FOREIGN LANGUAGE ACCENT PERCEPTION OF BRAZILIAN PORTUGUESE AND SECOND LANGUAGE ACQUISITION OF ORAL AND NASAL VOWELS

by

SUZANNE CARLA FRANKS

(Under the Direction of Don R. McCreary)

ABSTRACT

Although contextual nasalization is a common phenomenon in the world's languages, contrastive nasal vowels are less common. The pronunciation of contrastive nasal vowels in Portuguese is a challenge for adult language learners. This study examines Brazilian Portuguese (BP) oral and nasal vowels through acoustic analysis of native speakers (NSs) and nonnative speakers (NNSs) and accent perception by BP NSs. In a production experiment, 11 NSs, 13 inexperienced NNSs, and nine experienced NNSs of BP were recorded in an elicited imitation task with tokens containing [a i u ɐ̃ ĩ ũ] in syllables bearing primary stress. These disyllabic tokens, recorded in carrier phrases, contain target vowels in syllables bearing stress in ultimate or penultimate position. Segment duration, intensity, F_1, F_2, and F_3 of each target vowel were measured using Praat. Statistical analyses determined which acoustic characteristics were most significantly different among the three groups of participants. These most significantly different acoustic cues were vowel height of [a] and [ɐ̃], vowel advancement of [u], and duration of word-final [i] and [u]. In an accent perception experiment, 20 BP NSs assigned accent ratings to the previously recorded tokens in carrier phrases. Statistical analyses of the accent ratings showed that level of experience with BP as a foreign language correlated with higher accent ratings (i.e., more nativelike). In a comparison of accent ratings and acoustic characteristics of vowel segments, shorter segments correlated with higher accent ratings for four of the six vowels. Furthermore, acoustic cues suggesting a lower articulation for [a], a higher articulation for [ɐ̃], and a more anterior (less fronted) articulation for [u] correlated with higher accent ratings. The comparisons among the two levels of NNS groups and the NS group suggest that more time spent learning BP tends to improve vowel segment pronunciation and accentedness. These findings add to existing research on second language acquisition and BP phonetics and phonology. Also, some practical pedagogical implications for the teaching of pronunciation of Portuguese as a foreign language emerge from the results.

INDEX WORDS: Brazilian Portuguese, second language acquisition, acoustic phonetics, phonology, nasal vowels, nonnative speech

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CHAPTER 1

INTRODUCTION

Portuguese is a Romance language that descended from Vulgar Latin, which was taken to the Iberian Peninsula by its Roman conquerors. Through Portuguese exploration and colonization the language spread all over the world. Today Portuguese is the official language of seven countries: Brazil, Portugal, Angola, Mozambique, Cape Verde, Guinea-Bissau, and São Tomé and Principe. Portuguese is also a co-official language in East Timor and Macau, China. A law is pending in Equatorial Guinea to make Portuguese its third official language. While precise numbers on how many people speak Portuguese as a native or foreign language worldwide are hard to determine, a reasonable estimate can be inferred from the total population of the countries that have Portuguese as an official language, calculated at over 244 million inhabitants (CPLP, 2012). Although the vast majority of Portuguese speakers live in the Southern Hemisphere, the language's status as one of the 24 official languages of the European Union suggests its undeniable value and importance for Europe as well.

Perhaps because of its similarity to Spanish, Portuguese at times has been overlooked and understudied in the linguistics community. But in 2012, Brazil's economy surpassed the economy of the United Kington to become the sixth largest economy in the world based on gross domestic product (Darlington, 2012). With the increased interest in Brazil as a destination for economic activity and tourism, Portuguese has become a more desirable foreign language to study, especially at the university level. Now firmly established as a world language, Portuguese has two major varieties, European Portuguese and Brazilian Portuguese (BP), and several additional African and Asian varieties. BP is the most widely spoken variety of Portuguese because of Brazil's population, which is over 191 million (CPLP, 2012).

Motivation for this Research

Linguists have long recognized BP's distinctive phonology (Delgado Martins, 2002; Escudero, Boersma, Rauber, & Bion, 2009; Mateus & d'Andrade, 2000) and lexicon (Alves, 2004; Silva, 2006), and to a lesser degree, its syntactic differences from other varieties of Portuguese (Farias, 2006; Galves, Torres Moraes, & Ribeiro, 2004; Lima, 2006; Oliveira, Cunha, & Goncalves, 2004). Although BP phonology and phonetics have been studied, mostly by researchers within Brazil's academic community, and some of the knowledge gaps have begun to be filled, the acquisition of BP pronunciation as a second language (L2) has largely been ignored.

Moreover, this dissertation is motivated by an interest in BP's relatively complex vowel system and how learners of BP handle the challenges related to perceiving and producing sounds that are not part of a speaker's first language (L1). Understanding of the structure and sound system of BP is still fragmented, and the few experimental studies on vowels that are available have relatively small numbers of participants and small data sets.

Cross-linguistically, nasalization is also an understudied area. Evidence of this deficiency was confirmed by Beddor (1993) in her comment, "much of the phonological research on quality differences between oral and nasal vowels has focused on vowel height" (p. 186). This dissertation examines vowel quality and durational characteristics of vowel segments. Concerning duration, which falls within the area of speech prosody, second language (L2) acquisition of speech prosody is an underresearched area (Li & Post, 2014). Even greater is the lack of research on speech prosody of nonnative speakers (NNSs) of BP.

Purpose of this Research

The research here seeks to inform linguists and instructors of Portuguese as a second or foreign language about some aspects of BP phonology that affect learner production and how their production is perceived by native BP speakers. More specifically, this study aims to discover which aspects of vowel acquisition lag behind others, and thus require special attention. We hope that the results of this dissertation will inform the language-teaching community by explaining how certain aspects of BP L2 pronunciation deviate from NS production and thus how L2 speakers may benefit from explicit instruction. Though this researcher does not believe that foreign accent eradication should be the goal of most language learners, a more detailed knowledge of speech production and accent perception will benefit both the educator and the language learner.

Through an investigation of the acquisition of BP oral and nasal vowels by students of Portuguese as a foreign language at an American university and the production of these vowels by Brazilian NSs, this study seeks to identify what difficulties L2 BP speakers encounter while learning how to pronounce these vowels. When learning a new language as an adult, first language (L1) transfer may bring a negative or positive contribution to L2 production. Another goal of the research conducted in this dissertation is to discover how well L2 speakers are able to produce BP sounds and in which cases negative L1 transfer are evident. In order to focus on some important BP oral and nasal vowel contrasts, we seek to identify which of the vowels are acoustically closer to or farther away from NS production. An additional and extremely important objective of this study is to find correlations between acoustic characteristics of speech production and BP NS perception through accent ratings.

By adding to the existing body of knowledge about BP phonology, it is my hope that the results from this research, presented in an accessible manner, will prove to be a suitable resource for creating instructional materials on BP pronunciation designed to aid Portuguese teachers in the future. BP nasal vowels are contrastive as seen in (1).

1. a. pau [pau̯] ‘a stick or piece of wood’

   b. pão [pɐ̃u̯] ‘bread’

Since this study investigates the acquisition of BP nasal vowels by students in a foreign-language context, this dissertation adds to the current body of literature on second language acquisition in general, and more specifically in relation to the acquisition of contrastive nasal vowels, which are relatively rare in the world’s languages. Nasal vowels are more marked than oral vowels since all languages that have nasal vowels also have oral vowels, but all languages that have oral vowels do not have nasal vowels. Contrastive nasal vowels are present in approximately 25% of the world's languages (Hajek, 2011), and among Indo-European languages, only Portuguese, French and Polish have contrastive or phonemic nasal vowels (Moraes, 2013:97).

Research Questions

The research questions in this dissertation spring from an interest in learning more about BP oral and nasal vowels and how they are acquired. In general, the research questions in this dissertation ask about the characteristics of BP oral and nasal vowels, how NNSs carry out their production, and how NSs perceive accentedness when hearing words containing these vowels. These questions can be broken down into several subparts.

