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Comparative Analysis of Vowel Space of L1 Spanish Speakers and General American English

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COMPARATIVE ANALYSIS OF VOWEL SPACE OF L1 SPANISH SPEAKERS AND GENERAL AMERICAN ENGLISH

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1.0 Introduction

Much like the classic experiment on acoustics and vowel space done in Bell Telephone Laboratories by Peterson and Barney (1952) did with the acoustics of General American English vowels, the purpose of this study was to measure the vowel space based on the formant measurements produced by speakers whose L1 is Spanish, speaking eleven monophthong vowels in an /hVd/ context. The study then compares these measurements with the standard vowel productions of all these eleven monophthong vowels found in General American English (GAE).

The main focus of this study is to look into areas where L1 Spanish speakers' vowel pronunciations may cause issues in intelligibility with speakers of General American English.

Research Questions: What are the vowel characteristics (based on vowel height and frontness) that make L1 Spanish speakers' speech accented in comparison with General American English? What are the possible areas of unintelligibility? Are there differences between males and females?

1.1 General American Vowels

The vowel space illustration below provides a graphical method of showing where a speech sound, such as a vowel, is located in both "acoustic" and "articulatory" space. The illustration shows an acoustic vowel space based on the first two formants for vowels (formants are the bands of energy that correspond to the resonances of the vocal tract for particular shapes). The vertical axis represents the frequency of the first formant (F1). The horizontal axis shows the frequency gap between the first two formants (F2-F1).

This 2-dimensional representation corresponds, to a certain degree, to tongue body position, with indications of high vs. low and front vs. back positions -- an articulatory space.

General American English is considered to have an inventory of 11 vowels, i.e., /i/, /ɪ/, /e/, /ɛ/, /æ/, /ɑ/, /o/, /ɔ/, /ʊ/, /u/, and /ʌ/. These are arranged in the vowel quadrant below.

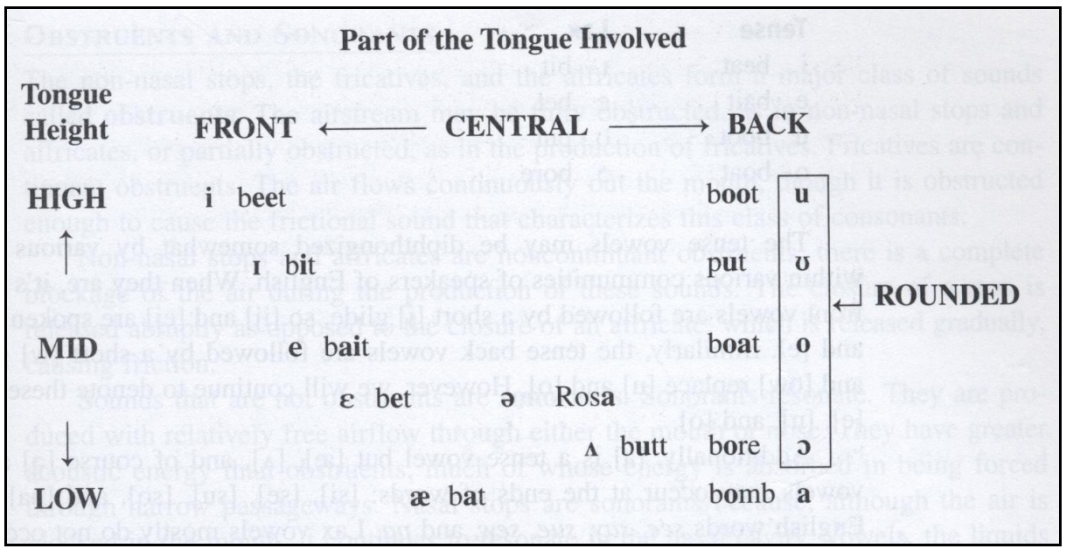

Figure 1: Classification of American English vowels

1.2 Vowels of Spanish

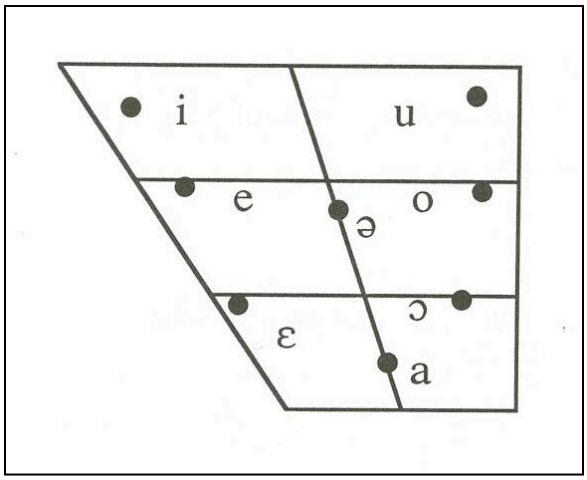

Figure 2: Vowel Quadrant of Spanish vowels

Source: Handbook of the International Phonetic Association: A Guide to the Use of the International Phonetic Alphabet (p. 61), by the International Phonetic Association, 1999, Cambridge, United Kingdom: Cambridge University Press.

