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Ettien Koffi
St. Cloud State University, enkoffi@stcloudstate.edu

Lillian Duarte Ribeiro
St. Cloud State University, lilliandribeiro@hotmail.com

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THE ACOUSTIC CORRELATES OF BRAZILIAN PORTUGUESE-ACCENTED ENGLISH VOWELS

ETTIEN KOFFI AND DUARTE RIBEIRO[1]

ABSTRACT

This study is an acoustic phonetic analysis of Brazilian Portuguese English (BPE) vowels produced by seven Brazilian students. The research was carried out in the Spring of 2016 when the participants, mostly exchange students, were in their last semester of study in the United States after an average length of residency (LOR) of 19.71 months at St. Cloud State University. They were recorded producing the 11 vowel phonemes of American English. The main findings are that four vowels in particular – [ɪ, æ, ʌ, ʊ] – interfere with intelligibility the most. The participants' inability to produce these vowels intelligibly has a cascading masking effect on their entire L2 English vowel system, thereby affecting the intelligibility of other vowels. The corpus on which the findings are based consists of 1,386 tokens. Even though six acoustic correlates –F0, F1, F2, F3, Intensity, Duration –were investigated, only F1 and F2 were used to assess intelligibility and to build comparative acoustic vowel spaces.

1.0 Introduction

English has become a hot commodity all over the world (Jenkins, 2003; Crystal, 2003). Being able to speak it well in Brazil can give access to employment in multinational corporations or in Brazilian companies operating overseas. Yet, for many Brazilians attaining a high level of oral proficiency in English is often elusive. Curricular decisions, ill-adapted pedagogical strategies, the learning environment, the structural differences between Brazilian Portuguese (BP) and English, and a host of other issues are formidable obstacles that hinder fluency in English. Though the obstacles are multifaceted, we have chosen to focus on the pronunciation of English vowels because they have a greater functional load in English than consonants. Therefore, mispronouncing vowels creates more unintelligibility than mispronouncing consonants. The paper is organized in six main sections. The first provides an overview of English instruction in Brazil, the second introduces the participants, the third reports on the acoustic characteristics of BP, the fourth describes the methodology and the measurements used to create the comparative acoustic vowel spaces, the fifth addresses issues related to transfer and masking, and the sixth makes some observations for pedagogical applications.

2.0 Overview of English in Brazilian Schools

In Brazil, English education starts in primary school, that is, from the ages of 6 to 14 (SEF 1998:53). In the past, English was not given a high priority at school, but things are changing now

[1]**Authorship responsabilities:** The first author assigned this project to the second author who conducted the research to fulfill the requirements of her BA in Linguistics. They met weekly to discuss her progress. She is listed as the second author of this paper to the extent that she did all the measurements, the spectrographs, the acoustic vowel spaces, and provided all the background information on the participants. Significant portions of the capstone paper are included in the present version of the paper. However, the paper in its current form is substantially different from the version that the second author wrote for her capstone project. The first author has reinterpreted the acoustic phonetic measurements in light of masking thresholds and Relative Functional Load percentages. The second author has read the present version of the paper and agrees with its content. The first author assumes full responsibility for any erroneous interpretations of acoustic measurements.

because of globalization. The National Education Guidelines from the Secretaria de Educação Fundamental (SEF) deem it essential for Brazilian students to be informed about different cultures in an interconnected global economy (British Council 2013, p. 11). In spite of this lofty goal, English proficiency in Brazil is not yet where it should be. Several obstacles stand in the way of oral proficiency. Some obstacles have to do with the lack of adequate textbooks, others with the limited hours allotted to English instruction, still others with a lack of qualified teachers (SEF, 1998, p.24). Another impediment is the curricular focus on reading and writing at the expense of listening and speaking. The British Council (2013, p. 8) reports that BP teachers of English have more confidence in their reading abilities than in their speaking skills. Most foreign language tests in Brazil require that students demonstrate reading proficiency (SEF, 1998, p. 24). Even in big metropolitan areas, the number of people who regularly use English is still very small (SEF, 1998, p. 20). Students who want to able to speak it fluently have to enroll at English-medium schools. However, a gradual shift from reading and writing to listening and speaking is taking place. Brazil's role as an emergent economy on the world stage has something to do with this shift. The influence of English is growing as multinational corporations invest in Brazil and as Brazil invests in other countries. As a result, there is a growing number of Brazilians who want to study abroad or work for international corporations. In 2011 alone, 215,000 Brazilian students studied abroad with the stated goal of learning or improving their English (British Council, 2013, p. 53). In 2014 and 2016, Brazil hosted two major sporting events - the World Cup in 2014, and the Summer Olympic games in 2016. Events of this magnitude have caused interest in English to surge. The soaring interest in oral proficiency in English makes this paper timely because it investigates the pronunciation of vowels, which is widely acknowledged as being one of the most difficult aspects of English. Vowels are so crucial to intelligibility that Practor and Robinett (1985, p. 13) gave the following piece of advice to L2 learners of English: "If you wish to understand and be understood in English, you must be able to distinguish and make the distinction among the vowel sounds with accuracy."

3.0 An Overview of Brazilian Portuguese Vowels

The ultimate goal of this paper is to compare and contrast Brazilian Portuguese (BP) vowels with that of General American English (GAE). In so doing, we must first acquaint ourselves with the BP vowel system. It is widely accepted that BP has seven oral vowels and five nasalized vowels. The information in Table 1 taken from Barbosa and Albano (2004, p. 229) gives us an overview of BP oral vowels. The vowels under consideration are in bold. They are embedded in lexical minimal pairs. In other words, they represent the seven oral phonemic vowels of BP:

Vowels	Orthography	IPA transcription	Phoneme	English gloss
i	<s**i**co>	[s**i**ku]	/i/	chigoe
e	<s**e**co>	[s**e**ku]	/e/	dry
ɛ	<s**e**co>	[s**ɛ**ku]	/ɛ/	I (dry)
a	<s**a**co>	[s**a**ku]	/a/	bag
ɔ	<s**o**co>	[s**ɔ**ku]	/ɔ/	I (hit)
o	<s**o**co>	[s**o**ku]	/o/	hit (noun)
u	<s**u**co>	[s**u**ku]	/u/	juice

Table 1: BP Oral Vowels

These vowels are often placed in a vowel quadrant such as the one in Figure 1:

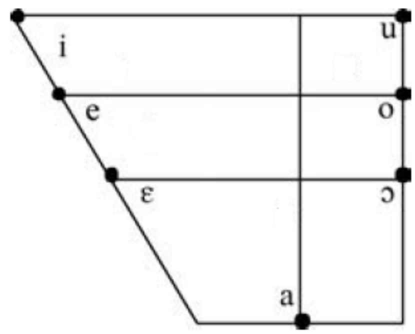

Figure 1: Brazilian Portuguese Oral Vowels[2]

3.1 An Acoustic Description of BP Vowels

Vowel quadrants, such as the one above, were once thought to be accurate representations of the vowel systems of languages. However, it is now clear that they represent "idealized" vowel systems, not the vowels that the speakers of the language actually produce. To get a more accurate picture of vowel systems, more and more researchers are building vowel quadrants from actual acoustic vowel measurements. This is what we will do by turning to the data from Escudero (2008) and Santos (2013).

Escudero (2008) recorded 20 Brazilian Portuguese speakers, 10 males and 10 females, with the average age of 30 years. His data contained the same seven phonemic vowels of BP mentioned earlier. These vowels were embedded in words with a canonical syllable structure of CVCV. His data consisted of 2800 vowel tokens. F1 and F2 measurements were obtained from the vowel of the stressed syllable. Santos (2013, p. 67) undertook an acoustic phonetic analysis of the same seven phonemic vowels in BP. He recorded 10 Brazilian Portuguese speakers, 5 males and 5 females with the average age of 50 years. His sample consisted of 213 words: 29 with the vowel [i], 33 with [u], 33 with [e], 26 with [ɛ], 30 with [o], 27 with [ɔ], and 35 with [a]. All these analyses were done in *Praat*. Tables 2 and 3 display the F1 and F2 measurements from these two studies. They give us a global picture of the intrinsic values of BP vowels. Table 2 contains data from male data, while Table 3 has data from female data.

F1	**[i]**	**[e]**	**[ɛ]**	**[ɑ]**	**[ɔ]**	**[o]**	**[u]**
Escudero (2008)	285	357	518	683	532	372	310
Santos (2013)	322	486	614	726	581	440	384
Mean	**303**	**421**	**566**	**704**	**556**	**406**	**347**
F2	**[i]**	**[e]**	**[ɛ]**	**[ɑ]**	**[ɔ]**	**[o]**	**[u]**
Escudero (2008)	2198	2028	1831	1329	927	804	761
Santos (2013)	2159	2008	1591	1369	998	832	865
Mean	**2178**	**2018**	**1711**	**1349**	**962**	**818**	**813**

Table 2: Vowel Formants-BP Males

[2] Barbosa & Albano (2004, p. 229)

F1	**[i]**	**[e]**	**[ɛ]**	**[ɑ]**	**[ɔ]**	**[o]**	**[u]**
Escudero (2008)	307	425	646	910	681	442	337
Santos (2013)	415	536	642	824	622	497	412
Mean	**361**	**480**	**644**	**867**	**651**	**469**	**374**
F2	**[i]**	**[e]**	**[ɛ]**	**[ɑ]**	**[ɔ]**	**[o]**	**[u]**
Escudero (2008)	2676	2468	2271	1627	1054	893	812
Santos (2013)	2536	2416	2243	1553	1033	879	873
Mean	**2606**	**2442**	**2257**	**1590**	**1043**	**886**	**842**

Table 3: Vowel Formants-BP Females

Acoustic vowel spaces based on the data from these two tables are provided to paint a picture of how these vowels look like in the "mouths" of BP speakers. This visual display is necessary as we provide comparative acoustic vowel spaces later to compare and contrast them with General American English (GAE) on the one hand, and Brazilian Portuguese English (BPE) on the other. The vowel sound in <heed> corresponds to the sound [i] in BP, the one in <hayed> corresponds to [e], <head> to [ɛ], <hod> to [ɑ], to <hawed> to [ɔ], to <hoed> to [o], and <who'd> to [u]. Figure 2 displays the acoustic vowel space of BP males, while Figure 3 shows that of females.

