoneme. This is a significant difference in the vowel productions of L2 learners of Spanish and native speakers, pointing toward the possible maintenance of a foreign accent in Spanish speech by even advanced learners.

5. Discussion

The few previous empirical studies to address the acquisition of the Spanish vocalic system by English speakers demonstrate that while intermediate L2 learners of Spanish are able to perceive Spanish vowels in a way similar to that of native Spanish speakers (Garcia de las Bayonas 2004), their production of Spanish vowels retains some features of the English vocalic system (Cordero, Munson & Face 2006, Hammerly 1982 and Simões 1996). Findings from this study provide acoustic evidence to support previous impressionistic analyses that intermediate learners produce Spanish vowels with different acoustic properties than native speakers. Specifically, fourth-semester learners' productions of front and central vowels are more back and their production of the high, back vowel is more fronted when compared to the vowel productions of native speakers. Moreover, the acoustic vowel space of these intermediate learners is much smaller than that of native speakers.

With the exception of Cordero, Munson & Face (2006), previous studies did not address more advanced learners and the question of whether English L2 learners of Spanish are able to produce Spanish vowels in a native-like way remained unanswered. The subjects in Cordero, Munson, and Face did not differentiate their English and Spanish vowels; in other words, both were produced with similar F1 and F2 values, which would point towards non-native pronunciations of the Spanish vowels. Findings from this study, however, do not support this conclusion. Both graduating seniors and Ph.D. students generally produce Spanish vowels with mean formant values similar to those of native speakers. Additionally, the vowel spaces of each of these three groups overlap and occupy the same portion of the acoustic vowel space as seen in Figure 4.

Previous work (Hammerly 1982 and Stockwell & Bowen 1965) proposed that the diphthongized nature of the English mid vowels would interfere with L2 learners' pronunciations of the Spanish mid vowels. Although /e/ and /o/ do not appear to be any more difficult for L2 learners than the other vowels in this study, limitations in the analysis techniques limit our ability to comment on this. Because vowels were measured only half-way through the vowel, any movement in the formants is ignored and some descriptive details of learner productions are lost.⁶

Although a complete trajectory of learners' movement toward native speaker norms and all the details of each stage of learner development cannot be determined from this study given its cross-sectional nature, this study does begin to identify some features of learner vowel productions. Comparing learners across levels, there is substantial movement toward native-speaker norms between the fourth-semester group and graduating Spanish majors. More specifically, the vowel space of more advanced learners expands, particularly on the front-back dimension, to occupy roughly the same acoustic space as that of native speakers. Learner productions of /i/, /e/, and /a/ move forward in the vowel space while articulation of /u/ moves

further back between the fourth semester of language study and the final semester of majoring in Spanish; the front vowels, /i/ and /e/, also move higher in the vowel space during this time. It could be said that front and central vowels become more fronted and higher, while back vowels become more back and slightly higher. Beyond the graduating Spanish major level, few changes are seen in the pronunciations of Spanish vowels by L2 learners. Mean formant values alone suggest that by the end of an undergraduate major in Spanish, L2 learners are able to produce Spanish vowels in a native-like manner.

When the effect of stress is considered, however, the picture changes slightly. Although it is generally accepted that Spanish speakers do not centralize unstressed vowels, findings from this study show that bilingual Spanish-English speakers do in fact show some centralization tendencies when unstressed vowels are compared to their stressed counterparts. This finding is of interest because it is generally argued in the Spanish L2 literature that vowel reduction is something to be avoided by L2 learners of Spanish (e.g. Elliot 1997, Simões 1996 and Stockwell & Bowen 1965). The data presented here do not point to the need to completely avoid reduction, but they do show greater centralization/reduction on the part of L2 learners as compared to native speakers. In general, learners reduce in the same manner, i.e. on the front-back (F2) dimension, as native speakers, but the amount of reduction appears to be greater for learners as evidenced by the number of phonemes for which there are statistical differences in formant values.

Of the five phonemes, /a/ appears to be the vowel that poses the greatest challenge with respect to vowel reduction for English L2 learners of Spanish. This can be argued given that all three learner groups produce unstressed /a/ with more centralized formant values on both the front-back and high-low dimension. In contrast, the native speaker control group, like the speakers in Willis (2005), does not demonstrate significant centralization or reduction for either F1 or F2 frequencies of this particular phoneme in unstressed syllables. These findings are in line with the high frequency with which English speakers reduce /a/ and the finding of Willis (2005) that bilingual Spanish-English speakers do not reduce /a/ with any regularity.