It should be noted that the chart above was taken from the *Handbook of the International Phonetic Association*, and is the chart for the vowel inventory of Catalan, which is a Romance language closely related to Spanish as well as Italian. They belong to the Indo-European family. This chart was chosen because it also best represented the Spanish vowel inventory, which includes the same phones. Most charts found elsewhere contained only the phonemes (i.e. /a/, /e/, /i/, /o/, /u/), so that vowels such as

/ɛ/ and /ɔ/ were missing, even though both are used. For example, when saying the common phrase, "¿Cómo estás?" or translated into English "How are you? (informal)" it would be pronounced [kómo ɛstás] and not [kómo estás]. In comparing Figure 1 and Figure 2, often two English vowels share the 'phonetic space' occupied by one Spanish vowel, so in theory one-to-one correspondences would be difficult.

2.0 Method

In order to examine the vowel production of Spanish speakers in comparison with speakers of GAE, a total of eight speakers were recorded: four male and four female. All of the speakers were born in a primarily Spanish-speaking country, and the majority of the speakers are specifically from the Central American region of Latin America. All of the participants were year-long university exchange students at Saint Cloud State University in the years 2009 and 2010 who, apart from that, had not traveled or lived out of their countries for a significant amount of time that could affect his or her speech. All of them are also between the ages of 21 to 25. Table 2.1 summarizes the background information about the participants in the study.

	Gender	Country of Origin	Age
Participant 1	Male	Panama	25
Participant 2	Male	Costa Rica	22
Participant 3	Male	Costa Rica	21
Participant 4	Male	El Salvador	24
Participant 5	Female	Chile	22
Participant 6	Female	Chile	23
Participant 7	Female	Dominican Republic	22
Participant 8	Female	El Salvador	23

Table 1: Background Summary of Spanish-speaking participants

2.1 Elicitation and Analysis

This study replicates the most widely cited, yet surprisingly simple, experiment on vowel acoustics, conducted at Bell Telephone Laboratories by Peterson and Barney (1952) in which they analyzed the sounds of General American English. The speakers were given a list of twelve words. The list contained twelve monosyllabic words containing a consonant-vowel-consonant phoneme structure, each beginning with [h] and ending with [d] and differing only in the vowel (i.e. /hVd/ context). The words the participants had to pronounce were <heed>, <hid>, <hayed>, <head>, <had>, <hawed>, <hoed>, <hod>, <hood>, <who'd>, <hud>, and <heard>. The /hVd/ structure was chosen in order to have a minimal effect on the realization of the vowels. For the purposes of this study, <heard> was not used during data collection, as the focus was on the eleven monophthong vowels of GAE and not the r-colored vowel (i.e. /ɚ/) found in the word <heard>. The findings reported in Table 2 involve the pronunciation of eleven vowels, i.e., /i/, /ɪ/, /e/, /ɛ/, /æ/, /ɑ/, /o/, /ɔ/, /ʊ/, /u/, and /ʌ/ as found in the word list above.

Each person provided 33 tokens (11 words repeated three times). Collectively, the participants provided 264 tokens (33 x 8). Even though the number speakers and tokens is much smaller than Peterson

and Barney's data (76 participants and 1,520 recorded words), the number of speakers and tokens for the present analysis is more than sufficient for an exploratory acoustic phonetic analysis.

All of the recordings were done using an internal laptop microphone. The recorded data was converted into .wav files. The acoustic measurements and analyses were done with Praat, an online open source software designed for acoustic phonetic analyses. Several acoustic correlates were measured: $F_{1,}$ $F_{2,}$ and duration of the entire vowel. Each word was spoken three times by each speaker, and averages were taken for each value for each speaker. The whole vowel was measured from the onset to the offset. Figure 3 below highlights the onset and offset areas of the vowels used in the analysis. They are indicated on the spectrogram by vertical lines. Averages for each value were then calculated for the entire group. This data was compared to average formant frequency data found in Peterson and Barney (1952) on GAE, because the focus of this study is to determine the intelligibility of these L1 Spanish speakers in comparison with GAE speakers.