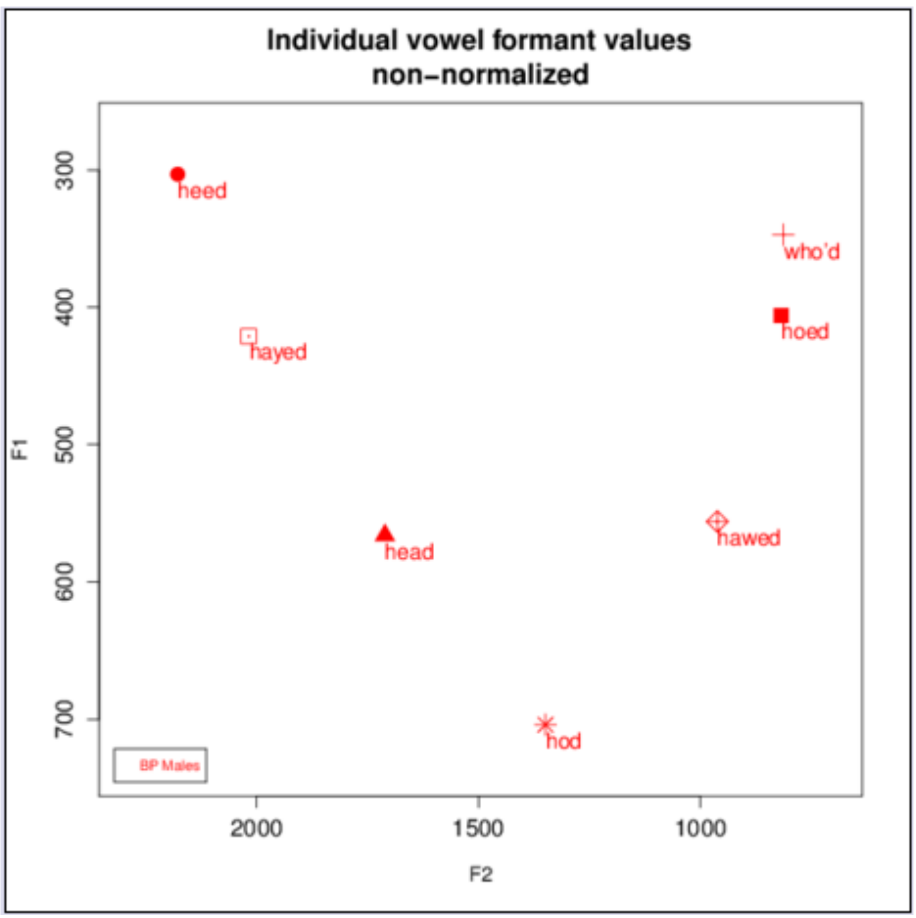

Figure 2: Acoustic Vowel Space of BP Males

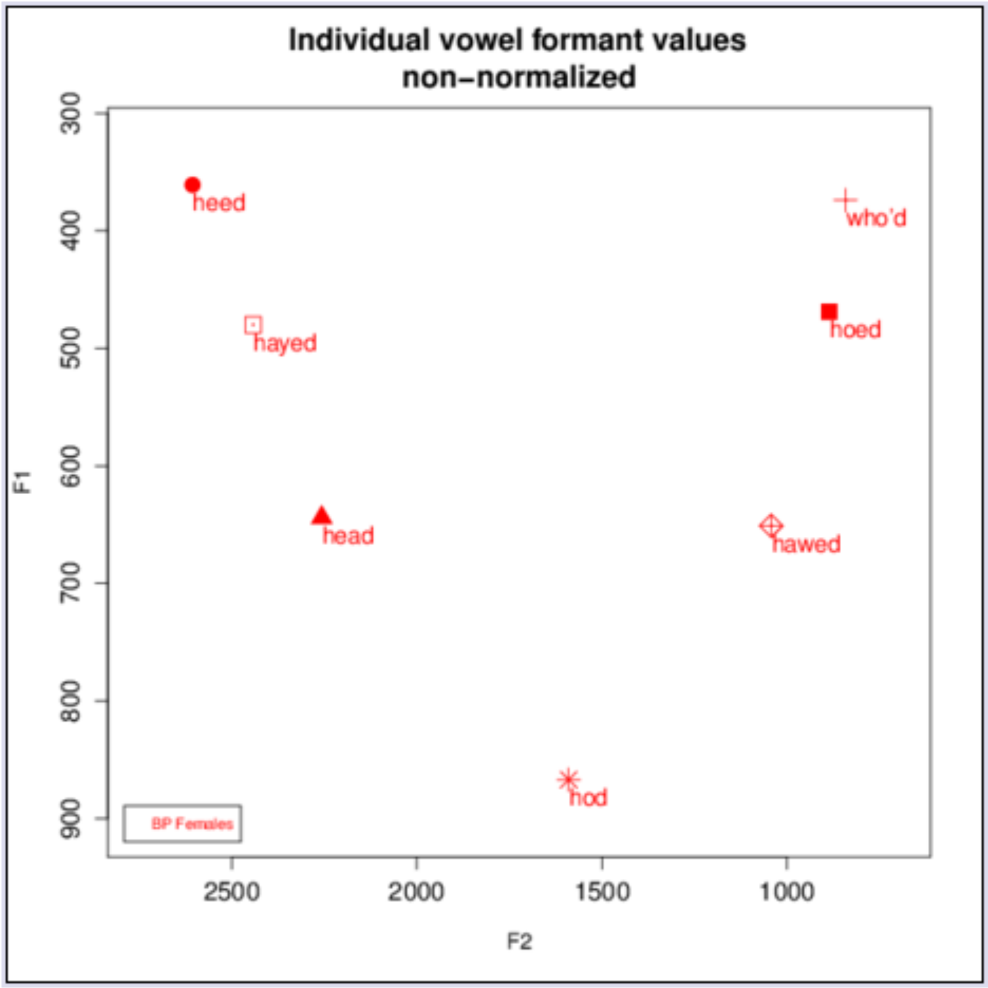

Figure 3: Acoustic Vowel Space of BP Females

4.0 Participants, Data, and Methodology

Figures 2 and 3 represent BP vowels. We now turn to the English vowels that the seven participants in our study produced. We refer to their vowels in the remainder of the paper as BPE. The participants are four males and three females. They were studying at St. Cloud State University, in Minnesota, USA at the time of the recording. They ranged in age from 20 to 24 years old. Three of the males (1M, 3M, and 4M) were exchange students. They had each been in the USA for approximately seven months when the recordings began. Female 2F was also an exchange student, but had been in the USA for about nine months. She first learned English at the Intensive English Center of St. Cloud State University before starting attending classes in her major field of study. Two females (1F and 3F) and one male (2M), were regular international students at St. Cloud State University, and had been in the USA for 36 months each. Collectively, the seven participants had a length of residency (LOR) of 138 months, which averages to 19.71 months per person.

The participants were recorded reading the words listed below, which contain the 11 phonemic monophthong vowels of English. They were instructed to read the words as naturally as possible.