6. Conclusions

This study begins to fill a gap in the L2 Spanish research base by investigating the acquisition of Spanish vowels with acoustic measures and including learners at both intermediate and advanced levels of Spanish language study. The results point to a general difficulty on the part of L2 learners at early stages of acquisition in producing the five Spanish vowels, but learners at more advanced levels do not demonstrate the same difficulty. In fact, their mean formant frequencies by and large resemble those of native speakers. Nonetheless, even the advanced learners retain a mark of English in their Spanish pronunciation; this foreign accent is

exposed in atonic syllables. This finding provides empirical, acoustical evidence to support what was previously only theorized and/or supported with impressionistic data (Elliot 1997, Hammerly 1982, Simões 1996 and Stockwell & Bowen 1965).

Although this study addresses some of the questions that had not been previously investigated, it leaves several questions unanswered. One question that remains to be answered is how learners' vowel productions contribute to perception of a foreign accent by native speakers. Although this acoustic analysis points to some differences in the pronunciations of learners and native speakers, how meaningful these differences are to the native speaker ear has yet to be determined. In this same way, the question of formant movement within vowels, most specifically the mid vowels which tend to be produced as diphthongs in English, remains unaddressed.

Other questions related to ultimate attainment are also left unresolved. For instance, how native-like can native English speaking adult learners of Spanish become in producing the Spanish vowels? In other words, how do even more advanced learners of Spanish produce the five Spanish vowels? And while this study looks at three groups of learners who differ in the amount of Spanish language study, it does not address other possible differences such as motivation or the desire to sound like a native speaker, which have been previously linked to pronunciation (e.g. Brown & Yule 1983, Hedgcock & Lefkowitz 2000, Lefkowitz & Hedgcock 2002, 2006, Lybeck 2002 and Tarone 1978).

Given that the possible effect of age is controlled for in this study in that all subjects began language study after the age of 12, questions about learners who began earlier also remain unresolved: Do English speakers who begin language study at an earlier age show the same differences from native speaker peers? How native-like are younger learners able to be in their productions of Spanish vowels? Finally, the path learners take in their movement towards native-like pronunciation of Spanish vowels continues to lack specific details. Longitudinal studies that follow learners over a period of years would allow for this area to be explored.

In spite of these lingering questions, this study provides an important first step in the study of L2 Spanish vowel production. It provides specific acoustic details as to how the pronunciations of intermediate and advanced learners both resemble and differ from those of native speakers as well as corroborating the much theorized impact of stress.

Notes

- 1 Interesting to note is that 54% of the productions of [ə] occurred in six of the ten most common lexical items: *the, uh, a, to, of, was*.
- 2 The terms "error" and "problem" are used by Hammerly to refer to non-targetlike productions of L2 learners; we employ these terms here only to accurately reflect the data as reported by Hammerly.

- 3 Simões utilizes the terms “wrong”, “incorrect”, and “acceptable” in his writing.
- 4 The other two patterns were a lack of linking across word boundaries and inappropriate hesitation.
- 5 Native Spanish speakers were 100% accurate for both tasks.
- 6 It was the intention of the researchers to analyze formant movement within the vowel, but the script was unable to consistently measure the vowel at more than the mid-point given the low amount of energy at the beginning and end of many of the vowel tokens.

Appendix A

Mean formant values are presented for each vowel in this section (Tables 1, 4, 7, 10, and 13) followed by a summary of the ANOVA statistical analysis and the p-values attained via post-hoc LSD multiple comparisons.