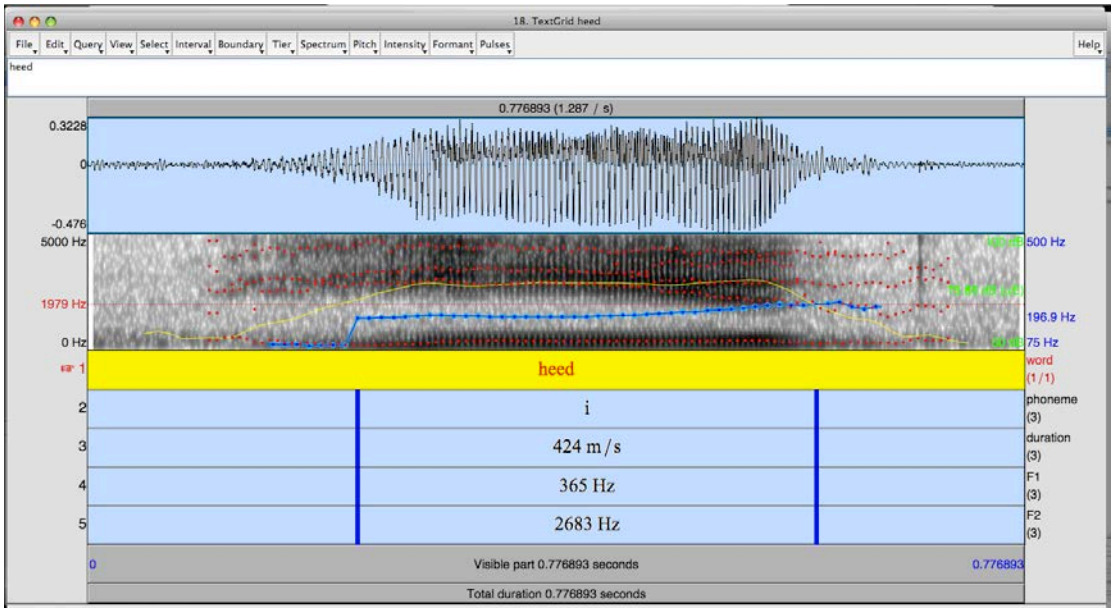

Figure 3: Spectrograph of Vowels

Because the words are read in a word list speech style, they are enunciated fully so that their onset and their offset are clearly visible on a spectrogram. This elicitation technique ensures that all the vowels are stressed.

3.0 Formant Averages and Analyses

Averages were calculated from the collected values of the F_1 and F_2 values to see if Spanish speakers allocate the same vowel space as speakers of GAE when producing the same vowels. For this study, I take the F_1 and F_2 values given by Peterson and Barney (1952, p. 183) to be representative of

GAE vowels, except for the vowels /e/ and /o/.[1] The vowels produced by the L1 Spanish speakers are compared and contrasted to these formant values, as shown in Table 2 below:

N0	Vowels	US Male F1	SP Male F1	US Male F2	SP Male F2	US Female F1	SP Female F1	US Female F2	SP Female F2
1.	<heed> [i]	270	351	2,290	1,979	310	399	2,790	2,560
2.	<hid> [ɪ]	390	393	1,990	2,033	430	450	2,480	2,273
3.	<hayed> [e]	476	400	2,089	2,068	536	506	2,530	2,354
4.	<head> [ɛ]	530	545	1,840	1,819	610	645	2,330	1,968
5.	<had> [æ]	660	647	1,720	1,491	860	847	2,050	1,773
6.	<hawed> [ɔ]	570	562	840	985	590	607	920	1,290
7.	<hoed> [o]	497	463	910	983	555	504	1,035	1,137
8.	<hod> [ɑ]	730	593	1,090	1,196	850	746	1,220	1,446
9.	<hood> [ʊ]	440	329	1,020	1,031	470	449	1,160	1,431
10.	<who'd> [u]	300	335	870	1,003	370	399	950	1,385
11.	<hud> [ʌ]	640	531	1,190	1,529	760	719	1,400	1,493

Table 2: Mean Formant Values in GAE and L1 Spanish Speakers

3.1 Vowel Intelligibility Inquiry

In comparing F1 and F2 formant values among different dialects/languages for intelligibility purposes, it is good to keep Baart's (2010, p. 67) interpretive framework in mind: A frequency difference of, say, 200 Hz is much more noticeable for people (and perceived as a much greater difference if lower frequencies are involved (as in the difference between 200 and 400 Hz) than if higher frequencies are involved (as in the difference between 2000 and 2200 Hz).

A methodology proposed by Koffi (2011) indicates that the 200 Hz frequency that Baart uses is just a general example for languages. He contends that basic frequency calculations must be performed for each language under investigation to gauge frequency differences that matter. In this case, the

[1]Male and female frequencies for /e/ and /o/ are based on Hillenbrand et al., Journal of the Acoustic Society of America, Vol. 97, No 5, Part 1, May 1995, p. 3103. Peterson and Barney did not investigate these two vowels.

frequency distance needs to be calculated for General American English. The median frequency range is 135 Hz for F1, and 170 Hz for F2, as displayed in Table 3:

No.	Vowel Pairs by Natural Class	F1 Difference	F2 Difference
1.	[ɪ] vs. [ɛ]	140	150
2.	[ɪ] vs. [æ]	270	270
3.	[ɛ] vs. [æ]	130	120
4.	[ʊ] vs. [ɔ]	130	180
5.	[ʊ] vs. [ʌ]	200	170
6.	[ɔ] vs. [ʌ]	70	170

Table 3: Frequency Distance between GAE Vowels

Koffi (2011) proposes that in vowel intelligibility, if the F1 and F2 frequencies between GAE and SpanE vowel of the same type are lower or equal to 135 Hz and 170 Hz respectively, then the SpanE vowel is intelligible. The reason for this is because the difference in frequency falls within the median range. However, if F1 and F2 frequencies are in excess of 135 Hz or 170 Hz, then the SpanE vowel under consideration is moderately to strongly accented. It is hard to state decisively that a vowel is unintelligible just by looking at frequency differences. However, when frequency differences are plotted in the same vowel quadrant, a clearer picture of which vowel(s) may or may not be intelligibility emerges.