1. Heed
2. Hid
3. Hayed
4. Head
5. Had
6. Hod
7. Hawed
8. Hoed
9. Hood
10. Who'd
11. Hud

This same list of words has been used since Peterson and Barney (1952) to study the acoustic characteristics of American English vowels.[3] Their methodology was replicated in 1995 by Hillenbrand et al. to study Midwest American vowels. It has since been replicated in countless studies of both L1 and L2 English vowels. For our study, the seven participants produced a total of 1,386 tokens, that is, (7 speakers x 11 vowels x 3 repetitions x 6 acoustic correlates). The acoustic correlates investigated are F0, F1, F2, F3, intensity, and duration. However, we focus only on F1 and F2 in this paper because they are the correlates that phoneticians deem most relevant for intelligibility. Appendices A and B display many other details that are not used in the body of the paper. The annotated spectrograph in Figure 4 shows the procedure that was followed to collect the relevant measurements:

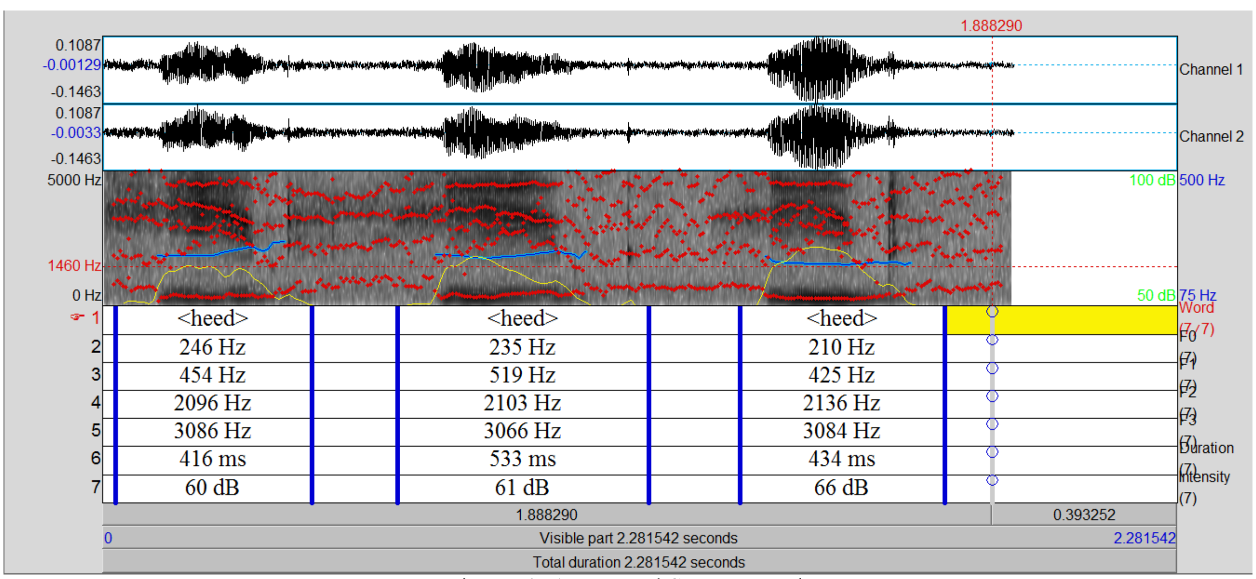

Figure 4: Annotated Spectrograph

[3] The word <*heard*> is purposefully omitted in this study because [ɚ] is not a phoneme in English, but an allophone of a variety of vowels followed by [ɹ].

The measurements seen in Figure 4 are those of the vowels only. They do not include the word-initial /h/ nor does it include the word-final /d/. Boundaries were drawn around each word. The whole duration of the vowel, from the onset to the offset of the vowel, was measured.

5.0 Brazilian-Accented English Vowels

The measurements in Tables 4 and 5 below are based on the methodology described above.

Words		**heed**	**hid**	**hayed**	**head**	**had**	**hod**	**hawed**	**hoed**	**hood**	**who'd**	**hud**
Male Vowels		**[i]**	**[ɪ]**	**[e]**	**[ɛ]**	**[æ]**	**[ɑ]**	**[ɔ]**	**[o]**	**[ʊ]**	**[u]**	**[ʌ]**
Speaker 1M	**F1**	415	412	427	536	548	569	579	512	474	569	532
Speaker 2M	**F1**	412	482	467	588	653	719	666	565	556	608	611
Speaker 3M	**F1**	501	571	494	692	632	838	712	794	665	673	670
Speaker 4M	**F1**	677	533	501	666	554	717	711	570	535	589	732
Mean BPE	**F1**	**501**	**499**	**472**	**620**	**596**	**710**	**667**	**610**	**557**	**609**	**636**
Mean GAE	**F1**	**270**	**390**	**476**	**530**	**660**	**730**	**570**	**497**	**440**	**300**	**640**
Speaker 1M	**F2**	2038	1699	1982	1681	1659	1317	1366	1538	1578	1794	1592
Speaker 2M	**F2**	2126	1884	2063	1741	1684	1521	1486	1506	1777	1844	1695
Speaker 3M	**F2**	2224	2120	2241	1949	1959	1673	1939	1998	1807	1974	1568
Speaker 4M	**F2**	2136	1997	1991	1741	1661	1492	1597	1590	1478	1539	1761
Mean BPE	**F2**	**2131**	**1925**	**2069**	**1778**	**1740**	**1500**	**1597**	**1658**	**1660**	**1787**	**1654**
Mean GAE	**F2**	**2290**	**1990**	**2089**	**1840**	**1720**	**1090**	**840**	**910**	**1020**	**870**	**1190**

Table 4: F1 and F2 of Male Vowels

Words		**heed**	**hid**	**hayed**	**head**	**had**	**hod**	**hawed**	**hoed**	**hood**	**who'd**	**hud**
Female Vowels		**[i]**	**[ɪ]**	**[e]**	**[ɛ]**	**[æ]**	**[ɑ]**	**[ɔ]**	**[o]**	**[ʊ]**	**[u]**	**[ʌ]**
Speaker 1F	F1	622	603	563	797	817	986	992	712	503	502	796
Speaker 2F	F1	466	537	471	664	661	668	587	595	___[4]	565	527
Speaker 3F	F1	454	558	506	750	829	826	719	506	603	424	620
Mean BPE	**F1**	**514**	**566**	**513**	**737**	**769**	**826**	**766**	**604**	**553**	**497**	**647**
Mean GAE	**F1**	**310**	**430**	**536**	**610**	**860**	**850**	**590**	**555**	**470**	**370**	**760**
Speaker 1F	F2	2358	2379	2452	2068	2098	1671	1676	1417	1755	1703	1829
Speaker 2F	F2	2111	2168	2142	2070	2063	1463	1474	1525	___	1409	1428
Speaker 3F	F2	2048	2168	2447	1812	1935	1436	1199	1070	1643	1182	1833
Mean BPE	**F2**	**2172**	**2238**	**2347**	**1983**	**2032**	**1523**	**1449**	**1337**	**1699**	**1431**	**1696**
Mean GAE	**F2**	**2790**	**2480**	**2530**	**2330**	**2050**	**1220**	**920**	**1035**	**1160**	**950**	**1640**

Table 5: F1 and F2 of Female Vowels

In subsequent sections, the F1s and F2s of the vowels produced by the male and female BPE speakers are compared and contrasted with those produced by the male and female speakers of GAE. Most of the GAE measurements are from Peterson and Barney (1952), except for the vowels /e/ and /o/ that are taken from Hillenbrand et al.'s (1995) study of Midwest vowels.

5.1 Usefulness of Comparative Acoustic Vowel Spaces

Acoustic vowel spaces are constructed using information from F1 and F2. For the study of intelligibility, only F1 matters because it alone accounts for 80% of the acoustic energy found in vowels (Ladefoged and Johnson, 2015, p. 207). F1 provides information about mouth aperture and F2 about tongue advancement or retraction in the pronunciation of vowels. For F2, higher

[4] Speaker 2F inadvertently failed to pronounce <hood>. This was omission was caught only duration the analysis of the data. By then, it was too late to track her down.

values correlate with frontness, while lower values correspond to backness. It is important to keep in mind when interpreting F1 data that the lower values mean that the vowel in question is high, while higher values correspond to low vowels. For F2, higher values mean that the vowel is fronted, while lower values show that it is retracted. Measurements such as those in Tables 4 and 5 can be plotted in Norm[5] to create comparative acoustic vowels spaces such as shown in Figures 5 and 6. For teaching the pronunciation of vowels, Ladefoged and Johnson (2015, p. 234) recommend creating comparative acoustic vowel spaces such as the ones in Figures 5 and 6. They explain their usefulness as follows:

> Vowel charts provide an excellent way of comparing different dialects of a language. This kind of plot arranges vowels in a similar way to the vowels in the IPA vowel chart. The formant frequencies are spaced in accordance with the Bark scale, a measure of auditory similarity, so that the distance between any two sounds reflects how far apart they sound.