First of all, BP nasal vowels tend to be longer than oral vowels due to a weakening or loss of the nasal coda and the nucleation of the nasal feature (Bailey, 2012; Medeiros, 2012; Seara, 2000; Sousa, 1994). Will the proposed durational differences be confirmed in the production data? How does the position of a vowel within a word affect durational values? How does vowel height interact with vowel segment duration? How similar or different are NNS production patterns to NS patterns with regard to duration?

Secondly, which acoustic features are similar or different for NSs, inexperienced NNSs, and experienced NNSs? Which differences are significant? Although the phonemic status of nasal vowels in BP is disputed, phoneticians agree that BP nasal vowels are characterized by increasing vowel nasalization throughout their trajectory and no discernable nasal coda, or in many instances a short nasal murmur is present at the end of the nasal vowel (Fails, 2011; Seara, 2000; Sousa, 1994). Based on available descriptions of BP nasal vowels, some questions regarding the trajectory of nasal vowels should be asked. Do nasal codas produced by NSs differ from those uttered by NNSs? Do NSs produce shorter nasal codas with more gradual spectral movement associated with glides rather than more abrupt movement associated with nasal consonants (Medeiros, 2012; Stevens, 2000)?

Finally, in an analysis of accent perception and its correlation to production, several questions are addressed. How well do NS raters agree with one another? This question concerns the validity and reliability of the accent perception/rating task. Do language learners begin to sound more nativelike as more time is spent in foreign language study? To answer this question, I ask if accent ratings correlate to level of experience with BP. How do accent ratings relate to token characteristics, such as whether they have oral or nasal vowels? Finally, what are the correlations between accent ratings and the acoustic characteristics of vowels, and how do these differences relate to what we know about the learners' L1?

Significance of this Research

This research is important to SLA because it explores the acquisition of vowel contrasts that are not present in English or many other languages. Although the acquisition of BP nasal vowels is considered to be difficult for NNSs (Eckman, 1977), little is known about the acoustic cues used to perceive and produce these sounds or about their acquisition rate compared to other sounds in BP. The acoustic characteristics of BP oral vowels have received much more attention than those of nasal vowels (for example, Gama-Rossi, 2001; Nobre & Ingemann, 1987; Rauber, 2008; Redenbarger, 1981). On the other hand, only a handful of studies focusing on acoustic measures of nasal vowels have been performed, and the comparison at times has been limited to [a] versus [ɐ̃] (for example, see Kelm, 1989; Seara, 2000; Sousa, 1994). The results from the production experiment in this dissertation contrast three BP oral and nasal vowels, [a i u] versus [ɐ̃ ĩ ũ], and supply an acoustic analysis of these segments. Additional aspects of this study not included in the previous experimental studies on BP nasal vowels are (1) the analyses of production of nonnative BP speakers with English as a primary L1 in the setting of university-level foreign language instruction; (2) a greater number of participants: 11 NSs and 22 NNSs; (3) the division of NNS participants possessing two distinct levels of proficiency, inexperienced and experienced.

Outline of this Dissertation

Chapter 2 begins with a summary of the BP vowel system, followed by a discussion of the phonemic status of BP vowel nasalization. I report on three pertinent acoustic studies of BP oral and nasal vowels. Next, theories of second acquisition of speech are discussed, beginning with the markedness differential hypothesis (Eckman, 1977; 1987) and its later form referred to as the interlanguage structural conformity hypothesis (Eckman, Moravcsik, & Wirth, 1989), the Perceptual Assimilation Model (Best, 1995) and the speech learning model (Flege, 1995). Subsequently, I report on two cross-linguistic studies that compare the production of Portuguese and Spanish vowels while focusing on each language’s treatment of vowel nasalization. Finally, I review a study that examines the perception of nasal consonants and vowels by English and Hindi speakers.

Chapter 3 presents the research design and hypotheses. I explain the research questions that I seek to answer through the experimental studies and ensuing analyses. Then, I discuss the methods and materials used in the production and accent rating experiments conducted for this dissertation. This chapter also gives details on the participants, experimental conditions, and the technology used for data collection and analysis.

Chapter 4 reports on the experimental results, describes and compares NS, experienced NNS and inexperienced NNS vowels visually using two dimensional F_1 by F_2 vowel plots. Next, detailed statistical analyses of acoustic and accent perception are presented and explained.

Chapter 5 offers a discussion of experimental results and conclusions. First, I consider the experimental results on vowel segment duration. Second, vowel quality, nasalization, and L1 transfer are discussed. Third, correlations between acoustic analysis results and accent ratings are considered. Afterward, the theoretical implications of the results are discussed in light of theories of second language acquisition of speech. This chapter also discusses the pedagogical implications that emerge from the experimental results in this dissertation. Some practical suggestions are made in relation to how Portuguese teachers could address students’ needs in regard to BP oral–nasal vowel contrasts and durational characteristics of BP vowels. At last, limitations and future SLA research on BP phonology are considered.

CHAPTER 2

REVIEW OF LITERATURE

Roughly 80% of the world's Portuguese-speaking population speaks Brazilian Portuguese. Literature has been published about both European Portuguese and BP phonology and phonetics, recognizing the similarities and differences between the two varieties (Delgado Martins, 2002; Escudero, Boersma, Rauber, & Bion, 2009; Mateus & d'Andrade, 2000). Special attention should be given to phonological features in BP that differ from European Portuguese, one of these features being the degree of vowel nasalization that occurs in BP contrastive nasal vowels. Although a number of descriptions of BP phonology are available (Callou, Morais, & Leite, 2013; Gama-Rossi, 2001; Morais, Callou, & Leite, 1996; Nobre & Ingemann, 1987; Rauber, 2008; Redenbarger, 1981; Seara, 2000; Sousa, 1994), some gaps still exist in detailed acoustic phonetic descriptions of the sounds of BP. The current project seeks to fill some of these voids by supplying acoustic descriptions of oral and nasal vowel segments as produced both by NSs of BP and students learning Portuguese as a foreign language in an American university setting.

The Vowel System of Brazilian Portuguese

The BP inventory of vowel phonemes is relatively large, consisting of seven oral monophthongs /i e ɛ a ɔ o u/ and five nasal monophthongs [ĩ ẽ ɐ̃ õ ũ]. Square brackets are used around the nasal vowels because I maintain an agnostic view regarding the phonemic status of these five nasal monophthongs. (In a later section of this chapter, I discuss some different views of BP nasal vowels.) In addition to the monophthongs, syllable rimes may have as many as 13 oral diphthongs, four oral triphthongs, five nasal diphthongs, and two nasal triphthongs (Cristófaro-Silva, 1998; Whitlam, 2011).

All seven oral vowel phonemes occur in syllables bearing stress, also referred to as tonic syllables. Primary stress falls most frequently on the penultimate syllable (in about 62% of words), but the ultimate (25%) and antepenultimate (12%) syllable may also receive primary stress (Viaro & Guimarães-Filho, 2007). Figure 2.1 shows the monophthongs that occur in tonic syllables. Unstressed syllables are categorized as either pre-tonic, medial post-tonic or word-final post-tonic. In pre-tonic syllables, /a/ may be pronounced as [ə] or [ɐ], /e/ may be [e], [i] or [ɛ], and /o/ may be [o], [u] or [ɔ] depending on the dialect of the speaker. Figure 2.2 illustrates the inventory of vowel segments in pre-tonic syllables. The vowels in parentheses represent variations, due to regional dialect or register. For most speakers of BP five vowels [i e a o u] occur in medial post-tonic syllables, with /e/ sometimes reducing to [i] and /o/ sometimes reducing to [u] depending on dialect and register. Some dialects, particularly in Northeastern and Northern regions of Brazil, have all seven monophthongs in medial post-tonic syllables. Figure 2.3 illustrates the medial post-tonic vowel inventory, with variations due to dialect or register placed in parentheses. In word-final post-tonic syllables, the inventory of vowel sounds for most BP speakers consists of three vowels: (1) the high front vowel, realized as [ɪ] for /i/, /e/, and /ɛ/; (2) the high back vowel, realized as [ʊ] for /u/, /o/, and /ɔ/; and (3) the low central vowel, realized as [ɐ] for /a/. Figure 2.4 shows the word-final post-tonic vowel inventory, with vowels in parentheses representing possible variations depending on dialect or register. Figure 2.5 plots average F_1 and F_2 values to illustrate the acoustic similarities and differences of BP and European Portuguese oral vowels.