3.2 Height Comparison between GAE and SpanE Vowels

Comparisons of GAE and SpanE vowel pairs of the same type yield the following differences:

No.	Minimal Pairs	F1 Frequency (Male)	F1 Difference (Male)	F1 Frequency (Female)	F1 Difference (Female)
1.	English [i] vs. Spanish [i]	270-351	81 Hz	310-399	89 Hz
2.	English [e] vs. Spanish [e]	476-400	76 Hz	536-506	30 Hz
3.	English [ɪ] vs. Spanish [ɪ]	390-393	3 Hz	430-450	20 Hz
4.	English [ɛ] vs. Spanish [ɛ]	530-545	15 Hz	610-645	35 Hz
5.	English [æ] vs. Spanish [æ]	660-647	13 Hz	860-847	13 Hz
6.	English [u] vs. Spanish [u]	300-335	35 Hz	370-399	29 Hz
7.	English [o] vs. Spanish [o]	497-463	34 Hz	555-504	51 Hz
8.	English [ɑ] vs. Spanish [ɑ]	730-593	137 Hz	850-746	104 Hz
9.	English [ʊ] vs. Spanish [ʊ]	440-329	111 Hz	470-449	21 Hz
10.	English [ɔ] vs. Spanish [ɔ]	570-562	8 Hz	590-607	17 Hz
11.	English [ʌ] vs. Spanish [ʌ]	640-531	109 Hz	760-719	41 Hz

Table 4: Distance between GAE and SpanE Vowels

With the information in Table 4, it seems that the only GAE vowel that is produced in an accented fashion for males is [ɑ] because of the frequency difference between GAE and SpanE exceeds 135 Hz. The L1 Spanish speakers' pronunciation of [ɪ], [ɛ], [æ] and [ɔ] do not appear to be accented because the frequency differences between them are below 20 Hz, which is beyond what frequencies human ears can detect. Therefore, when these speakers say the words <hid>, <head>, <had> and <hod>, GAE hearers probably cannot detect a difference.

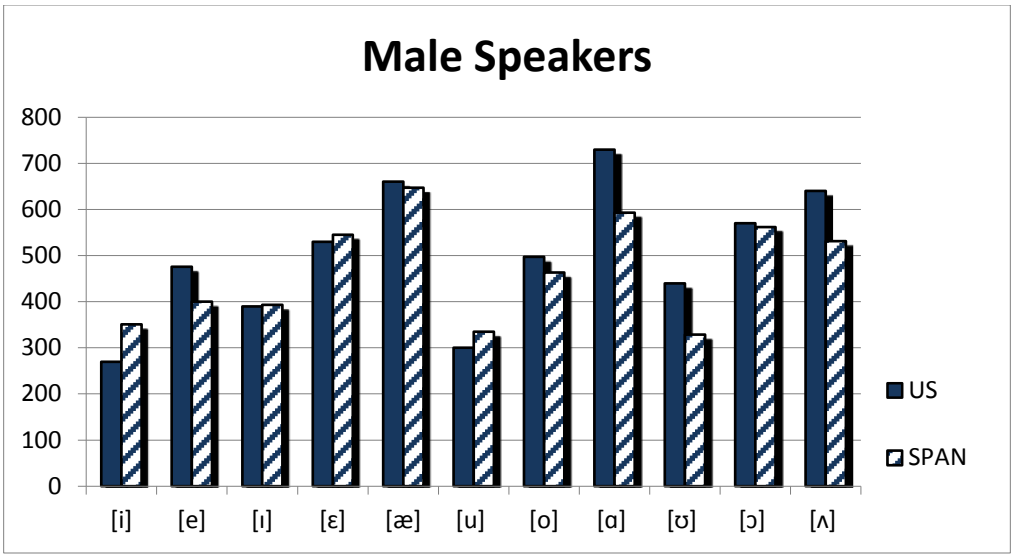

Figure 4: F1 Frequency Graph for Male Speakers

In contrast, the female L1 Spanish speakers studied here had no productions of vowels that were in an accented fashion based on the vowel heights. The frequency differences of all of the vowels were well below the value of 135 Hz.