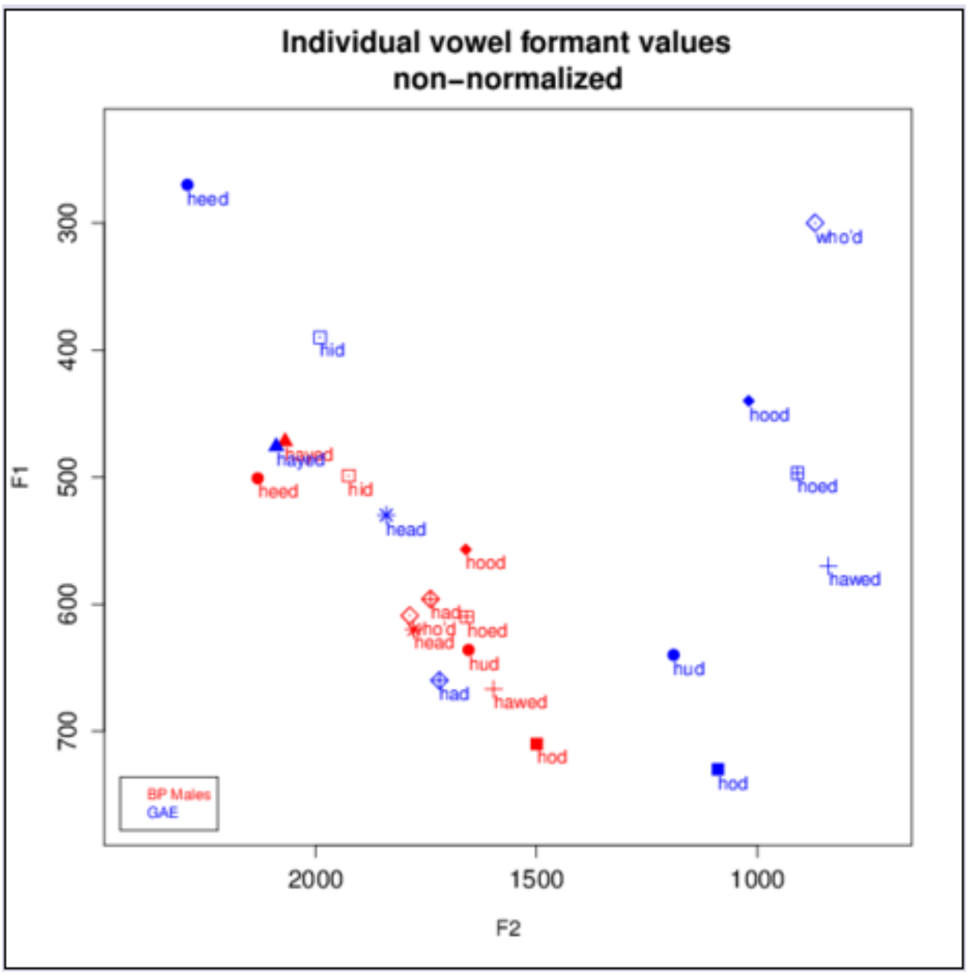

Figure 5: Comparative Acoustic Vowel Space-Male Vowels

At first glance, we can make two quick observations. First, the back vowels in BPE are centralized. Secondly, most of the vowels in BPE are lower than their counterparts in GAE. These

[5] Norm is an open source software available at http://lingtools.uoregon.edu/norm/norm1.php.

idiosyncratic characteristics of male BPE vowels will be commented on further in subsequent sections. Next, we turn to the vowels produced by the three female participants:

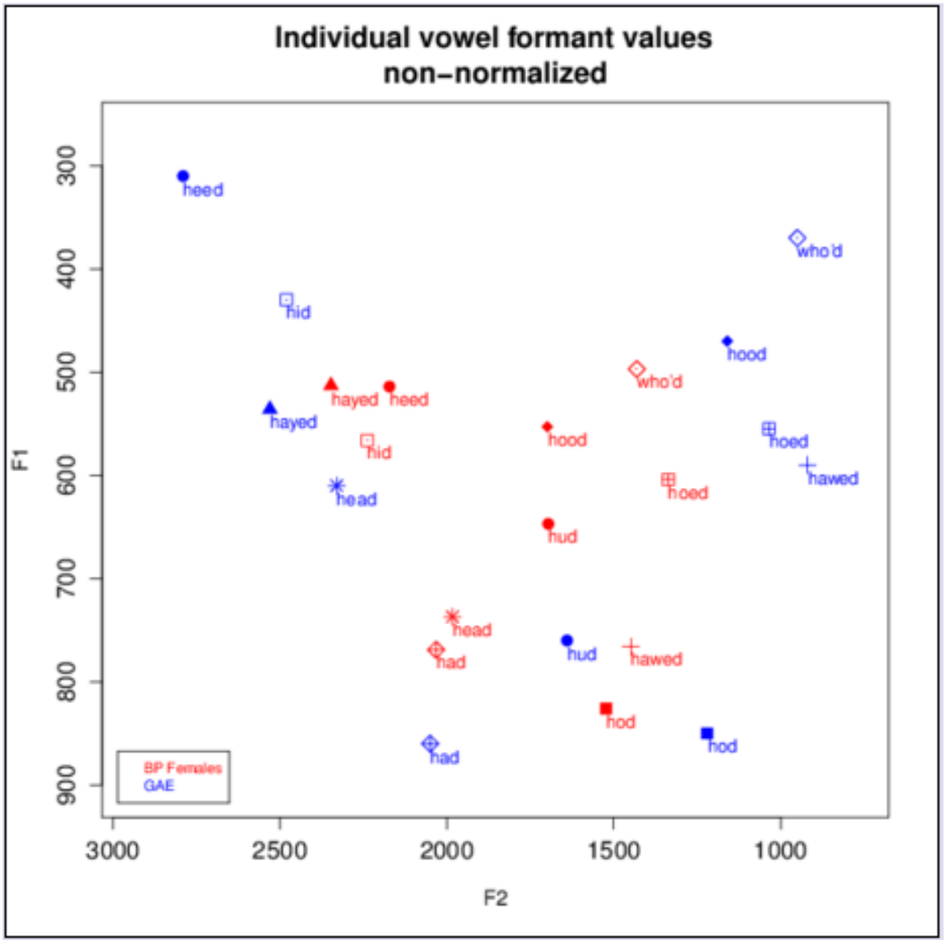

Figure 6: Comparative Acoustic Vowel Space-Female Vowels

The vowels produced by the BPE females are more dispersed than those produced by their male counterparts. The same two tendencies observed in male pronunciation also apply to female pronunciation, but to a lesser extent. Back vowels in female speech are less centralized. Yet, their high vowels are lowered just as they are in male speech.

5.2 Visualization of Vowels and the Principle of Sufficient Perceptual Separation

The comparative acoustic vowel spaces above help to inspect visually whether or not vowel pronunciation by the BPE speakers in our study concords with the principle of Sufficient Perceptual Separation (SPS) which Ladefoged and Johnson (2015, p. 238) explain as follows:

> One of the forces acting on languages may be called the principle of sufficient perceptual separation, whereby the sounds of a language are kept acoustically distinct to make it easier for the listener to distinguish one from another. … In this way, the vowels of a language are kept maximally distinct.

On page 295, they comment further on SPS, saying:

> A language must always maintain sufficient perceptual separation. Therefore, languages constrain speakers so that they keep words sufficiently distinct. The language makes sure that there is sufficient perceptual distance between sounds that occur in contrasting sets, such as the vowels in stressed monosyllables (as in beat, bit, bet, bat, etc. The principle of perceptual separation does not usually result in one sound affecting an adjacent sound.

SPS is designed to study how individual vowels of a given language relate to each other. It has not been used extensively to investigate how the vowels of L2 speakers relate with those of L1 speakers in the same vowel quadrant. Figures 5 and 6 show how the vowels of BPE speakers relate to those of GAE speakers. This visual display gives us a glimpse of issues related to intelligibility.

6.0 Masking, Relative Functional Load, and Intelligibility Rating

The measurements in Tables 4 and 5 and the plots in Figures 5 and 6 provide incredible insights about the intelligibility of BPE vowels. However, we must acquaint ourselves with two key concepts: masking and relative functional load (RFL) because they help us to relate acoustic measurements with segmental intelligibility. The concept of masking was introduced in psychoacoustics by Fletcher (1953, pp. 153-175). Though it is a very useful concept, it is only recently that it has been applied to pronunciation research to assess intelligibility (Koffi, 2016, p. 113). For vowels, masking occurs when the F1 distance between two adjacent vowels that are phonemically different is less than 60 Hz. This threshold is known as Just Noticeable Difference (JND). If the JND between two phonemically different vowels is > 60 Hz, intelligibility is optimal. Readers can find more information about this JND and others in (Koffi 2016). Suffice it to say that there are five masking levels, as shown in Table 6:

F1 Distance	Masking Levels	Hearing Acuity
> 60 Hz	No masking	Excellent
50 Hz – 60 Hz	Slight masking	Good
30 Hz – 49 Hz	Moderate masking	Average
21 Hz – 29 Hz	Severe masking	Degraded
0 Hz – 20 Hz	Complete masking	Poor

Table 6: Acoustic Distance and Intelligibility

If the acoustic distance between two segments is less than 20 Hz, masking is absolute. If it is less than 30 Hz, masking is severe. Generally, this is considered the "red zone" of masking. This gives some clues about the physical disturbances that may affect the acuity of perception. However, calculation of intelligibility is determined by the RFL of the pair of segments under consideration. Catford (1987, pp. 87-100) calculated the RFL of many English phonemes. When the RFL of vowels and consonants are tallied up, the mean RFL of vowels is 38%, while that of consonants is 46%. English has 11 vowel phonemes and 24 consonant phonemes. This translates into an RFL of 3.5% per vowel versus an RFL of 1.91% per consonant. In other words, the RFL of vowels is almost twice that of consonants. Everything being equal, mispronouncing vowels impairs intelligibility more negatively than mispronouncing consonants. This explains the rationale for the aforementioned admonition by Practor and Robinett about the importance of learning to produce vowels intelligibly. Table 7 correlates masking levels, RFLs, and intelligibility ratings:

F1 Distance	Masking Levels	RFL	Intelligibility Rating
> 60 Hz	No masking	1-19%	Good intelligibility
50 Hz – 60 Hz	Slight masking	20-39%	Moderate intelligibility
30 Hz – 49 Hz	Moderate masking	40–59%	Average intelligibility
21 Hz – 29 Hz	Severe masking	60–79%	Poor intelligibility
0 Hz – 20 Hz	Complete masking	80–100%	Unintelligibility

Table 7: Relative Functional Load

The combination of F1 distances, masking levels, and RFL calculation data help to access the intelligibility of BPE vowels. This is what we will do in the remainder of the paper.