The following abbreviations are used in the tables which report the p-values of across group comparisons: 4th = Fourth-semester; major = graduating Spanish major, NS = native speaker.

| | F1 mean (standard deviation) | F2 mean (standard deviation) |
|-----------------------------------|---------------------------------|---------------------------------|
| Fourth-semester N = 389 | 689.8994 (146.02) | 1549.3690 (197.24) |
| Graduating Spanish Major N=393 | 672.0072 (129.9) | 1617.0274 (244.85) |
| Ph.D. N=388 | 656.8536 (160.15) | 1658.8935 (212.26) |
| Native speaker N=119 | 699.6425 (144.98) | 1671.3326 (267.54) |

/a/ F1 between groups ANOVA results: F(3)=4.546, p=0.004

/a/ F2 between groups ANOVA results: F(3)=18.611, p<0.001

Table 1. Mean formant values of /a/ by subject group

| | 4 th | Major | Ph.D. | NS |
|-----------------|-----------------|-------|-------|-------|
| 4 th | N/A | 0.086 | 0.002 | 0.523 |
| Major | 0.086 | N/A | 0.147 | 0.070 |
| Ph.D. | 0.002 | 0.147 | N/A | 0.005 |
| NS | 0.523 | 0.070 | 0.005 | N/A |

Table 2. p-value of across group comparisons of mean F1 values for /a/

| | 4 th | Major | Ph.D. | NS |
|-----------------|-----------------|--------|--------|--------|
| 4 th | N/A | <0.001 | <0.001 | <0.001 |
| Major | <0.001 | N/A | 0.009 | 0.021 |
| Ph.D. | <0.001 | 0.009 | N/A | 0.596 |
| NS | <0.001 | 0.021 | 0.598 | N/A |

Table 3. p-value of across group comparisons of mean F2 values for /a/

| | F1 mean (standard deviation) | F2 mean (standard deviation) |
|--------------------------|---------------------------------|---------------------------------|
| Fourth-semester | 537.40 | 1858.18 |
| N = 381 | (92.83) | (317.32) |
| Graduating Spanish Major | 516.34 | 2009.84 |
| N=392 | (71.8) | (294.0) |
| Ph.D. | 496.83 | 2028.51 |
| N=397 | (85.17) | (248.02) |
| Native speaker | 507.01 | 2023.27 |
| N=117 | (82.38) | (287.65) |

/e/ F1 between groups ANOVA results: F(3)=15.763, p<0.001

/e/ F2 between groups ANOVA results: F(3)=28.531, p<0.001

Table 4. Mean formant values of /e/ by subject group

| | 4 th | Major | Ph.D. | NS |
|-----------------|-----------------|--------|--------|-------|
| 4 th | N/A | <0.001 | <0.001 | 0.001 |
| Major | <0.001 | N/A | 0.001 | 0.289 |
| Ph.D. | <0.001 | 0.001 | N/A | 0.246 |
| NS | 0.001 | 0.289 | 0.246 | N/A |

Table 5. p-value of across group comparisons of mean F1 values for /e/

| | 4 th | Major | Ph.D. | NS |
|-----------------|-----------------|--------|--------|--------|
| 4 th | N/A | <0.001 | <0.001 | <0.001 |
| Major | <0.001 | N/A | 0.362 | 0.657 |
| Ph.D. | <0.001 | 0.362 | N/A | 0.863 |
| NS | <0.001 | 0.657 | 0.863 | N/A |

Table 6. p-value of across group comparisons of mean F2 values for /e/

| | F1 mean (standard deviation) | F2 mean (standard deviation) |
|-----------------------------------|---------------------------------|---------------------------------|
| Fourth-semester N = 382 | 413.89 (85.48) | 1998.53 (461.48) |
| Graduating Spanish Major N=391 | 385.73 (63.41) | 2341.6 (397.01) |
| Ph.D. N=397 | 387.03 (99.88) | 2403.10 (335.71) |
| Native speaker N=119 | 385.83 (79.66) | 2334.75 (372.10) |

/i/ F1 between groups ANOVA results: $F(3)=9.693$, $p<0.001$

/i/ F2 between groups ANOVA results: $F(3)=78.925$, $p<0.001$

Table 7. Mean formant values of /i/ by subject group

| | 4 th | Major | Ph.D. | NS |
|-----------------|-----------------|--------|--------|-------|
| 4 th | N/A | <0.001 | <0.001 | 0.001 |
| Major | <0.001 | N/A | 0.827 | 0.991 |
| Ph.D. | <0.001 | 0.827 | N/A | 0.891 |
| NS | 0.001 | 0.991 | 0.891 | N/A |