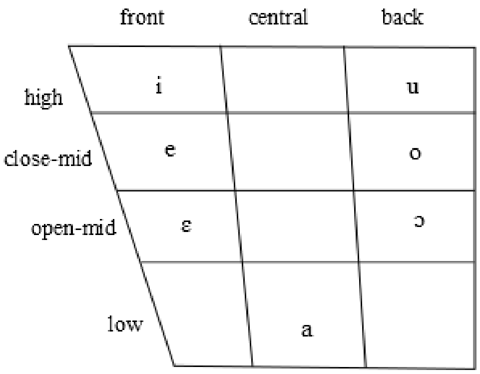

Figure 2.1 BP oral vowels (tonic syllables).

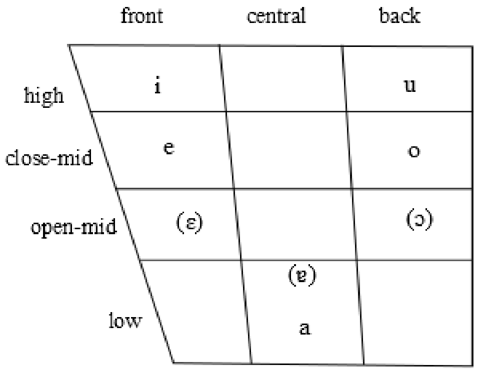

Figure 2.2 BP oral vowels (pre-tonic syllables).

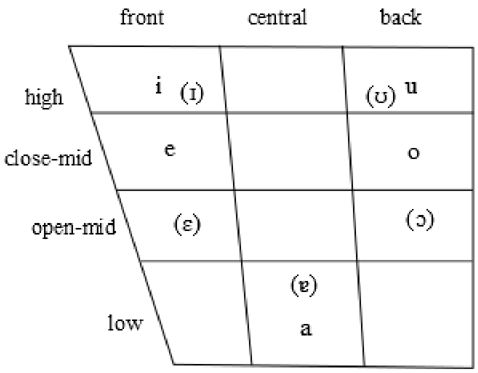

Figure 2.3 BP oral vowels (medial post-tonic syllables).

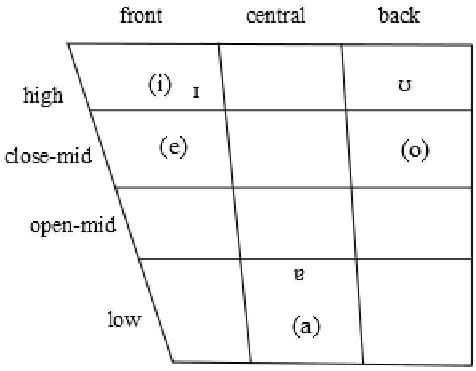

Figure 2.4 BP oral vowels (word-final post-tonic syllables).

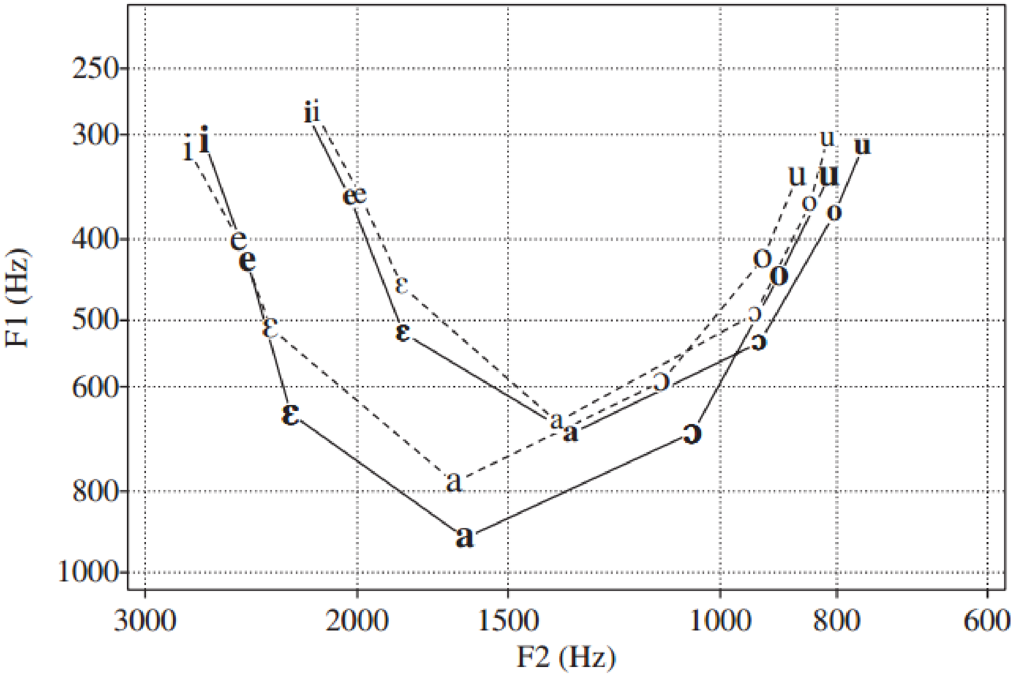

Figure 2.5 The vowel space of 4 groups (10 females and 10 males from São Paulo, 10 females and 10 males from Lisbon). Solid lines and bold symbols=BP; dashed lines= European Portuguese. Large font: women; small font: men. (Escudero, Boersma, Rauber, & Bion, 2009:1385).

All five nasal vowels [ĩ ẽ ɐ̃ õ ũ] occur in tonic, pre-tonic, and post-tonic syllables. Figure 2.6 presents the vowel inventory for nasal vowels. These nasal vowels are represented orthographically by a tilde <~> above the vowel in the syllable nucleus or by a tautosyllabic nasal consonant <m> or <n>. According to Cristófaro Silva (1998), the realization of nasal vowels occurs in all dialects of BP. The terms *nasal vowel* and *nasalized vowel* are sometimes used interchangeably sometimes the choice of terminology depends on the researcher's view on the status of BP nasal vowels. In the next section, I discuss the different kinds of nasalization in BP.

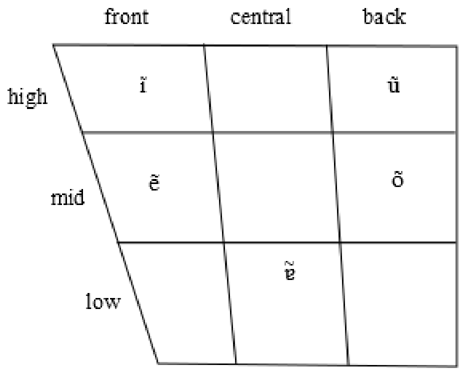

Figure 2.6 BP nasal vowels**.**

Strong vowel nasalization, defined as a relatively large velo-pharyngeal port opening) is a salient phonological characteristic of BP (Kelm, 1989). Varying degrees of nasalization based on phonological context have been recognized in BP. BP has both allophonic and coarticulatory nasalization. Allophonic nasalization appears in a vowel belonging to a syllable bearing primary stress that is followed by a syllable with a nasal consonant onset (*cama* 'bed' [ˈkɐ̃.mɐ]) or in a vowel flanked by nasal consonants on both sides (*humano* 'human' [u.ˈmɐ̃.nʊ]). Coarticulatory nasalization, which varies among BP individual speakers and dialects, takes place in pre-tonic syllables followed by a tonic syllable containing a nasal consonant onset (*camada* 'layer' [kɐ̃.ˈma.dɐ]). A third kind of vowel nasalization, which is obligatory for all BP dialects, occurs in vowels followed by a nasal consonant in the same syllable (*campo* ‘field’ [ˈkɐ̃^{m}.pu]) or a word ending in a syllable marked orthographically by a tilde <~> on the syllable nucleus.[1] (See Cristófaro Silva, 1998 for a more detailed description of the BP vowel system.)