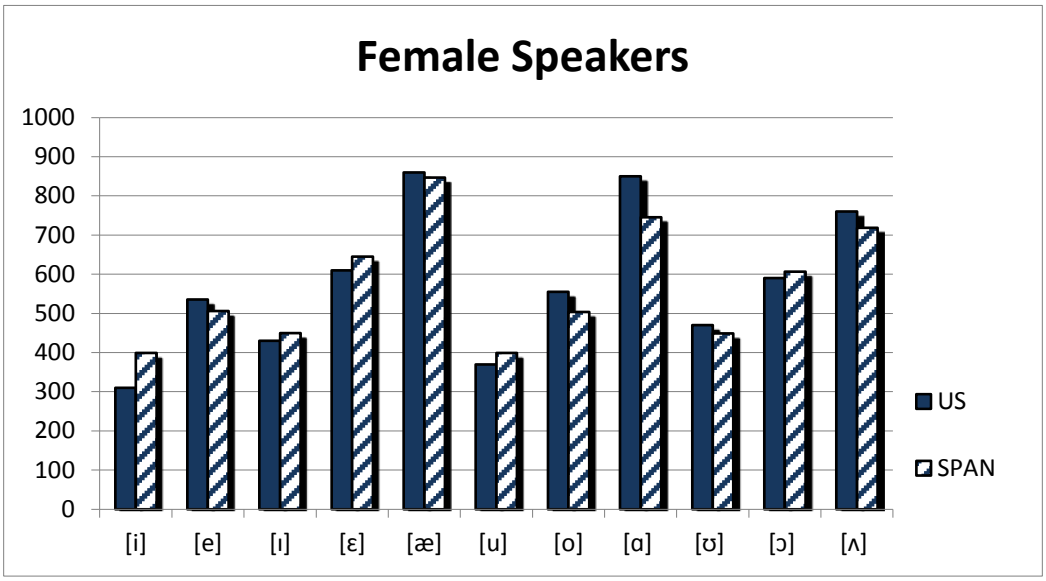

Figure 5A: F1 Frequency Graph for Female Speakers

3.3 Backness Comparison between GAE and SpanE Vowels

Comparisons of GAE and SpanE vowel pairs of the same type yield the following differences. The median F2 frequency range for English vowels is 170 Hz. If a vowel is produced with a frequency difference greater than 170 Hz, that vowel is not considered accented.

No.	Minimal Pairs	F2 Frequency (Male)	F2 Difference (Male)	F2 Frequency (Female)	F2 Difference (Female)
1.	English [i] vs. Spanish [i]	2,290-1,979	311 Hz	2,790-2,560	230 Hz
2.	English [e] vs. Spanish [e]	2,089-2,068	21 Hz	2,530-2,354	176 Hz
3.	English [ɪ] vs. Spanish [ɪ]	1,990-2,033	43 Hz	2,480-2,273	207 Hz
4.	English [ɛ] vs. Spanish [ɛ]	1,840-1,819	21 Hz	2,330-1,968	362 Hz
5.	English [æ] vs. Spanish [æ]	1,720-1,491	229 Hz	2,050-1,773	277 Hz
6.	English [u] vs. Spanish [u]	870-1,003	133 Hz	950-1,385	435 Hz
7.	English [o] vs. Spanish [o]	910-983	73 Hz	1,035-1,137	102 Hz
8.	English [ɑ] vs. Spanish [ɑ]	1,090-1,196	106 Hz	1,220-1,446	226 Hz
9.	English [ʊ] vs. Spanish [ʊ]	1,020-1,031	11 Hz	1,160-1,431	271 Hz
10.	English [ɔ] vs. Spanish [ɔ]	840-985	145 Hz	920-1,290	370 Hz
11.	English [ʌ] vs. Spanish [ʌ]	1,190-1,529	339 Hz	1,400-1,493	93 Hz

Table 5B: F2 Distance between GAE and SpanE Vowels

Accordingly, the vowels [i], [æ], and [ʌ] may tentatively be thought of as being accented in SpanE for males. These vowel productions have a difference of more than 170 Hz from the GAE F2 vowel frequencies.

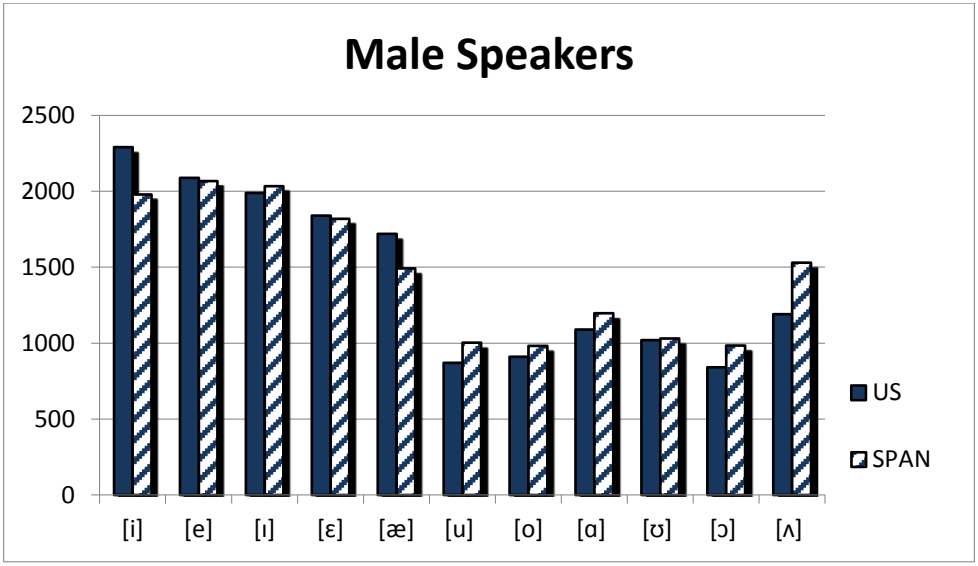

Figure 6: F2 Frequency Graph for Male Speakers

Almost all of the Spanish-speaking females in the study had differences that would make their speech be considered accented (with the exception of [ʌ]), as shown in Table 5. However, as also mentioned in Koffi (2011), the word "tentatively" is the key word here because the discussions later on in the paper will show that F2 has only a marginal effect on vowel perception.