Table 8. p-value of across group comparisons of mean F1 values for /i/

| | 4 th | Major | Ph.D. | NS |
|-----------------|-----------------|--------|--------|--------|
| 4 th | N/A | <0.001 | <0.001 | <0.001 |
| Major | <0.001 | N/A | 0.030 | 0.870 |
| Ph.D. | <0.001 | 0.030 | N/A | 0.101 |
| NS | <0.001 | 0.870 | 0.101 | N/A |

Table 9. p-value of across group comparisons of mean F2 values for /i/

| | F1 mean (standard deviation) | F2 mean (standard deviation) |
|--------------------------|---------------------------------|---------------------------------|
| Fourth-semester | 552.42 | 1322.61 |
| N = 389 | (100.99) | (264.61) |
| Graduating Spanish Major | 526.51 | 1289.19 |
| N=392 | (88.03) | (431.21) |
| Ph.D. | 520.66 | 1339.33 |
| N=392 | (121.36) | (404.36) |
| Native speaker | 564.59 | 1379.49 |
| N=113 | (124.74) | (421.66) |

/o/ F1 between groups ANOVA results: F(3)=9.581, p<0.001

/o/ F2 between groups ANOVA results: F(3)=2.123, p=0.096

Table 10. Mean formant values of /o/ by subject group

| | 4 th | Major | Ph.D. | NS |
|-----------------|-----------------|-------|--------|--------|
| 4 th | N/A | 0.001 | <0.001 | 0.284 |
| Major | 0.001 | N/A | 0.441 | 0.001 |
| Ph.D. | <0.001 | 0.441 | N/A | <0.001 |
| NS | 0.284 | 0.001 | <0.001 | N/A |

Table 11. p-value of across group comparisons of mean F1 values for /o/

| | 4 th | Major | Ph.D. | NS |
|-----------------|-----------------|-------|-------|-------|
| 4 th | N/A | 0.218 | 0.537 | 0.160 |
| Major | 0.218 | N/A | 0.064 | 0.026 |
| Ph.D. | 0.537 | 0.064 | N/A | 0.321 |
| NS | 0.160 | 0.026 | 0.321 | N/A |

Table 12. p-value of across group comparisons of mean F2 values for /o/

| | F1 mean (standard deviation) | F2 mean (standard deviation) |
|--------------------------|---------------------------------|---------------------------------|
| Fourth-semester | 413.62 | 1286.77 |
| N = 388 | (76.17) | (242.50) |
| Graduating Spanish Major | 395.85 | 1143.20 |
| N=398 | (66.95) | (324.9) |
| Ph.D. | 396.4 | 1068.6 |
| N=379 | (72.38) | (312.67) |
| Native speaker | 399.53 | 1007.43 |
| N=114 | (56.44) | (256.24) |

/u/ F1 between groups ANOVA results: $F(3)=5.337$, $p=0.001$

/u/ F2 between groups ANOVA results: $F(3)=47.15$, $p<0.001$

Table 13. Mean formant values of /u/ by subject group

| | 4 th | Major | Ph.D. | NS |
|-----------------|-----------------|--------|-------|-------|
| 4 th | N/A | <0.001 | 0.001 | 0.062 |
| Major | <0.001 | N/A | 0.914 | 0.625 |
| Ph.D. | 0.001 | 0.914 | N/A | 0.679 |
| NS | 0.062 | 0.625 | 0.679 | N/A |

Table 14. p-value of across group comparisons of mean F1 values for /u/

| | 4 th | Major | Ph.D. | NS |
|-----------------|-----------------|--------|--------|--------|
| 4 th | N/A | <0.001 | <0.001 | <0.001 |
| Major | <0.001 | N/A | <0.001 | <0.001 |
| Ph.D. | <0.001 | <0.001 | N/A | 0.050 |
| NS | <0.001 | <0.001 | 0.050 | N/A |

Table 15. p-value of across group comparisons of mean F2 values for /u/

Appendix B

Mean formant values are presented according to syllable stress and subject group in the following tables. Alongside the mean values are the mean difference between stressed and unstressed productions and results of Independent Samples t-tests.