The brief description of BPs vowel system provided here demonstrates, in part, the level of complexity and challenge encountered by learners of languages with smaller or very different vowel inventories. While contrastive nasal vowels represent only part of the hurdles learners deal with to become proficient, nasalization of phonemically nasal vowels is a salient feature of BP phonology and occurs in many high frequency words, such as the examples in (2).

2. a. sim [sĩ] ‘yes’
   b. são [sɐ̃u̯] ‘be’ 3rd PL PRESENT
   c. estão [es.ˈtɐ̃u̯] ‘be’ 3rd PL PRESENT

Some BP words with nasal vowels are easier to produce by L2 speakers (at least for learners with English or Spanish as their L1). A pilot study regarding accent ratings of BP tokens with nasal vowels by L2 speakers revealed that words ending in [ĩ] such as (3a) were judged to be more nativelike than words ending in [ũ] in (3b) and [ĩɐ̃u̯] as in (3c). The least nativelike, thus perhaps the hardest to produce, was [ẽɪ̯] as in (3d).

3. a. fim [fĩ] ‘end’
   b. atum [a.ˈtũ] ‘tuna’
   c. união [u.ˈnĩɐ̃u̯] ‘union’
   d. também [tɐ̃^{m}.ˈbẽɪ̯] ‘also’

Research Perspectives on Vowel Nasalization in Brazilian Portuguese

Among the three kinds of nasalized vowels described in BP, the most disputed is the third kind described earlier, sometimes called phonemic nasal vowels. These vowels are obligatorily nasalized and they are either followed by a nasal consonant in the same syllable as in *tinto* ‘tinted [ˈt͡ʃĩ^{n}.tu] (/VN.C/, tonic or atonic syllables) and sim ‘yes’ [sĩ] (/VN#/, word-final post-tonic syllables) or are marked by an orthographic tilde as in *cristã* ‘Christian’ FEM. [kɾis.ˈtɐ̃] (/Ṽ#/, word-final tonic syllables). According to Azevedo (1981), the tautosyllabic nasal consonant is realized as a weakened, shorter segment, but is obligatorily elided only phrase finally.

Nevertheless, the phonemic status of BP vowel nasalization in /VN.C/, /VN#/, and /Ṽ#/ environments has long been controversial. One view of BP vowel nasalization considers five BP nasal vowels /ɐ̃ ẽ ĩ õ ũ/ to be phonemic (Lacerda & Head, 1963; Simões, 1989; Techner & Simões, 2007). This analysis is often referred to as the monophonemic view. A more common interpretation, the biphonemic view, proposes that BP nasalization is a /V/ plus an archiphoneme /-N/, resulting in an analysis of syllables with nasal vowels to be closed syllables (Azevedo, 1981; Bisol, 2013; Lipski, 1975; Mattoso Câmara, 1972; Mateus & d’Andrade, 2000; Moraes & Wetzels, 1992; Morales-Front & Holt, 1997; Reed & Leite, 1975). A less common, yet intermediate, interpretation proposes “nasal vowels are true diphthongs [a vowel mora plus a glide-like mora], and thus open syllables” (Parkinson, 1983:158).

Many scholars argue for the biphonemic view of BP vowel nasalization. Reed and Leite (1975) stated that nasal vowels are phonemically oral vowels followed by a nasal consonant in word internal position, and word- or phrase-finally they are followed by /ɲ/, sometimes also realized as [ŋ], but the nasal consonant does not reach full closure in absolute final position. More recently, Bisol (2013) employed three main arguments to support the biphonemic view.

First of all, the pronunciation of /r/ has two realizations in many BP dialects. A two-way opposition happens only when /r/ occurs intervocalically. The weak form, which is realized as a [ɾ], is represented orthographically as “r”, such as in the word *caro* [ˈka.ɾʊ] ‘expensive’. The strong form, which is realized as [x] or [h], is represented orthographically as “rr”, such as in the word *carro* [ˈka.xʊ] ‘car’. The /r/ following another consonant is always realized as the strong form, such as in *honra* [ˈõⁿ.xa] ‘honor’ and *genro* [ˈʒẽⁿ.xʊ] ‘son-in-law’. Bisol argued that the presence of the strong form implies the presences of a coda consonant in the previous syllable; therefore the intervocalic [ɾ] does not appear after the nasal segment as it would intervocalically.

Bisol (2013) gave another argument in favor of the biphonemic view, which is the impossibility of a hiatus of a nasal vowel followed by another vowel, suggesting that something blocks a hiatus in derivational morphology. Rather than a hiatus, (1) the nasal element is completely lost, such as in the feminine derivation of the masculine from *bom* [bõ] ‘good’ to the feminine *boa* [ˈbo.ɐ] but not *[ˈbõ.ɐ]; (2) alternatively the nasal element fills the onset position of the following syllable in the feminine derivation of the masculine *brincalhão* [bɾĩᵑ.ka.ˈʎɐ̃ṷ] > *brincalhona* [bɾĩᵑ.ka.ˈʎo.nɐ] ‘playful’.

A third argument by Bisol in favor of the biphonemic view is that juncture or liaison between word boundaries does not occur when a word ends in a nasal vowel as in (4) but does occur for two adjacent oral vowels as seen in (5).

4. lã amarela
   [‘lɐ̃ ɐ.mɐ.ˈɾɛ.lɐ]
   wool yellow
   ‘yellow wool’

5. sofá amarelo

[so.ˈfa.mɐ.ˈɾɛ.lʊ]

sofa yellow

‘yellow sofa’

Writing from the perspective of autosegmental phonology, D’Angelis (2002) affirmed Mattoso Câmara’s (1972) biphonemic proposal that BP syllable codas may be made up only of four different archiphonemes, /S/, /L/, /R/, and /N/. Nonetheless, D’Angelis also acknowledged that for many BP speakers the phonological existence of a closed syllable is only justified by the nasalization found in the nucleus of the syllable to which the nasal coda belongs; no audible consonantal trace exists to the right of the nucleus. On the other hand, the BP syllable rarely allows consonant clusters in coda position. The only possible complex coda occurs in lexical items ending in a nasal consonant (according to the biphonemic view) that have received the plural “-s” morpheme. Words ending in /S/ and /R/ receive an epenthetic vowel before the plural morpheme, and words ending in /L/ undergo either epenthesis or gliding before the plural morpheme.

Moraes and Wetzels (1992) carried out a durational study of [a] and [ɐ̃] in different consonantal and stress environments based on a non-linear phonological theory proposed by Clements and Keyser (1981, 1983). To account for the possible syllable structures of all natural languages, Clements and Keyser proposed a three-tiered theory of the syllable within generative phonology. In this theory, syllable trees consist of three tiers: a syllabic tier, a CV tier, and a segmental tier. Regarding the CV tier, Clements and Keyser wrote, “the elements of the CV tier are interpreted as corresponding to the timing units of speech that are produced at the sub-syllabic level” (1983:34). The existence of the two tiers below the syllabic tier is used to account for segmental loss in the segmental tier without the loss of the temporal unit in the CV tier. For example, in BP *canta* ‘to sing’, the nasal consonant is lost only in the segmental tier, and the adjacent nasal vowel associates to both timing slots; in other words, the nasal vowel undergoes compensatory lengthening. Within the scope of the tree-tiered theory of the syllable, Moraes and Wetzels (1992) used acoustic durational data to confirm a phonological explanation for longer duration in contrastive nasal vowels, but not in nasalized vowels. Likewise, they discarded alternative articulatory and coarticulatory explanations, which would have required longer nasalized vowels as well. Moraes and Wetzels’s analysis of contrastive BP nasal vowels thus supported the biphonemic view of nasalization.