6.1 Transfer Issues

Tables 8 and 9 provide information about F1 and F2 of GAE, BPE, and BP in male and female speech. Furthermore, Distance 1 and Distance 2 are computed to assess the degree of masking. **Distance 1** calculates the acoustic distance between **GAE and BP** vowels. **Distance 2** does the same for the distance between **GAE and BPE** vowels.

Male Vowels		**[i]**	**[ɪ]**	**[e]**	**[ɛ]**	**[æ]**	**[ɑ]**	**[ɔ]**	**[o]**	**[ʊ]**	**[u]**	**[ʌ]**
GAE	F1	270	390	476	530	660	730	570	497	440	300	640
BPE	F1	501	499	472	620	596	710	667	610	557	609	636
BP	F1	303	NA	421	566	NA	704	556	406	NA	347	NA
Distance 1	**F1**	**33**	**NA**	**55**	**36**	**NA**	**26**	**14**	**91**	**NA**	**47**	**NA**
Distance 2	**F1**	**231**	**109**	**4**	**90**	**64**	**20**	**97**	**113**	**117**	**309**	**4**
GAE	F2	2290	1990	2089	1840	1720	1090	840	910	1020	870	1190
BPE	F2	2131	1925	2069	1778	1740	1500	1597	1658	1660	1787	1654
BP	F2	2178	NA	2018	1711	NA	1349	962	818	NA	813	NA
Distance 1	**F2**	**112**	**NA**	**71**	**129**	**NA**	**259**	**122**	**92**	**NA**	**57**	**NA**
Distance 2	**F2**	**159**	**65**	**20**	**62**	**20**	**410**	**757**	**748**	**640**	**917**	**464**

Table 8: Vowel Transfer in Male Speech

Female Vowels		**[i]**	**[ɪ]**	**[e]**	**[ɛ]**	**[æ]**	**[ɑ]**	**[ɔ]**	**[o]**	**[ʊ]**	**[u]**	**[ʌ]**
GAE	F1	310	430	536	610	860	850	590	555	470	370	760
BPE	F1	514	566	513	737	769	826	766	604	553	497	647
BP	F1	361	NA	480	644	NA	867	651	469	NA	374	NA
Distance 1	**F1**	**51**	**NA**	**56**	**34**	**NA**	**17**	**61**	**86**	**NA**	**4**	**NA**
Distance 2	**F1**	**204**	**136**	**23**	**127**	**91**	**24**	**176**	**49**	**83**	**127**	**113**
GAE	F2	2790	2480	2530	2330	2050	1220	920	1035	1160	950	1640
BPE	F2	2172	2238	2347	1983	2032	1523	1449	1337	1699	1431	1696
BP	F2	2606	NA	2442	2257	NA	1590	1043	886	NA	842	NA
Distance 1	**F2**	**184**	**NA**	**88**	**73**	**NA**	**370**	**123**	**149**	**NA**	**108**	**NA**
Distance 2	**F2**	**618**	**242**	**183**	**347**	**18**	**303**	**529**	**302**	**539**	**481**	**54**

Table 9: Vowel Transfer in Female Speech

The rationale behind Distance 1 is to see if BPE speakers transfer /i, e, ɛ, a, ɔ, o, u/ from their native Portuguese into their L2 English. If they do, the F1 distance between the respective vowels would be 50 Hz or less because, according to Ladefoged (2003, p. 128) when a person produces the same vowel twice, the F1 difference between the repetitions should not be greater than 50 Hz.

A cursory look at the data shows that BPE speakers do not transfer the F1 characteristics of their native BP into English. If they did, Distance 2 (GAE – BPE) would be 50 Hz or less; this is not the case. On average, the participants lowered the F1 of their vowels by 105 Hz. In articulatory terms, this means that the participants dropped their lower jaw too much when producing English vowels. The F2 of the participants' vowels is also substantially different from those of GAE speakers. This is particularly true for male speakers. They strongly fronted their back vowels so much so that they almost overlap with some front vowels (see Figure 5). This tendency was more pronounced in the speech of 1M and 2M (see Appendix A). Length of residence in the USA does not seem to matter because even though 2M had been living in St. Cloud for almost thirty-six months, he produced his back vowels in the same way as 1M and 2M, who had been in the US for only seven months, pronounced theirs. The female speakers also fronted their back vowels /u, o, ɔ/, but not nearly as much as their male counterparts. All in all, the participants in the study did not transfer the acoustic characteristics of their native L1 vowels into their L2 English. This is a pity because doing so would have resulted into a positive transfer.

6.2 Substitution Issues

BP lacks the vowels /ɪ, ʊ, æ, ʌ/ that GAE has. How did the participants fare in producing these vowels? The vowel [ɪ] was often replaced by either [i] or by [e]. More often than not, it was produced as [i] by both males and female BPE speakers. On occasions, [ɪ] is produced as [e]. The vowel [ʊ] was produced remarkably well, even though it does not exist in BP. Its F1 is considerably higher in BPE than in GAE, but this is not a serious problem because the lowering of [ʊ] also happens in some American dialects, especially in Central Minnesota English (Koffi, 2016, pp. 4-5). The central vowel [ʌ] was produced intelligibly overall. Yet, when we dig deeper into the data and examine individual speaker's productions, some patterns emerge. Males 2 and 3 pronounced [ʌ] in ways that made it indistinguishable from [u]. The data also shows that [æ] was produced intelligibly by all seven participants. However, the pronunciation of /ɪ/ and /ʌ/ proved very challenging for the participants, not only because they do not exist in BP, but also because they caused considerable masking with other vowels.

7.0 Masking Issues

There are two sides to masking: internal masking versus external masking. Internal masking has to do with the acoustic distance between BPE vowels themselves. External masking focuses on the acoustic distance between BPE and GAE vowels. In correlating masking and intelligibility, we focus both on complete and severe masking levels. The former occurs when the acoustic distance between two segments is < 20 Hz; the latter when the distance is < 30 Hz. In the former, unintelligibility is absolute; in the latter, it is very high. It is worth emphasizing that in masking studies, the focus is on adjacent front vowels, adjacent back vowels, or adjacent low vowels. Front vowels are not normally contrasted with back vowels, nor are high vowels contrasted with low vowels. The pairs of adjacent vowels in GAE that are candidates for masking studies are [i] vs. [ɪ], [ɪ] vs. [e], [e] vs. [ɛ], [ɛ] vs. [æ] for front vowels; [u] vs. [ʊ], [ʊ] vs. [o], [o] vs. [ɔ], [ɔ] vs. [ɑ] for back vowels; and [ʌ] vs [æ], [ʌ] vs. [ɑ], and [ɔ] vs. [ɑ] for low vowels. More importantly, comparative acoustic vowel spaces such as those in Figures 5 and 6 help to "visualize" how vowels relate to each other in geometrical space.

7.1 Internal Masking between Front Vowels

The BPE speakers in the study did not differentiate intelligibly between the vocalic pairs [i] vs. [ɪ] and [ɪ] vs. [e]. The acoustic difference between BPE [i] (499 Hz) and [ɪ] (501 Hz) is only 2 Hz in male speech. This means that the male speakers do not discriminate in pronunciation between the vowel sounds in <beat> and <bit>. This masking has very serious consequences on intelligibility because the RFL of [i] vs. [ɪ] is 95% (Catford, 1987, pp. 87-100). Speaker 1F also does not discriminate between [i] (622 Hz) and [ɪ] (603 Hz) in pronunciation. The pronunciation problem with [ɪ] has a domino effect and compromises the intelligibility of [e] (472 Hz) in male speech. The acoustic distance between them is 27 Hz. With an RFL of 80%, confusing [ɪ] and [e] causes poor intelligibility. The ways in which male speakers produce [ɛ] (620 Hz) vs. [æ] (596 Hz) also creates some masking. The distance between these two vowels is 24 Hz. Substituting [ɛ] for [æ] and vice versa leads to average intelligibility because their RFL is at 53%. BPE speaker 2F does not differentiate between the vowel sounds in <bad> and <bed> because the F1 distance between her [ɛ] (664 Hz) and [æ] (661 Hz) is only 3 Hz.

7.2 External Masking between Front Vowels

Male speakers of BPE lower their [i] (501 Hz) so much so that it masks both [e] (476 Hz) and [ɛ] (530 Hz) in GAE. As a result, when they say <heat> it may sound like <hate> to GAE hearers; and when they say <hail> GAE hearers may perceive it as <hell>. The acoustic distances between [i] and [e] and [ɛ] in GAE are respectively 25 Hz and 29 Hz. The [i] (514 Hz) of BPE female speakers masks [e] (536 Hz) in GAE with an acoustic distance of 22 Hz. The RFL of [e] vs [ɛ] is 53%, which corresponds to average intelligibility. Catford (1987, pp. 87-100) does not have any RFL calculations for [i] vs [e] and [i] vs [ɛ]. Consequently, we cannot estimate the impact that this masking has on intelligibility.