| | Stressed F1 (No.) | Unstressed F1 (No.) | Levene's Test for Equality of Variances | | t-test for Equality of Means | | |
|-----|----------------------|------------------------|-----------------------------------------------|-------|------------------------------|-----|--------------------|
| | | | F | Sig. | t | df | Sig. (2-tailed) |
| /i/ | 410.07 (198) | 418.01 (184) | 1.572 | 0.211 | -0.907 | 380 | 0.365 |
| /e/ | 542.55 (179) | 532.84 (202) | 0.426 | 0.515 | 1.020 | 379 | 0.308 |
| /a/ | 728.59 (195) | 651.01 (194) | 1.000 | 0.318 | 5.428 | 387 | <0.001 |
| /o/ | 560.6 (194) | 544.29 (195) | 4.788 | 0.029 | 1.595 | 387 | 0.111 |
| /u/ | 408.24 (198) | 419.22 (190) | 0.069 | 0.793 | -1.421 | 386 | 0.156 |

Table 1. Mean F1 values for fourth-semester learners according to syllable stress

| | | | Levene's Test for Equality of Variances | | t-test for Equality of Means | | |
|------|----------------------|------------------------|-----------------------------------------------|-------|------------------------------|-----|--------------------|
| | Stressed F2 (No.) | Unstressed F2 (No.) | F | Sig. | t | df | Sig. (2-tailed) |
| /i/ | 2045.22 (198) | 1948.28 (184) | 0.766 | 0.382 | 2.060 | 380 | 0.040 |
| /e/ | 1907.96 (179) | 1814.06 (202) | 0.989 | 0.321 | 2.911 | 379 | 0.004 |
| /a/ | 1518.08 (195) | 1580.82 (194) | 0.002 | 0.967 | -3.173 | 387 | 0.002 |
| /o/ | 1293.91 (194) | 1351.15 (195) | 0.432 | 0.511 | -2.140 | 387 | 0.033 |
| /u/* | 1251.5 (198) | 1323.53 (190) | 10.74 | 0.001 | -2.954 | 386 | 0.003 |

*Given the significant p-value of Levene's Test for Equality of Variances, equal variances were not assumed, and the t-test numbers reported reflect this.

Table 2. Mean F2 values for fourth-semester learners according to syllable stress

| | | | Levene's Test for Equality of Variances | | t-test for Equality of Means | | |
|-----|----------------------|------------------------|-----------------------------------------------|-------|------------------------------|-----|--------------------|
| | Stressed F1 (No.) | Unstressed F1 (No.) | F | Sig. | t | df | Sig. (2-tailed) |
| /i/ | 375.28 (197) | 396.33 (194) | 3.533 | 0.061 | -3.323 | 389 | 0.001 |
| /e/ | 516.24 (193) | 516.44 (199) | 0.209 | 0.648 | -0.028 | 390 | 0.978 |
| /a/ | 720.99 (198) | 622.27 (195) | 0.488 | 0.485 | 8.135 | 391 | <0.001 |
| /o/ | 536.46 (198) | 516.36 (194) | 0.432 | 0.511 | -2.140 | 387 | 0.033 |
| /u/ | 395.77 (200) | 395.94 (198) | 0.335 | 0.563 | -0.026 | 396 | 0.980 |

Table 3. Mean F1 values for graduating Spanish majors according to syllable stress

| | Stressed F2 (No.) | Unstressed F2 (No.) | Levene's Test for Equality of Variances | | t-test for Equality of Means | | |
|------|----------------------|------------------------|-----------------------------------------------|-------|------------------------------|-----|--------------------|
| | | | F | Sig. | t | df | Sig. (2-tailed) |
| /i/ | 2452.08 (197) | 2229.41 (194) | 11.22 | 0.001 | 5.770 | 389 | <0.001 |
| /e/ | 2086.63 (193) | 1935.36 (199) | 0.495 | 0.482 | 5.264 | 390 | <0.001 |
| /a/ | 1561.76 (198) | 1673.14 (195) | 5.906 | 0.016 | -4.625 | 391 | <0.001 |
| /o/ | 1236.43 (198) | 1343.03 (194) | 1.107 | 0.293 | -2.463 | 390 | 0.014 |
| /u/* | 1064.24 (200) | 1222.97 (198) | 10.11 | 0.002 | -5.020 | 396 | <0.001 |

*Given the significant p-value of Levene's Test for Equality of Variances, equal variances were not assumed, and the t-test numbers reported reflect this.