Generally speaking, acoustic phonetic studies of BP vowel nasalization do not subscribe to a strong monophonemic or biphonemic view, but rather look at acoustic data in order to describe the physical reality of vowel nasalization. Moraes and Wetzels (1992) observed coda nasal consonantal loss (either full or partial loss) and absorption of the nasal feature in the nucleus with compensatory lengthening of the nucleus. In the case of nasal vowels followed by a heterosyllabic fricative, a nasal coda or nasal murmur was completely missing. Sousa (1994) concurred with Moraes and Wetzel regarding compensatory lengthening in nasal vowels. They found that syllables containing nasal vowels were longer that those with oral vowels in all environments; however, the presence of a short nasal murmur preceding fricatives was found in her data counter to Moraes and Wetzel’s findings. In fact, the duration of the nasal murmur varied greatly in Sousa’s data leading her to conclude that the realization of the nasal murmur in nasal vowels may be influenced by regional dialect and idiolects. The three vowels in the extreme corners of the nasal vowel space, [ɐ̃], [ĩ], and [ũ], had longer nasal murmurs than [ẽ] and [õ] which had a strong tendency to diphthongize to [ẽi̯] and [õʊ̯] respectively (Sousa, 1994).

Although each view on BP contrastive nasal vowels has its own merit, the current study analyses BP nasal vowels as complex nuclei, containing more than one part, a nasal vowel and a nasal murmur. Whether or not the nasal murmur is more vowel-like and thus part of the nucleus or more consonant-like and thus part of the coda remains an open question. Because of the difficulty of determining when the vowel portion of the nasal vowel ends and when the nasal murmur begins, this study treats both parts of the nasal vowel as the syllable nucleus.

Three Acoustic Studies of Brazilian Portuguese Vowels

A handful of studies, such as Bailey (2012), Kelm (1989), Seara (2000), and Sousa (1994), have described one or more BP nasal monophthongs acoustically. Since the tools necessary to do phonetic research were not very accessible to many linguists interested in Portuguese until more powerful personal computers and free or inexpensive software became available, there is little research that readily applies to this dissertation prior to 1989. In this section, I summarize the latter three studies in chronological order beginning in 1989, leaving the first one for a later section in this chapter which includes two studies that make cross-linguistic comparisons of Portuguese and Spanish vowels. The latter part of Chapter 2 will cover two recent studies that apply to this dissertation. These are Fails (2011), which compares Portuguese and Spanish in an experimental study that uses nasometer data rather than acoustic data, and Bailey (2012), which compares Spanish and Portuguese production by L1 Spanish speakers from a language acquisition perspective. Another reason the number of acoustic studies on BP vowel nasalization is still low may be because the acoustic cues of nasalized vowels are not nearly as straightforward as those for oral vowels.

A Production Study of One Oral–Nasal Vowel Contrast

Reporting on a cross-sectional study with 30 native-speaker BP participants, Kelm analyzed one nasal–oral contrast in BP while adopting the biphonemic or /V/ plus /-N/ view of

BP vowel nasalization. The purpose of his investigation was to gain a better understanding of nasalization in BP by comparing three disyllabic minimal pairs with [a] and [ɐ̃]. His aim was to analyze changes in vowel quality and segment duration resulting from the nasalization of /a/ when followed by a tautosyllabic nasal consonant. Kelm mentioned the highly subjective nature of the debate on whether the nasal consonant in the coda position of nasal(ized) vowels is retained, or whether it is deleted after vowel nasalization. He suggested that "opinions are based on the degree of phonemic versus phonetic precision, phonetic environment, register and/or dialect" (1989:854). Perhaps based on these comments, Kelm chose to segment nasal vowels without the nasal coda or nasal murmur. He separated the nasal consonant from the vocalic segment only if there was a clear reduction in amplitude or if there was a definite change in the vowel formant frequencies, such as loss of the formants. Because of the decision not to include the nasal element in the duration measure of the nasal vowels, the duration results in Kelm were rather different from the results of other acoustic studies included in this literature review.

Six tokens, *tato* 'touch', *tanto* 'so much', *dado* 'gave' (part), *dando* 'giving', *caça* 's/he hunts', and *cansa* 's/he tires', were used in Kelm's production study. All target vowels belonged to stressed syllables in penultimate position. Thirty adult males from the city of São Paulo were recorded doing the same tasks in the same order. These participants were asked to do four different tasks containing the same six tokens. First, they were instructed to read some sentences at a normal speaking style as if they were speaking to a friend. Second, they were asked to read the same sentences two times, as fast as they could, to obtain reduced forms of the tokens. Third, they read the tokens in carrier phrases at a normal pace. Fourth, the participants read the tokens carefully, preceded by Portuguese cardinal numbers to provide citation forms and avoid any effects of overlapping adjacent tokens. Statistical analyses of F_1 and F_2 formant frequencies and segment duration of [a] and [ɐ̃] in three sets of minimal pairs led Kelm to draw seven different conclusions. (1) /a/ exhibited “significant vowel raising when nasalized by a subsequent tautosyllabic nasal element” (1989:858). (2) Vowel centralization resulted from increased speaking velocity, both for tonic oral and nasalized /a/. (3) Nasalized /a/ was shorter than its oral counterpart. In fact, tokens with nasalized vowels were shorter than those with only oral vowels. Kelm’s analysis of these results suggested that nasalization may be signaled more by vowel quality than by duration. (4) In careful pronunciation (citation form), tonic and atonic vowels had balanced duration, but as speaking velocity increased, the vowels in unstressed syllables became proportionately shorter. (5) Before the voiceless fricative /s/, the postvocalic nasal disappeared and the vowel was nasalized. (6) In the token *dando* the /d/ following the nasal consonant was deleted, resulting in a syllable-initial nasal consonant [ˈdɐ̃.nu]. (7) Before the voiceless obstruent /t/, a short postvocalic nasal consonant was produced. Also, the vowel in the unstressed syllable in *tato* and *tanto* underwent extreme reduction resulting in a short voiceless [u̥] or no vowel at all.

This work is important because it is the first published study to acoustically compare minimal pairs containing oral–nasal /a/. Kelm asserted that experimental data on BP nasalization had been fragmented and scarce up until the publication of his (1989) study. The methodology used was unique in its comparison of four different forms, ranging from careful citation form to reduced form in continuous speech. The results demonstrated the importance of implementing carefully controlled experimental conditions for acoustic studies of vowel nasalization.

A Production Study of Oral and Nasal Vowels

Though unpublished, Sousa (1994) is oft cited and considered by many researchers to be an important source on BP vowel nasalization. This study stands out for its thorough treatment of

BP vowel acoustics in spite of the exploratory nature of the experiments therein. In this master's thesis, Sousa reported on a series of four experiments. The first two experiments used only one informant and were designed as pilot studies. The third experiment recorded three informants for the purpose of examining BPs three nasal consonants /m/, /n/, and /ɲ/. In the fourth experiment, which is the most relevant to the present study, four participants from distinct regions of Brazil read monosyllabic words in a carrier phrase. Two of the 12 tokens were real Portuguese words: *pá* [pa] 'dust pan' *pé* [pɛ] 'foot'). The other 10 tokens were nonsense words. All tokens consisted of /pV/, with seven of the tokens having oral monophthongs /i e ɛ a o ɔ u/ and the remaining five tokens having nasal vowels [ĩ ẽ ɐ̃ õ ũ]. Measurements of formant frequencies F_1, F_2, F_3, F_4 and segment duration were recorded for each vowel segment. Statistical analyses were performed on F_1, F_2 and duration values. F_3 and F_4 were excluded from the statistical analysis due to their inconsistent nature in the data sets.