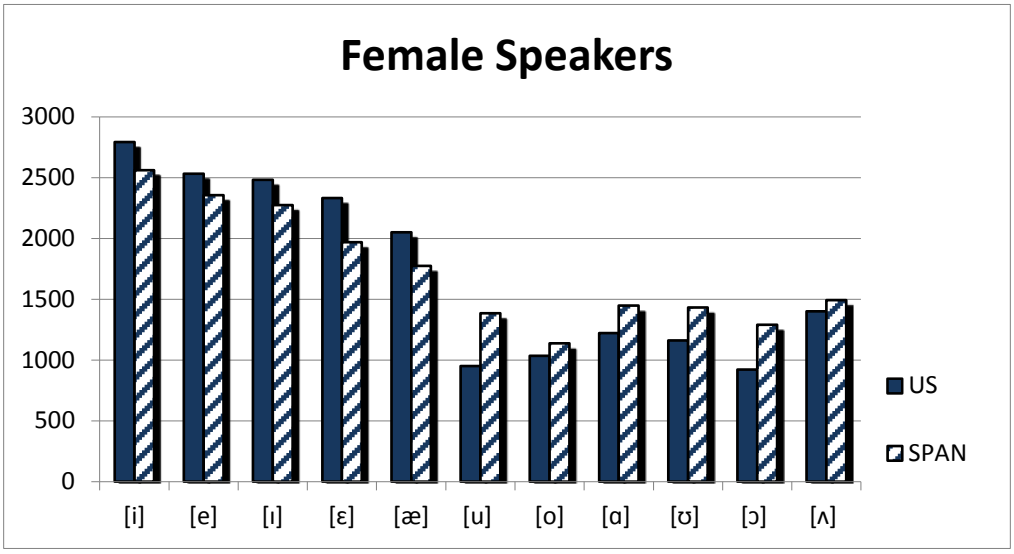

Figure 7: F2 Frequency Graph for Female Speakers

3.4 Acoustic Vowel Space

Additional insights between the two vocalic systems can be gained by plotting GAE vowels in the same vowel quadrant as SpanE vowels, like in Figure 8 and 9 below. First, let us compare male vowel space and draw some conclusions. In 3.4.2, we will do the same for female speakers.