7.3 Internal Masking between Back Vowels

We see in Figure 5 that male BPE speakers produced [u] (609 Hz) and [o] (610 Hz) in such a way that they mask each other. The acoustic distance between them is only 1 Hz. As a result, they do not differentiate between <boat> and <boot> in pronunciation. However, intelligibility is not seriously threatened because the RFL between [o] and [u] is 51%. Female talkers produced all their back vowels intelligibly. However, when we dig deeper into the data and examine individual speaker's productions, some patterns emerge. Because of the extreme lowering and centralization of [u], it masks [ʌ] in the pronunciation of Males 2 and 3. Male 2 pronounced [u] (608 Hz) and [ʌ] (611 Hz) with only 3 Hz difference between them. Male 3 also has only 3 Hz difference between [u] (673 Hz) and [ʌ] (670 Hz). Furthermore, Male 3's [ʊ] (665 Hz) masked both his [u] and his [ʌ]. The [o] (565 Hz) produced by Male 2 absolutely masks his [ʊ] (556 Hz). Finally, Female 1 produced [ʊ] (503 Hz) and [u] (502 Hz) identically with only 1 Hz difference between them. The RFL of [o] vs [ʊ] is 51%, that of [ʊ] vs. [ʌ] is 9%. Overall, intelligibility is not seriously compromised.

7.4 External Masking between Back Vowels

The only clear evidence of external masking between back vowels is the one between [ɔ] in BPE and [ʌ] in GAE. In male speech, the [ɔ] (667 Hz) masks [ʌ] (640 Hz) in GAE. The acoustic distance between them is 27 Hz. In female speech, [ɔ] (766 Hz) masks [ʌ] (760 Hz) in GAE. They almost mask each other in the former, and absolutely in the latter. When BPE speakers produce words <hut> and <hot>, GAE hearers may mistake one for the other. With an RFL of 65% between [ɔ] and [ʌ], intelligibility is poor.

7.4 Internal Masking between Low Vowels

Fromkin et al. (2014, p. 241), Ladefoged and Disner (2012, p. 133), and Ladefoged and Johnson (2015, p. 228) classify [æ], [ʌ], and [ɑ] as low vowels. We investigate the F1s of these vowels to see whether or not BPE speakers differentiate between them in pronunciation. In male speech, the distance between [æ] (596 Hz) and [ʌ] (636 Hz) is 40 Hz. That of [ʌ] (636 Hz) and [ɑ] (710 Hz) is 74 Hz. Also, the distance between [æ] (596 Hz) and [ɑ] (710 Hz) is 114 Hz. Only the pair [æ] and [ʌ] mask each other somewhat. With an RFL of 68%, the failure to clearly differentiate between these two vowels leads to poor intelligibility. Female speakers do not confuse their [æ] (769 Hz) and [ʌ] (647 Hz). There is no masking because the distance of 122 Hz between them is well beyond the masking threshold. Moreover, there is no masking between [ʌ] (647 Hz) and [ɑ] (826 Hz) because they are separated by 179 Hz. In female speech, only [æ] (769 Hz) and [ɑ] (826 Hz) mask each other. The masking is partial given that the acoustic distance between them is only 57 Hz. However, the RFL between them is 76%. This means that on the occasions when the speakers do not differentiate between [æ] and [ɑ], intelligibility will be poor.

7.5 External Masking between Low Vowels

When GAE hearers listen to male speakers of BPE, they are likely to mistake Brazilian-accented [æ] (596 Hz) for [ɔ] (570 Hz) in GAE. The acoustic distance between of 26 Hz corresponds to severe masking where confusion is more than likely to occur. Many GAE speakers and hearers have the propensity to confuse [ɔ] and [ɑ]. This means that Brazilian-accented [æ] can be misperceived as [ɑ]. Regardless of whether they confuse [æ] with [ɔ] or [æ] with [ɑ], the RFL is the same, that is, 76%. This confusion would lead to poor intelligibility. GAE hearers are most likely to confuse BPE-accented [æ] (769 Hz) with [ʌ] (760 Hz) in GAE because the two sounds mask each other completely. The distance between them is only 9 Hz. With an RFL of 68 %, confusing these two vowels causes intelligibility to be poor.

8.0 Pedagogical Implications

It stems from the preceding analyses that GAE vowels that are most problematic for the speakers in our study are the vowels [ɪ], [æ], [ʌ], and to a lesser extent [ʊ]. The vowel [ɪ] is by far more prone to unintelligibility than any other vowel because in BPE it overlaps in acoustic space with [i] and [e]. The participants in our study would benefit from instruction aimed at improving their pronunciation and aural discrimination of the triplet [ɪ, i, e]. Traditionally, [e] is classified as mid-vowel. However, in the BPE data, we see that [e] has risen above [ɪ]. The raising of [e] is not a problem in itself, since there is ample evidence of this in some dialects of American English (Ladefoged, 1999, p. 42; Koffi, 2016, pp. 4-5). The problem in this case is that vowel raising causes masking with [ɪ]. The vowel [ʌ] also needs attention because it masks [ɔ], [ʊ], and even [u], as in the speech of Males 2 and 3. Internal masking occurs with the vowels [i] vs. [ɪ], [ɪ] vs. [e] for front vowels; and [ʌ] vs. [ɔ] and [u] vs. [ʊ] for non-front vowels. External masking occurs with the vowels [e] vs. [ɛ], [æ] vs. [ʌ], [æ] vs. [ɔ/ɑ]. Intensive and sustained pronunciation and listening discrimination drills of the types suggested in Celce-Murcia (2010, pp. 135-155), Lado and Fries (1954, pp. 34-35), and Practor and Robinett (1985, p. 13) should be practiced over and over to help students learn to produce these vowels intelligibly.

English has become an important second language in Brazil. Therefore, Brazilian schools should shift the focus from writing and reading skills to listening and speaking skills. The curriculum should also focus on conversational practices and oral exams that force students to make extra effort to learn to pronounce English words intelligibly. As Larrotta et al. (2016, p. 168) point out, "Language is best learned through social interaction and when used for social communication, and the focus is on communication not on understanding how language works." To this end, we recommend that teachers make their students listen to songs and watch movies in English. This would expose them to native speakers' pronunciation and intonation, and provide examples of the rhythm of how sentences flow. According to Larrotta et al. (2016, p. 170) this shift seems to be taking place already:

> The instructors reported that students learn through mass media such as the Internet, TV, movies, music, radio, newspaper, and magazines. Some instructors said, 'the students use captions to learn while watching movies or TV programs.' 'My students learn through memorizing the lyrics of a song they really like and through listening to it many times.' 'Several students have told me they use the newspaper and magazines to practice reading and learning vocabulary words.' Most instructors reported their students learn through daily life needs, including practicing English in their jobs, going shopping, and reading signs.'

9.0 Summary

This study has allowed us to uncover several pronunciation patterns that can hinder the intelligibility of the BPE speakers in our study. The sample group is small, but the pronunciation issues uncovered appear to be widespread among Brazilian speakers of English. BP and GAE have the same vowels /i, e, ɛ, a, ɔ, o, u/ but BPE speakers did not transfer them positively. Teachers need to let their students know that they should produce these vowels exactly the same way as they produce them in Brazilian Portuguese. Therefore, teachers and students should focus their attention and devote instructional energy to /ɪ, æ, ʌ, ʊ/.

All in all, 72% of the vowels produced by the participants in our study mask each other in one way or another. Our data shows that being immersed in the language and living among native English speakers is not enough to produce /ɪ, æ, ʌ, ʊ/ intelligibly. One cannot learn to produce vowels intelligibly by osmosis. Otherwise, the participants would have succeeded since they had lived in the US on average for more than 19.71 months. There is a three-step process that BPE speakers (this process is applicable to other L2 learners of English as well) need to know in order to produce GAE vowels intelligibly. First, a full acoustic phonetic audit of the students' vowel production should be done (see the acoustic vowel spaces of the participants in Appendices A and B). Secondly, students should be given the chance to visualize their vowel audits and appreciate how their vowels stand in relation to GAE vowels. Third, they should be trained in the articulatory movements necessary to produce and differentiate the vowels that mask each other. The training should be based on oral and aural discrimination drills.

ABOUT THE AUTHORS

Ettien Koffi, Ph.D., is a professor of Linguistics at St. Cloud State University, Minnesota, USA, specializing in acoustic phonetics (Speech Intelligibility). His research interests center around sociophonetic variations in Central Minnesota English, acoustic phonetic accounts of intelligibility in L2 English, and acoustic phonetic and general description of Anyi, a West African Language spoken in Cote d'Ivoire. He is the author of four books and numerous papers covering topics as varied as syntax, translation, language planning and policy, orthography, and indigenous literacy training manuals. He can be reached at enkoffi@stcloudstate.edu.

Lillian Duarte Ribeiro, graduated from St. Cloud State University, St. Cloud, Minnesota, USA, with a BA in English (Linguistic emphasis), and a minor in Spanish. She works as a Portuguese-English and English-Portuguese translator/interpreter in Minnesota. Her future plans include going to graduate school for acoustic phonetics and/or phonology. She can be reached at lilliandribeiro@hotmail.com.

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Appendix A

Summary tables of the acoustic measurements of five correlates: F1, F2, F3, Duration, and Intensity.