In Sousa's experimental data, segment duration was an important acoustic measure for separating oral from nasal vowels, with nasal vowels being longer than all of the oral vowels. The nasal vowels had a nasal murmur phase which was missing only in some instances uttered by one informant from the mid-western city of Goiânia, suggesting that the absence of a nasal murmur is due to dialectal or individual differences. Sousa noted that the nasal vowels in the three corners of the F_1/F_2 acoustic vowel space [ĩ ɐ̃ ũ] had the longest nasal murmurs. She also observed that the division between nasal vowel and nasal murmur was hard to determine with certainty due to the gradualness of the formant transitions. Sousa observed that if the nasal murmur portion of the nasal vowels were excluded, these vowels would be shorter than most of their oral vowel counterparts. Furthermore, without the inclusion of the extra length that the nasal murmur portion contributed to the segment, Sousa stated that these vowels may not be recognized as being nasal. The nasal murmurs as well as the extra duration afforded to a nasal vowel by the existence of the nasal murmur appear to be important in a segment's identification as nasal or oral. Exceptionally, even without the nasal murmur [ẽ] was longer than both [e] and [ɛ] and [õ] was longer than [ɔ]. Both mid nasal vowels showed a strong tendency to diphthongize, /ẽ/ > [ẽɪ̯] and /õ/ > [õʊ̯] which contributed to the extra length in these two segments.

Some acoustic characteristics of nasal vowel trajectories were not analyzed quantitatively; rather Sousa offered some qualitative descriptions of the frequencies and intensities of formants in spectrographic representations and spectral slices taken from nasal vowels. The most noteworthy observations are listed here:

a. When compared to the other formants, F_1 was characterized by a more steady frequency and amplitude throughout the nasal vowels, rarely suffering interruptions.
b. A first nasal formant (Fn_1), between F_1 and F_2, was present in 95.8% of the front nasal vowels, but no Fn_1 appeared at this frequency level in the back nasal vowels. Fn_1 was only present 25% of the time in [ɐ̃]. In high nasal vowels [ĩ] and [ũ], it was practically impossible to separate F_1 from Fn_1.
c. F_2 underwent interruptions in 50% of occurrences. There was a tendency for the amplitude of F_2 to fall through the nasal vowel trajectory.
d. F_3 underwent interruptions in only 28.3% of occurrences.
e. A low energy nasal resonance occurred between F_2 and F_3 (1000-1200 Hertz (Hz)) in 75% of nasal vowels.
f. F_1 and F_2 merged in 96% of back nasal vowels.
g. F_2 and F_3 merged in front nasal vowels, with a 100% merger for [ẽ].

h. At least two distinct phases (nasal vowel and nasal murmur) were visible in nasal vowels. An initial oral vowel phase was sometimes visible on the spectrogram, but not audibly detectable.

i. The nasal murmur was coarticulated with the preceding vowel. The duration of the nasal murmur appeared to be conditioned by dialectal and idiosyncratic factors.

From these observations, Sousa concluded that vowel nasality has a complex relationship with formant frequencies and a unified pattern of nasal resonances that are independent of vowel quality would be hard to establish. Rather it seems more appropriate to compare a nasal vowel with its oral counterpart (1994:128). Although Sousa did not choose either side in the monophonemic versus biphonemic debate of BP nasal vowels, she pointed out that it is possible to argue that BP nasal vowels (composed of up to three phases) behaved as a unit such that none of the phases demonstrated autonomous characteristics, which could be an argument in favor of a monophonemic view (Lacerda & Head, 1963; Simões, 1989; Techner & Simões, 2007). On the other hand, Sousa mentioned the consistent occurrence of the nasal murmur at the end of nasal vowels, which could be used to support the biphonemic view of BP nasal vowels (Bisol, 2013; Mattoso Câmara, 1972; Mateus & d’Andrade, 2000; Moraes & Wetzels, 1992; Morales-Front & Holt, 1997; Reed & Leite, 1975).

A Production and Perception Study of Oral and Nasal Vowels

Seara’s (2000) doctoral dissertation on the acoustics and perception of BP nasal and oral vowels provided valuable and relevant information that serve as a backdrop and basis for comparison to the present study. Her experimental research added a great deal to Sousa’s (1994) previous acoustic findings in that Seara used polysyllabic tokens and examined vowels in tonic and pre-tonic syllables. The methodology used in the perception study continues to be innovative when compared to other research on BP phonetics to date.

Seara recorded five participants from the state of Santa Catarina in southern Brazil, and each participant uttered real and nonsense BP words in a carrier phrase for the purpose of acoustic analysis of all five BP nasal vowels and their five oral counterparts. Open-mid /ɛ/ and /ɔ/ were excluded from the analysis since the mid nasal vowels tend to pattern with close-mid /e/ and /o/. Nasal vowels were segmented and divided into phases, and three possible configurations were found in Seara's data. When all three phases were present, the nasal vowel consisted of a short oral vowel phase, a transitional nasal vowel phase, and a nasal murmur phase. A second configuration found in Seara's data was that of nasal vowels containing a nasal vowel phase and a nasal murmur. These first two configurations were also observed in Sousa (1994). Seara identified a third configuration for nasal vowels, an oral vowel plus a nasal murmur. She observed that when a nasal vowel had only two phases, the existing phases were longer, resulting in a similar duration to nasal vowels with three phases. Table 2.1 presents percentage of total occurrence of nasal vowels with all three phases, two phases consisting of nasal phase + nasal murmur, and two phases consisting of oral phase + nasal murmur.[2] The percentages in Table 2.1 indicate that [ĩ], [ũ], [õ], and [ẽ] had all three phases more frequently, and [ɐ̃] had more cases of nasal phase + nasal murmur. The high front nasal vowel [ĩ] had the longest nasal murmur. Segments containing an oral phase and nasal murmur occurred only in [ĩ], [ẽ], and [ũ], at 30%, 19%, and 3.8% respectively.

Table 2.1 Percentage of total occurrence of nasal vowels (in tonic and pre-tonic contexts) containing all three phases (oral phase + nasal phase + nasal murmur) or a combination of two phases. Summary of data presented in Seara (2000:117-118).

Vowel	**3 phases**	**nasal phase + murmur**	**oral phase + murmur**
[ĩ]	65%	5.2%	30%
[õ]	64%	36%	
[ũ]	60%	38.5%	3.8%
[ɐ̃]	35%	65%	
[ẽ]	52%	29%	19%

Seara (2000) and Sousa (1994) both compared nasal murmur duration to syllable rime duration using ratios obtained by dividing nasal murmur duration by syllable rime duration. See Table 2.2 for a summary of their results. Sousa analyzed vowels in monosyllabic words and only reported results for tonic syllables; whereas, Seara was able to make comparisons between vowels in pre-tonic and tonic syllables. Seara's results showed that nasal murmurs were longer in pre-tonic syllables than in tonic syllables. Nasal vowels including nasal murmurs were longer than oral vowels, and nasal vowels presented similar durations in tonic and pre-tonic syllables.

Table 2.2 Mean duration of vowel segments (in milliseconds) from Sousa (1994) for monosyllabic nonsense words and a comparison of mean ratios of nasal murmur to syllable rime in Sousa and Seara (2000).

Oral Vowel	**Mean duration**	**Nasal Vowel**	**Mean duration**	**Ratio (nasal murmur / rime) (Sousa 1994)**	**Ratio (nasal murmur / rime) (Seara 2000)**
[a]	123.0	[ɐ̃]	163.5	0.38	0.35
[e]	98.2	[ẽ]	170.0	0.26	0.33
[ɛ]	143.7				
[i]	86.9	[ĩ]	155.6	0.44	0.41
[o]	106.1	[õ]	161.6	0.36	0.36
[ɔ]	123.3				
[u]	88.5	[ũ]	144.4	0.47	0.30

In addition to duration measurements, Seara recorded formant frequencies and amplitudes for the vowel segments and performed statistical analyses. Seara labeled formant frequencies belonging to nasal vowels using F'i, but for the sake of consistency, I will continue to use F_i to refer to both oral and nasal formant frequencies. F_1 was found to be significantly higher than their oral counterparts for [ẽ] and [õ], indicating a lower articulation in comparison to [e] and [o]. Suggesting a higher articulation, F_1 was lower for [ɐ̃] and [ũ] with a marginally significant effect. No significant F_1 differences were found for [ĩ]. F_2 was significantly higher for [ĩ] in both tonic and pre-tonic contexts; F_2 was also significantly higher for [ẽ] only in pre-tonic syllables, pointing to a more anterior articulation of the high and mid front nasal vowels when compared to their oral counterparts. F_2 was lower for [ũ] with only a marginally significant effect, suggesting a more posterior articulation than for [u]. Measurements for formant amplitude (labeled A_i here) produced some significant results. When formant amplitude in nasal vowels was compared to the same in their oral counter parts, A_1 (amplitude of F_1) was significantly higher for [ĩ] and [ũ] due to the presence of a nasal formant nearby. A_2 was significantly lower for [ĩ] in both tonic and pre-tonic contexts, for [ũ] only in tonic syllables, and for [ɐ̃] only in pre-tonic syllables. A_2 for [õ] in tonic syllables was significantly higher than for its oral counterpart. These results showed that the spectral characteristics of BP nasal vowels vary not only according to vowel quality, but also according to the prominence of the syllable containing the vowel. Figure 2.7 plots mean F_1xF_2 values of BP oral and nasal vowels that occur in tonic syllables.