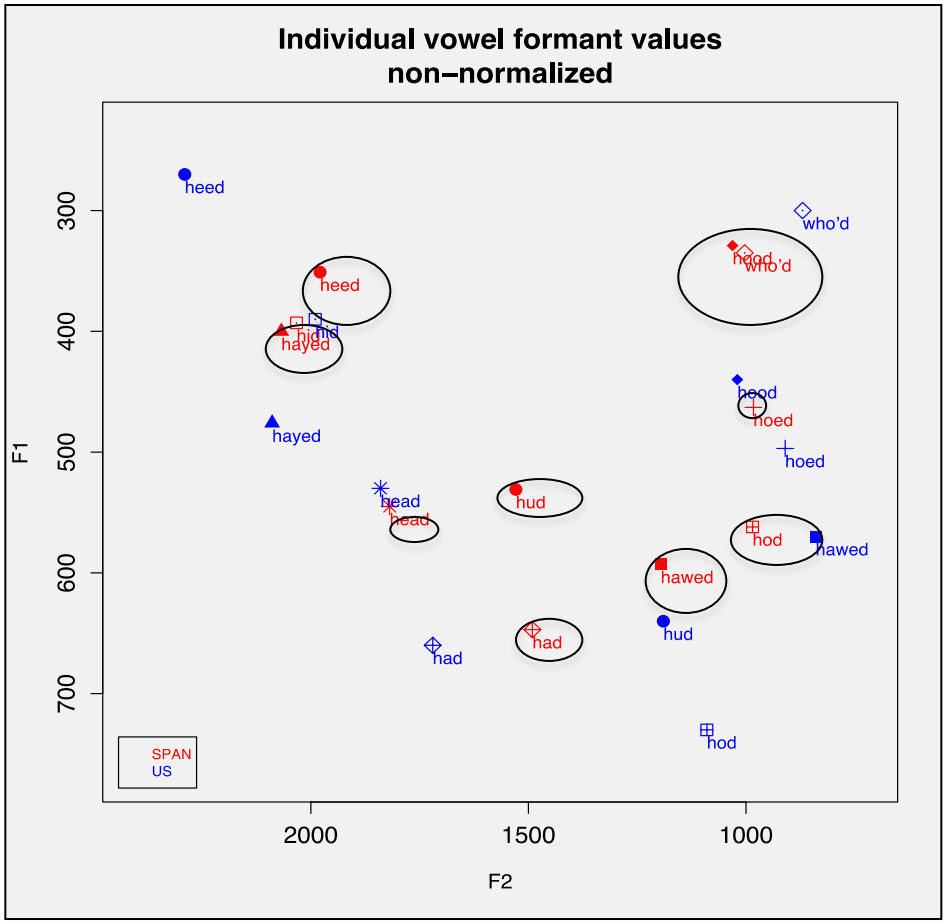

Figure 8: Comparative Vowel Quadrant for Male Speakers

3.4.1 Spanish L1 Male Speakers

These charts highlight some key information that was not obvious in comparing the frequencies of the vowels earlier. A few observations can be made: when it comes to Spanish speaking males, the words <hid> (F1 of 393 Hz and an F2 of 2,033 Hz), <heed> (F1 of 351 Hz and an F2 of 1,979 Hz) and <hayed> (F1 of 400 Hz and an F2 of 2,068 Hz) all may be pronounced fairly similar, which may result in some confusion. The F1 values for these vowels are all within a range of 50 Hz, and the difference in the range of the F2 values is 89 Hz. The difference between the words <hid> and <heed> is much smaller for Spanish speakers than the formant difference in GAE speakers. In analyzing the F2 of the vowels, which measures the backness of the vowels, the average native English speaker has a difference of 300 Hz between the vowels /i/ and /ɪ/, but Spanish speakers have a difference of only 54 Hz. Overall, it appears that the participants are less fronted than the production of /i/ in relation to GAE.

Some other areas in the vowel quadrant which may cause confusion are the productions of <hood> and <who'd>, which are pronounced almost exactly in the same area. In this case, /ʊ/ is pronounced as [u]. Also, when a Spanish speaker says the word <hoed>, a GAE speaker might confuse it with the word <hood>. There is only a difference of 6 Hz in the F1 values and 28 Hz in the F2 values. Both the word <hawed> may be confused with the word <hud>, as their vowel productions of <hawed> are more fronted than the ones in GAE. The vowel /o/ in the word <hoed> is raised in the L1 Spanish male speakers' pronunciation almost to the level of the GAE pronunciation of <hood>. There is only a 23 Hz difference in the F1 values and only a 37 Hz difference in the F2 values. In the male chart, <hud> is raised to the status of a mid-vowel, which is a huge difference from a GAE pronunciation. The F1 of /ʌ/ is 531 Hz in SpanE whereas it is 640 Hz in GAE. Finally, one other observation to note is that the lax vowel /ɛ/ is almost identical for to the GAE pronunciation, with a mere difference of 15 Hz in the F1 values and 21 Hz in the F2 values. This indicates that this vowel is not at all problematic for Spanish speakers.

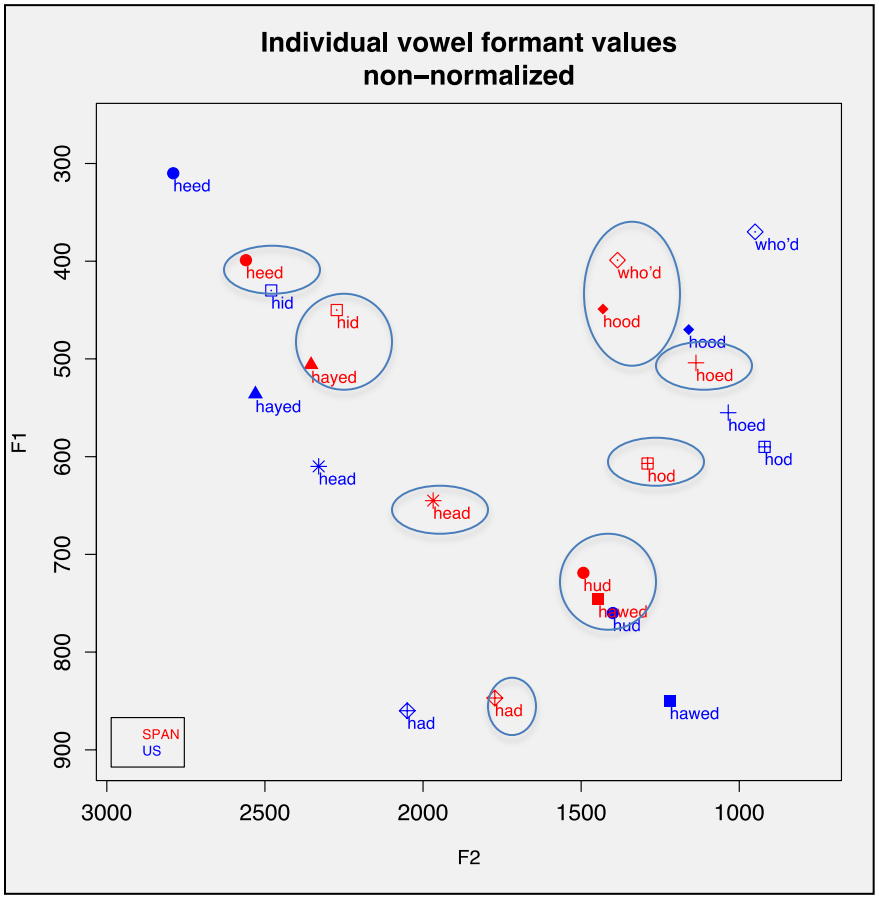

Figure 9: Comparative Vowel Quadrant for Female Speakers

3.4.2 Spanish L1 Female Speakers

Generally speaking the front vowels of the Spanish L1 female speakers are less fronted (in fact, most of the vowels are more centralized than their GAE counterparts), but their speech is definitely more intelligible. The one exception is the vowel /i/ whose formant values are closer to the GAE pronunciation of <hid>. Looking at Figure 9, one can also see that the female speakers' pronunciation of /ɔ/ in the word <hawed> is raised to be closer to the vowel [ʌ] like <hud>. Finally, /o/ in <hoed> for these speakers is raised up closer to the pronunciation of the word <hood>, with an F1 difference of 34 Hz and an F2 difference of 23 Hz between the two values.