Words		**heed**	**hid**	**hayed**	**head**	**had**	**hod**	**hawed**	**hoed**	**hood**	**who'd**	**hud**
Male Vowels		**[i]**	**[ɪ]**	**[e] ***	**[ɛ]**	**[æ]**	**[ɑ]**	**[ɔ]**	**[o] ***	**[ʊ]**	**[u]**	**[ʌ]**
Speaker 1M	F0	151	123	114	141	114	117	118	122	133	147	124
Speaker 2M	F0	104	120	100	97	107	95	93	102	149	110	101
Speaker 3M	F0	149	119	124	120	123	124	119	133	143	134	127
Speaker 4M	F0	129	138	122	109	108	116	110	113	118	120	120
Mean BPE	**F0**	**113**	**125**	**115**	**116**	**113**	**113**	**110**	**117**	**135**	**127**	**118**
Mean GAE	**F0**	**136**	**135**	**129**	**130**	**127**	**124**	**129**	**129**	**137**	**141**	**130**
Distance	F0	23	10	14	14	14	11	19	12	2	14	12
Speaker 1M	F1	415	412	427	536	548	569	579	512	474	569	532
Speaker 2M	F1	412	482	467	588	653	719	666	565	556	608	611
Speaker 3M	F1	501	571	494	692	632	838	712	794	665	673	670
Speaker 4M	F1	677	533	501	666	554	717	711	570	535	589	732
Mean BPE	**F1**	**501**	**499**	**472**	**620**	**596**	**710**	**667**	**610**	**557**	**609**	**636**
Mean GAE	**F1**	**270**	**390**	***476**	**530**	**660**	**730**	**570**	***497**	**440**	**300**	**640**
Distance	F1	231	109	4	90	64	20	97	113	117	309	4
Speaker 1M	F2	2038	1699	1982	1681	1659	1317	1366	1538	1578	1794	1592
Speaker 2M	F2	2126	1884	2063	1741	1684	1521	1486	1506	1777	1844	1695
Speaker 3M	F2	2224	2120	2241	1949	1959	1673	1939	1998	1807	1974	1568
Speaker 4M	F2	2136	1997	1991	1741	1661	1492	1597	1590	1478	1539	1761
Mean BPE	**F2**	**2131**	**1925**	**2069**	**1778**	**1740**	**1500**	**1597**	**1658**	**1660**	**1787**	**1654**
Mean GAE	**F2**	**2290**	**1990**	***2089**	**1840**	**1720**	**1090**	**840**	***910**	**1020**	**870**	**1190**
Distance	F2	159	65	20	62	20	410	757	748	640	917	464
Speaker 1M	F3	2798	2584	2643	2599	2580	2543	2604	2826	2623	2908	2639
Speaker 2M	F3	2873	2609	2670	2424	2364	2567	2499	2489	2401	2556	2491
Speaker 3M	F3	3145	2979	2944	2671	2698	2819	2952	3107	2989	3065	2700
Speaker 4M	F3	3043	2936	2866	2790	2720	2721	2814	2754	2778	2820	2810
Mean BPE	**F3**	**2964**	**2777**	**2780**	**2621**	**2590**	**2662**	**2717**	**2794**	**2697**	**2837**	**2660**
Mean GAE	**F3**	**3010**	**2550**	***2691**	**2480**	**2410**	**2440**	**2410**	***2459**	**2240**	**2240**	**2390**
Distance	F3	46	227	89	141	180	222	307	335	457	597	270
Speaker 1M	DUR	402	330	443	461	329	362	447	405	401	433	401
Speaker 2M	DUR	483	335	439	444	458	522	503	492	391	406	407
Speaker 3M	DUR	518	448	560	509	446	564	572	461	385	437	427
Speaker 4M	DUR	464	336	365	305	301	358	368	348	324	383	360
Mean BPE	DUR	**466**	**362**	**451**	**429**	**383**	**451**	**472**	**426**	**375**	**414**	**398**
Mean GAE	DUR	**243**	**192**	**267**	**189**	**278**	**267**	**283**	**265**	**192**	**237**	**188**
Distance	DUR	223	170	184	240	105	184	189	161	183	177	210
Speaker 1M	INTS	68	66	67	68	67	66	66	67	68	69	65
Speaker 2M	INTS	71	74	73	72	71	73	72	75	74	71	72
Speaker 3M	INTS	70	70	71	70	70	72	70	71	73	72	69
Speaker 4M	INTS	67	66	70	68	69	68	69	68	69	70	69
Mean BPE	INTS	69	69	70	69	69	69	69	70	71	70	68

Table 10: Acoustic Correlates of Male Vowels

Words		**heed**	**hid**	**hayed**	**head**	**had**	**hod**	**hawed**	**hoed**	**hood**	**who'd**	**hud**
Female Vowels		**[i]**	**[ɪ]**	**[e]**	**[ɛ]**	**[æ]**	**[ɑ]**	**[ɔ]**	**[o]**	**[ʊ]**	**[u]**	**[ʌ]**
Speaker 1F	F0	129	116	136	148	161	169	193	196	200	209	195
Speaker 2F	F0	230	213	218	145	207	187	210	196	-**	228	231
Speaker 3F	F0	206	195	189	174	177	186	175	184	204	196	200
Mean BPE	**F0**	**188**	**174**	**181**	**155**	**181**	**180**	**192**	**192**	**202**	**211**	**208**
Mean GAE	**F0**	**235**	**232**	***219**	**223**	**210**	**212**	**216**	***217**	**232**	**231**	**221**
Distance	F0	47	58	38	68	29	32	24	25	30	20	13
Speaker 1F	F1	622	603	563	797	817	986	992	712	503	502	796
Speaker 2F	F1	466	537	471	664	661	668	587	595	-	565	527
Speaker 3F	F1	454	558	506	750	829	826	719	506	603	424	620
Mean BPE	**F1**	**514**	**566**	**513**	**737**	**769**	**826**	**766**	**604**	**553**	**497**	**647**
Mean GAE	**F1**	**310**	**430**	***536**	**610**	**860**	**850**	**590**	***555**	**470**	**370**	**760**
Distance	F1	204	136	23	127	91	24	176	49	83	127	113
Speaker 1F	F2	2358	2379	2452	2068	2098	1671	1676	1417	1755	1703	1829
Speaker 2F	F2	2111	2168	2142	2070	2063	1463	1474	1525	-	1409	1428
Speaker 3F	F2	2048	2168	2447	1812	1935	1436	1199	1070	1643	1182	1833
Mean BPE	**F2**	**2172**	**2238**	**2347**	**1983**	**2032**	**1523**	**1449**	**1337**	**1699**	**1431**	**1696**
Mean GAE	**F2**	**2790**	**2480**	***2530**	**2330**	**2050**	**1220**	**920**	***1035**	**1160**	**950**	**1640**
Distance	F2	618	242	183	347	18	303	529	302	539	481	56
Speaker 1F	F3	3099	3049	2992	2753	2699	2853	3019	3066	3047	2955	3085
Speaker 2F	F3	3078	2191	3053	2931	2949	2886	2792	2931	-	2857	2783
Speaker 3F	F3	3047	2547	3060	2470	2542	2758	2666	2742	2723	2603	2709
Mean BPE	**F3**	**3074**	**2595**	**3035**	**2718**	**2730**	**2832**	**2825**	**2913**	**2885**	**2805**	**2859**
Mean GAE	**F3**	**3310**	**3070**	***3047**	**2990**	**2850**	**2810**	**2710**	***2828**	**2680**	**2670**	**2780**
Distance	F3	236	475	12	272	120	22	115	85	205	135	79
Speaker 1F	DUR	526	472	413	365	358	401	386	348	339	335	290
Speaker 2F	DUR	461	417	540	460	372	412	434	452	-	395	348
Speaker 3F	DUR	177	143	220	149	178	139	203	206	141	204	135
Mean BPE	DUR	**388**	**344**	**391**	**324**	**302**	**317**	**341**	**335**	**240**	**311**	**257**
Mean GAE	DUR	**306**	**237**	**320**	**254**	**332**	**323**	**353**	**326**	**249**	**303**	**226**
Distance	DUR	82	107	71	70	30	6	12	9	9	8	31
Speaker 1F	INTS	66	66	66	67	67	70	64	64	65	64	65
Speaker 2F	INTS	62	61	62	61	63	63	61	60	-	60	61
Speaker 3F	INTS	69	72	69	70	71	73	72	72	72	69	72
Mean BPE	INTS	**65**	**66**	**65**	**66**	**67**	**68**	**65**	**65**	**68**	**64**	**66**

Table 11: Acoustic Correlates of Female Vowels

Appendix B

Below are the vowel audits and acoustic vowel spaces of all the participants.