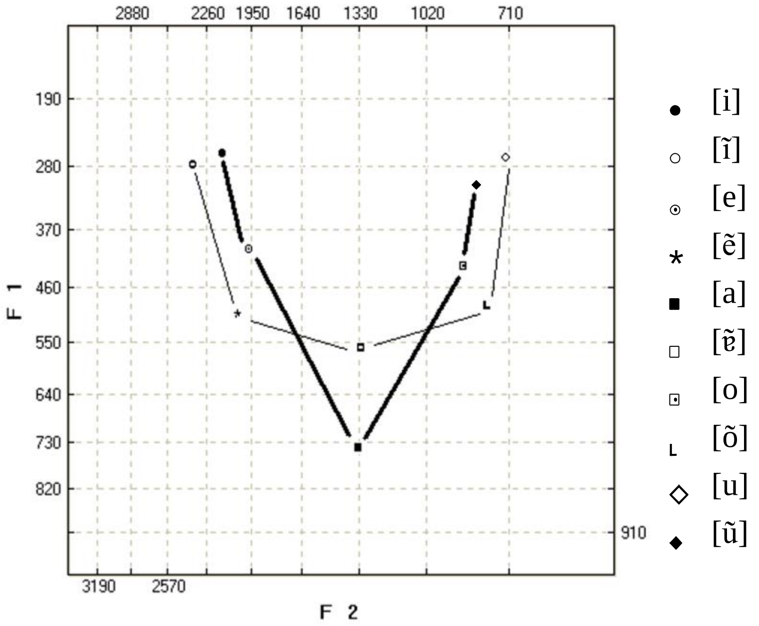

Figure 2.7 Plot in mel scale of mean F_1xF_2 values of BP vowels in tonic syllables. Oral vowels are along the thick line and nasal vowels are along the thin line (Seara, 2000:141).

Seara also carried out a perception study of vowel nasalization with five native BP listeners. Participants evaluated digitally manipulated vowel segments for level of nasality (on a six-point scale) and naturalness (+ or – natural). Results from the perception experiment showed that the absence of a nasal murmur did not affect the perception of the vowel as nasal with the exception of [ĩ], for which results were inconclusive. Mid nasal vowels without nasal murmur were perceived as nasal, but judged as less natural sounding, based on percentages of "+ natural" responses. In the same perception experiment, the nasal vowel phase (phase two of vowels having three phases) of naturally occurring BP nasal vowels was isolated and its duration was doubled. The perceived naturalness of these nasal vowels varied a great deal: [õ] was judged as natural sounding 100% of the time, [ẽ] 60%, [ɐ̃] 40%, [ũ] 20%, and [ĩ] 0%. When a nasal murmur was added at the end of a corresponding oral vowel, only [ɐ̃] and [ẽ] were judged as nasal, with 20% and 100% naturalness, respectively. The remaining segments [ĩ], [õ], [ũ] were not judged to be nasal, with 60%, 20%, and 60% naturalness, respectively. When a nasal murmur from a different vowel was added to an oral vowel, only [i] + nasal murmur from [ɐ̃], [a] + nasal murmur from [ĩ], and [u] + nasal murmur from [ɐ̃] were judged as nasal, but with low naturalness ratings, at 40%, 20%, and 40% respectively. Since the vowel quality (height in particular) of [ɐ̃] is similar to its oral counterpart in post-tonic position [ɐ], the final segment in [ˈpa.pɐ] was used in the perception task, both unmodified and doubled in length. When [ɐ] was not lengthened, it was not judged as nasal. The lengthened unstressed oral vowel [ɐ] was judged as nasal with 60% naturalness, suggesting that vowel length cues are more important than, or at least as important as, other spectral cues in judging BP vowel nasalization, in particular for low vowels. Seara acknowledged that further study is greatly needed to increase our understanding of the acoustics and perception of the oral–nasal vowel contrasts in BP and other languages that use these contrastively.

Seara's findings call attention to the acoustic complexity of BP vowel nasalization. Perhaps most important to the current study are Seara's multifarious observations that lead to the conclusion that BP vowel nasalization should not be viewed as a uniform process across all vowels, rather more useful results can be obtained if each oral-nasal vowel contrast is studied individually. All three of these studies (Kelm, 1989; Sousa, 1994; Seara, 2000) demonstrated the importance of segment duration and the frequent presence of a nasal murmur/coda as important elements in the study of BP nasal(ized) vowels.

Three Theories of Second Language Acquisition of Speech

Many different hypotheses on SLA phonological acquisition have emerged in the last half of the twentieth century. I will discuss some of the most influential theories in this section.

The Markedness Differential Hypothesis

Eckman (1977, 1987), proposed the markedness differential hypothesis (MDH), which is based on the view that typological (implicational) universals of a learner's native (or primary) language "can be used to explain certain realities about SLA" (Eckman, 1991:24). Within the framework of the MDH, Eckman proposed the "theory of markedness." A structure or contrast is unmarked when it is more common among the world's languages than a marked one. A NS of a language with a more marked structure (or contrast) than the target language will find it easier to learn the target language structure than in the opposite situation where the target language structure is more marked than the native language structure (Gass & Selinker, 2008). The MDH predicts more errors when the L2 speaker is learning a structure or contrast that is different from one's native language *and* is a more marked structure. Since the investigation in this dissertation is more concerned with gradient vowel and nasalization qualities, an “error” count per se is not relevant, and therefore details of the MDH are less pertinent here. But the general ideas of language differences and markedness behind the MDH are germane to the extent that oral-nasal vowel contrasts are less common in the world’s languages, thus more marked. Based in these ideas, we would expect L1 English speakers to have more difficulty perceiving the oral-nasal contrasts in BP. Also, L2 BP speakers may have more difficulty producing contrastive nasal vowels in comparison to oral vowels.

A later development of the MDH materialized as the interlanguage structural conformity hypothesis (SCH), developed by Eckman and colleagues (Eckman, Moravcsik, & Wirth, 1989), which placed more emphasis on interlanguages as languages that “can and must be described on their own grounds” (Bley-Vroman, 1983 in Eckman, 1991). There are two justifications for the interlanguage SCH. First, an interlanguage reflects a learner’s knowledge or version of the target language. Second, there is the assumption that the posited universal generalizations hold for all human languages, and since interlanguages belong to the set of human language, therefore universal generalizations apply to interlanguages. Eckman (1991) validated the interlanguage SCH by testing two such universal generalizations concerning consonant clusters. In those experiments, consonants were either missing or present in a participant’s interlanguage based on a predetermined threshold (defined as a consonant cluster being present at least 80% of the time). As with the MDH, the interlanguage SCH appears to be more suited for studying binary contrasts rather than the gradient qualities inherent to L2 vowel acquisition and vowel nasalization in particular. However, it is feasible to acknowledge that certain vowel segments or contrasts, as well as vowels in certain prosodic environments, may be easier or harder to master based on some universal generalizations.