3.5 Feature Hierarchy, Formant Hierarchy, and Intelligibility

Based on the previous sections, one may suggest that the vowels [ɑ], [i], [æ], and [ʌ] would pose challenges to understanding L1 Spanish speakers of English. However, this assessment fails to take into account feature hierarchy, and that phonologists claim that in analyzing vowel sounds, some features are more noticeable than others (Koffi, 2011). For phonologists, the most significant feature for vowels is height. Even though vowel quality encompasses many formants, only the first three (F1 for height, F2 for backness, and F3 for lip rounding) are acoustically relevant in many instances. According to Ladefoged, however, in many acoustic phonetic studies, very little mention is made of F3 because "[it] has very little function in distinguishing the vowels shown" (Ladefoged 2001, p. 46). F2 is also indispensible in the analysis of vowel acoustics. Yet, its role in analyzing for the discernment of intelligibility is somewhat limited and negligible. Previous studies suggest that dialectal changes involving F1 are more noticeable and more prevalent than those involving F2. Ladefoged (2006, p. 188) provides acoustic data to explain why F1 plays a more dominant role than F2, saying it carries about 80% of the energy of the vowel when produced. Since F1 has 80% of the energy in the vowel, it is clearly the most important formant. Consequently, in the perception and assessment of the intelligibility of vowels, it is the most important feature (Koffi, 2011).

4.0 Discussion

L1 Spanish Males

The spacing of SpanE vowels [ɪ] and [e] can lead to unintelligibility in some instances, as there is only a 35 Hz difference between the two. While, the English [i] is positively transferred for Spanish male speakers and does not pose any problems, the English [ɪ] does. The English [ɪ] is problematic and can be confused with [i]. The vowels in [hawed] and [hod] occupy a similar vowel space, but in many dialects of GAE these two phonemes are part of what is often called the "caught-cot merger," and many speakers cannot distinguish between [ɑ] and [ɔ] neither. Another observation in talking about vowel height is that L1 Spanish speakers in this study in general raised their production of [ʊ] to the point that it is in the same vowel space as the SpanE production of [u], with a 28 Hz height difference. This could potentially lead to misunderstanding. Fortunately, there are not many minimal pairs involving the vowels /u/ and /ʊ/. Therefore, the context of utterance will mitigate potential cases of lexical confusion. In general, the L1 Spanish speaking males vowel productions are more centralized than their GAE counterparts. One

observation to note is that the production of [ɛ] is almost the same for both the L1 Spanish speakers and the GAE speakers in Peterson and Barney's study.

L1 Spanish Females

Like the male participants, female speakers seem to have some trouble with [ɪ] in that in could be confused with [i]. For these speakers also, [ʌ] in <hud> and [ɔ] in the word <hawed> occupy a similar vowel space, which may cause some confusion. In general, the female speakers' vowels are more centralized than those in GAE, but the data shows that female speakers are more likely to be intelligible in their vowel productions than the males because their tense and lax vowels are fairly similar to those of GAE, except for the cases already mentioned.

5.1 Scope and Limitations

This is only an exploratory study. Yet, some significant insights have been gained by comparing and contrasting the acoustic vowel spaces of Spanish speakers and those of GAE speakers. It should also be noted that four of the participants (Participants 3 – 6) were recorded earlier in the study and as such, did not have all of their recordings analyzed. Their data is missing the values for <hoed>, <hod>, <hood>, <who'd>, and <hud>, or /o/, /ɔ/, /ʊ/, /u/, and /ʌ/, respectfully. Because these participants have since returned to their countries of origin, additional recordings to fill in the gaps could not be made.

Because the sample size is too small, additional studies with more participants should be done before definitive conclusions are made. Another aspect of the data that could be improved on is the samples from Participants 3 through 6. If this study were to be pursued further, the recordings will have to be made in a sound-treated room and with an external microphone. The internal microphone of the Macbook laptop is not ideal for serious acoustic phonetic work.

ABOUT THE AUTHOR

Lindsay Giacomino received her Bachelor of Arts in Linguistics and Spanish at Saint Cloud State University in May 2012. After a study abroad experience studying linguistics (more specifically phonetics and phonology) at the Universidad de Concepción in Concepción, Chile as well as teaching ESL there, she discovered her passion for linguistics as well as language teaching. She is currently interning at the non-profit Hands Across the World in St. Cloud, MN teaching English to refugees and immigrants. Upon completion of the internship, she hopes to teach abroad in either Latin America, Asia or the Middle East before continuing on to pursue a Master's/PhD in Applied Linguistics. She wrote this paper for her senior thesis under the supervision of Dr. Ettien Koffi.

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