Table 4. Mean F2 values for graduating Spanish majors according to syllable stress

| | Stressed F1 (No.) | Unstressed F1 (No.) | Levene's Test for Equality of Variances | | t-test for Equality of Means | | |
|-----|----------------------|------------------------|-----------------------------------------------|-------|------------------------------|-----|--------------------|
| | | | F | Sig. | t | df | Sig. (2-tailed) |
| /i/ | 374.8 (200) | 399.44 (197) | 4.095 | 0.044 | -2.473 | 395 | 0.014 |
| /e/ | 504.11 (198) | 489.58 (199) | 0.000 | 0.982 | 1.704 | 395 | 0.089 |
| /a/ | 708.11 (193) | 606.11 (195) | 0.010 | 0.919 | 6.609 | 386 | <0.001 |
| /o/ | 541.63 (197) | 499.48 (195) | 5.992 | 0.015 | 3.487 | 390 | 0.001 |
| /u/ | 395.48 (197) | 397.39 (183) | 0.335 | 0.563 | -0.026 | 396 | 0.980 |

Table 5. Mean F1 values for Ph.D. students according to syllable stress

| | Stressed F2 (No.) | Unstressed F2 (No.) | Levene's Test for Equality of Variances | | t-test for Equality of Means | | |
|-----|----------------------|------------------------|-----------------------------------------------|-------|------------------------------|-----|--------------------|
| | | | F | Sig. | t | df | Sig. (2-tailed) |
| /i/ | 2467.72 (200) | 2337.5 (197) | 1.590 | 0.208 | 3.934 | 395 | <0.001 |
| /e/ | 2099.71 (198) | 1957.67 (199) | 2.928 | 0.088 | 5.948 | 395 | <0.001 |
| /a/ | 1629.69 (193) | 1687.8 (195) | 5.906 | 0.016 | -4.625 | 391 | <0.001 |
| /o/ | 1335 (197) | 1343.7 (195) | 0.373 | 0.542 | -0.213 | 390 | 0.832 |
| /u/ | 1138.57 (197) | 1003.96 (183) | 9.600 | 0.002 | -4.282 | 377 | <0.001 |

Table 6. Mean F2 values for Ph.D. students according to syllable stress

| | Stressed F1 (No.) | Unstressed F1 (No.) | Levene's Test for Equality of Variances | | t-test for Equality of Means | | |
|-----|----------------------|------------------------|-----------------------------------------------|-------|------------------------------|-----|--------------------|
| | | | F | Sig. | t | df | Sig. (2-tailed) |
| /i/ | 380.5 (60) | 391.25 (59) | 1.707 | 0.194 | -0.735 | 117 | 0.464 |
| /e/ | 505.55 (58) | 508.45 (59) | 3.481 | 0.065 | -0.189 | 115 | 0.850 |
| /a/ | 720.44 (59) | 679.19 (60) | 0.362 | 0.548 | 1.561 | 117 | 0.121 |
| /o/ | 558.89 (57) | 570.5 (56) | 4.953 | 0.028 | -0.489 | 111 | 0.626 |
| /u/ | 402.39 (58) | 396.53 (55) | 6.018 | 0.016 | 0.550 | 111 | 0.584 |

Table 7. Mean F1 values for native Speakers according to syllable stress

| | Stressed F2 (No.) | Unstressed F2 (No.) | Levene's Test for Equality of Variances | | t-test for Equality of Means | | |
|-----|----------------------|------------------------|-----------------------------------------------|-------|------------------------------|-----|--------------------|
| | | | F | Sig. | t | df | Sig. (2-tailed) |
| /i/ | 2384.2 (60) | 2284.47 (59) | 0.101 | 0.751 | 1.469 | 117 | 0.145 |
| /e/ | 2117.32 (58) | 1930.82 (59) | 0.019 | 0.891 | 3.692 | 115 | <0.001 |
| /a/ | 1621.14 (59) | 1720.69 (60) | 1.720 | 0.192 | -2.057 | 117 | 0.042 |
| /o/ | 1329.34 (57) | 1430.53 (56) | 0.991 | 0.322 | -1.279 | 111 | 0.204 |
| /u/ | 942.62 (58) | 1076.94 (55) | 0.013 | 0.908 | -2.886 | 112 | 0.005 |

Table 8. Mean F2 values for native speakers according to syllable stress

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