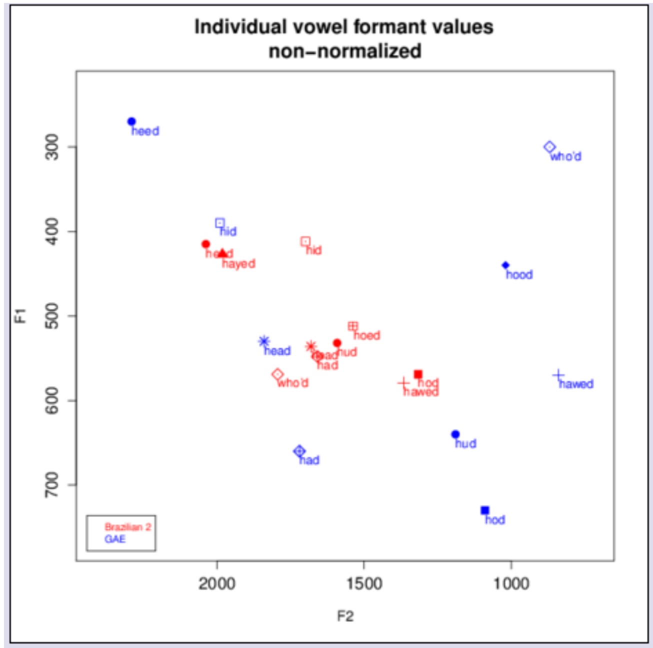

Figure 7: Vowel Audit of Male

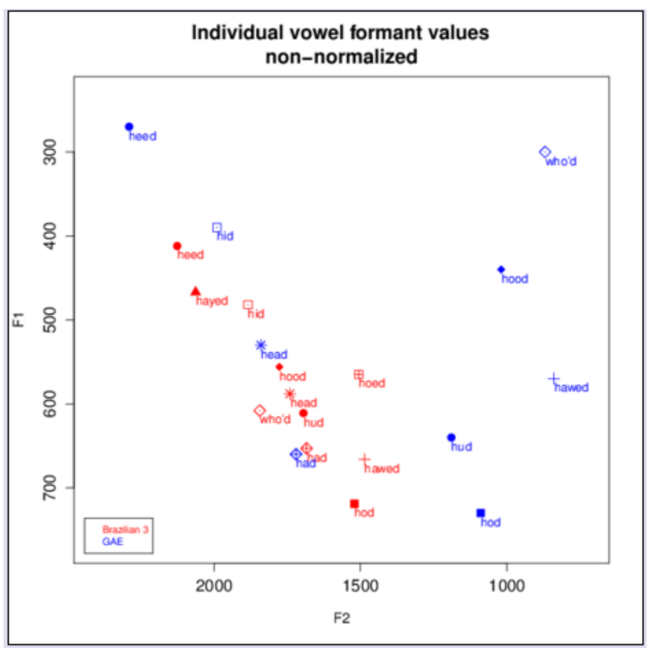

Figure 8: Vowel Audit of Male 2

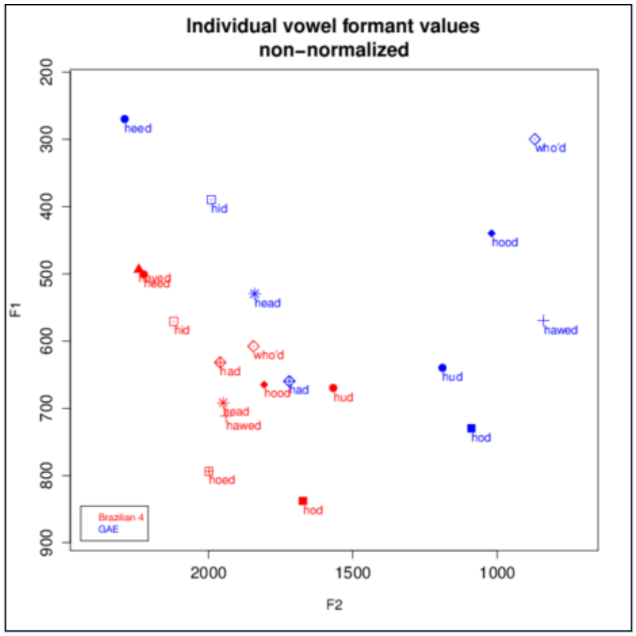

Figure 9: Vowel Audit of Male 3

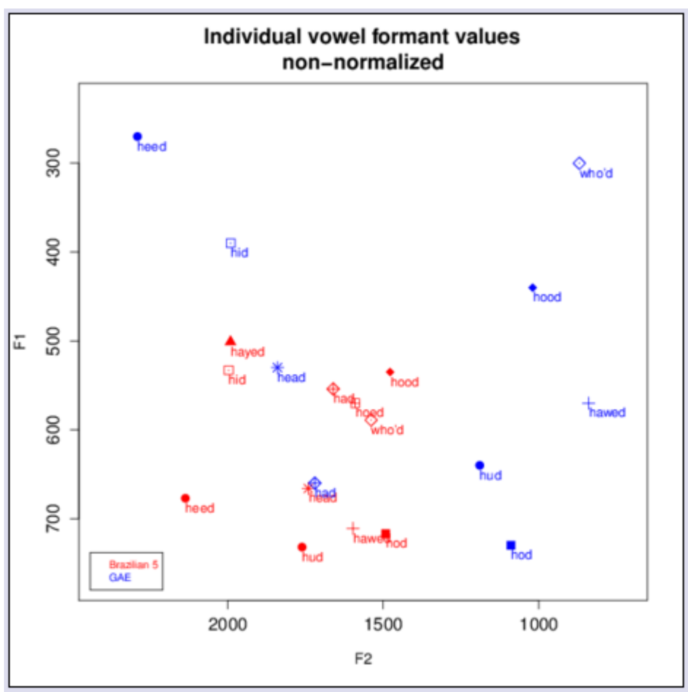

Figure 10: Vowel Audit of Male 4

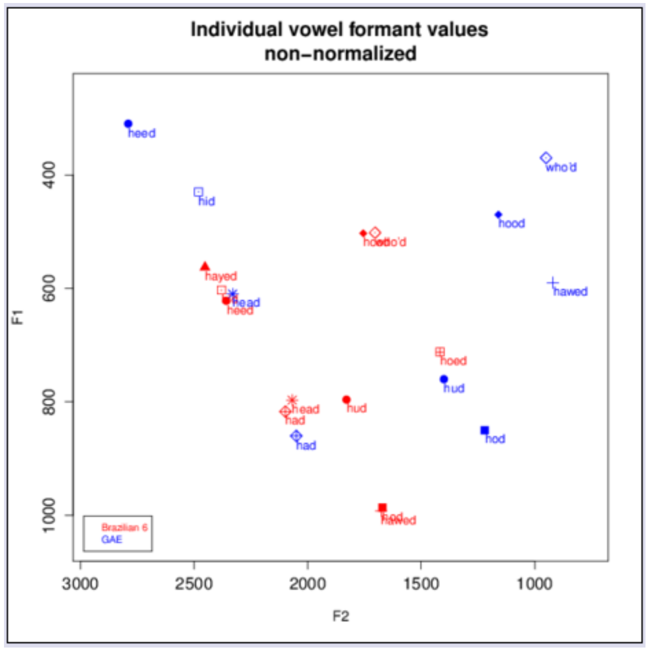

Figure 11: Vowel Audit of Female 1

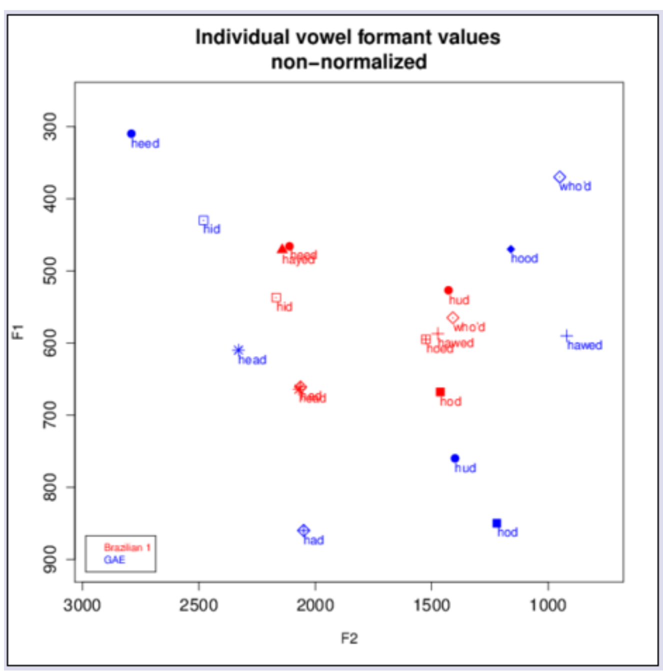

Figure 12: Vowel Audit of Female 2

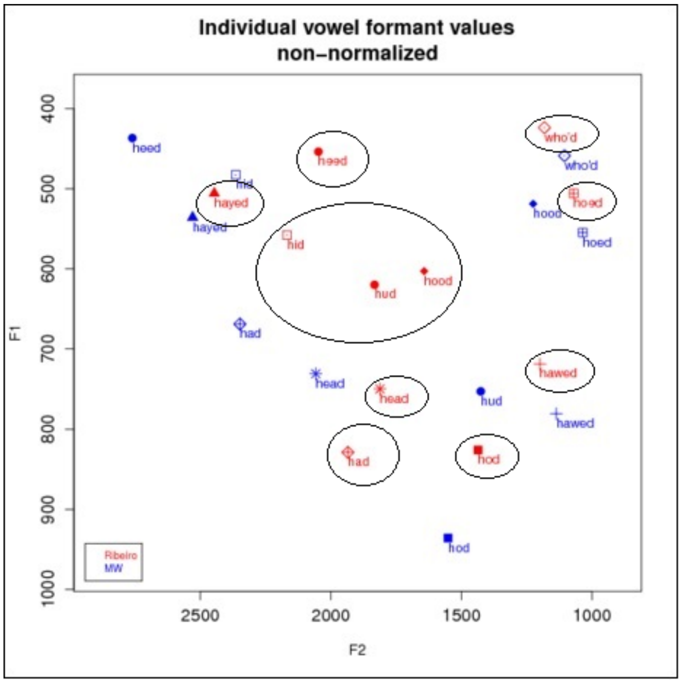

Figure 13: Vowel Audit of Female 3