The Perceptual Assimilation Model

Another hypothesis concerning speech L2 acquisition is Best's (1995) Perceptual Assimilation Model (PAM) of cross-language speech perception. A model that is more applicable to naïve listeners of a target language, the PAM rejects the group of theories known as the motor theory of speech perception and instead rests on the direct realist approach to speech perception. Direct realism is a philosophical point of view in the field of epistemology regarding the origins of perceptual knowledge. "Its central premise is that in all cases of perception, the perceiver directly apprehends the perceptual object and *does not* merely apprehend a representation or 'deputy' from which the object must be inferred or constructed from indirect representations of themselves" (Best, 1995:173, emphasis in original). The motor theory of speech perception, or simply motor theory, posits that the objects of perception are intended gestures, while direct realism proposes that these objects are actual vocal tract movements, in other words, that gestural information is perceived directly in speech. The acoustic signal is considered merely as energy created by vocal tract gestures, and therefore transmitting information about these gestures. Speech perception, which is initially devoid of linguistic meaning for infants, eventually shifts to a linguistic focus throughout human development. Whereas an infant only has access to the surface phonetic details of ambient speech, linguistic maturation leads the perceiver to develop an abstract phonological structure and thus a more economical process of tuning into critical cues necessary for category discrimination in a native language. Humans perceive native speech in terms of its linguistic affordances, or communicative objectives that can be accomplished. Since communication is the ultimate goal, perception and production of speech are said to be inextricably linked. In the direct realist approach of gestural phonology, a common gestural domain is assumed for phonetic detail and phonological structure. An important consideration with regard to the PAM and the direct realist view is the assumption that "perceptual learning continues into adulthood" (Best, 1995:198). According to the PAM, L2 speech learning is influenced by three different levels or patterns of perceptual assimilation, depending on how a new sound matches native language phonology. L2 category assimilation and discrimination depends of several cross-linguistic category correspondences. A nonnative contrast can exhibit *two-category assimilation*, where each nonnative category is assimilated to a different native category. Another type of contrast exhibits *single-category assimilation*, in which two nonnative segments are assimilated to the same native category, with equal perceived distance from the native archetype. Some nonnative contrasts may assimilate to one native category, but with a *category-goodness difference*, where the level of discrepancy from the native ideal is greater for one of the nonnative segments. A contrast can exhibit *uncategorized / categorized assimilation*; in this case one nonnative category is assimilated to a native category and the other falls within the native phonetic space, but outside any native category. Other contrasts are *both uncategorized*, where both nonnative sounds fall within native phonetic space, but not within any native category. Yet another possibility is *nonassimilable* contrasts, where both sounds are outside the native speech domain and may be judged as non-speech sounds. The PAM predicts that contrasts in all of the above classifications will fit within a range from good to excellent discriminability except for *single-category assimilation* and *both uncategorized.* Those fitting the *single-category assimilation* description are predicted to have poor discriminability. Finally, no specific predictions are made for contrasts that are *both uncategorized*.

The proposals of the PAM have been tested in a number of experimental studies involving consonant contrasts, but one in particular (Tyler, Best, Faber, & Levitt, 2014) looked at American English speakers' ability to discriminate six different nonnative vowel contrasts in /CV/ contexts. The contrasts consisted of two Norwegian contrasts /ki/–/ky/ and /ki/–/kʉ/; one Thai contrast /bɯ/–/bɤ/; and three French contrasts /bo/–/bõ/, /dø/–/dœ/, and /sy/–/sø/. Thirteen listeners performed two perception tasks. The first task was a categorical AXB discrimination test, in which listeners were asked to mark on an answer sheet whether the middle item (X) was the same as the first (A) or third (B) item. The second task was a keyword identification task. In this task participants heard one of the nonnative tokens two times. After hearing the token the first time they were asked to circle an English word corresponding to the vowel they heard in an item. Following the second listen participants rated the similarity of the vowel in the stimulus to the vowel in the keyword they had just chosen on a scale of 1 *unlike* to 5 *identical*. The results interpreted according to PAM were as follows: Three of the contrasts, /bɯ/–/bɤ/, /sy/–/sø/, and /ki/–/kʉ/, belonged to the cross-linguistic pattern of *uncategorized / categorized assimilation*. One of the French contrasts, /bo/–/bõ/, patterned as *both uncategorized*. Another French contrast, /dø/–/dœ/, exhibited *two-category assimilation* most frequently. One of the Norwegian contrasts, /ki/–/ky/, fit what PAM describes as *single-category assimilation*. All of the contrasts, except one, were discriminated correctly over 95% of the time. Only /ki/–/ky/, classified as *single-category assimilation*, were discriminated correctly 72.76% of the time, which was considered a poor discrimination rate yet significantly above chance, which fits within PAM's prediction for this pattern. Although no specific predictions are made in this model for the French /bo/–/bõ/ contrast, classified as *both uncategorized*, Tyler and colleagues elaborated on this contrast, "The categorization responses to /bo/ were largely split between English /o/ and /u/, and those for /bõ/ among /u/, /on/, and /ɑn/" (2014:17). Since these French segments fall in an "untuned" part of the native vowel space, they may be recognized as an unusual-sounding realization of more than one neighboring native category. The instability of responses may be caused by some overlap in the vowel space of native categories to which each, /o/ or /õ/, was assimilated. Tyler and colleagues asserted that PAM's predictions apply to vowels and that vowel discrimination is, in fact, better than consonant category discrimination.

The Speech Learning Model

Another influential view of SLA phonological acquisition is the speech learning model (SLM), developed by Flege (1995), which contains seven hypotheses. This model is especially relevant to the study of the acquisition of BP oral and nasal vowels because phonetic differences are addressed in several of its hypotheses. Hypothesis 1 is foundational to the SLM in that it establishes the importance of perception at the position-sensitive allophonic level rather than at a more abstract phonemic level. Flege's SLM hypotheses two and three are pertinent to the current study. Hypothesis 2 offers the principle that a new phonetic category can be created for a nonnative sound if it differs phonetically from the closest native sound and if experienced bilinguals are able to distinguish at least some of the differences between the native and nonnative sounds. Hypothesis 3 contends that the greater the perceived phonetic distance between a nonnative sound and the closest corresponding native sound, the more likely a listener will discern the phonetic differences between the sounds. Since the age of onset of Portuguese learning for all of the L2 participants in the current study was around or over the age of 18 years, the proposal in Hypothesis 4 though relevant, is not essential to our analysis. This hypothesis states that as the age of learning increases, there is a decrease in the likelihood that listeners will perceive the differences between native and nonnative sounds and discern the dissimilarities between two nonnative sounds that belong to the same native category. Hypothesis 5 speaks to the "mechanism of equivalence classification" which causes the formation of a new category for a nonnative sound to be blocked, resulting in a single phonetic category being used to process L1 and L2 sounds that are perceptually linked; thus these corresponding L1 and L2 sounds eventually become similar in production. It is possible that the nasal(ized) vowels in the present study could be affected by the mechanism of equivalence classification in Hypothesis 5 if an L2 speaker perceptually links a nasal vowel to a similar nasalized vowel allophone in the native language, therefore not noticing the distinctive characteristics of BP nasal vowels. Hypothesis 6 is about a common L1–L2 phonological space in which bilinguals organize sound categories. In order to maintain phonetic contrasts in a bilingual's inventory of sound categories, new categories may "deflect" away from L1 categories. The categories of bilinguals will be different from those of monolinguals since their mental representations hinge on different features or feature weights. One could argue that this hypothesis is less applicable to the present study since it likely refers to bilinguals at a more advanced level than the majority of the nonnative participants in the production experiment; however, as learners have more experience in an L2, it is entirely feasible that feature weights are adjusted to become more nativelike. In this sense, the analyses in this dissertation address acoustic cues as correlates of feature weights. Lastly, Hypothesis 7 proposes "The production of a sound eventually corresponds to the properties represented in its phonetic category representation" (Flege, 1995:239). This hypothesis is more descriptive in nature and is reminiscent of Eckman's MDH and interlanguage SCH. Hypothesis 7 does not directly pertain to the current study. However, it is important to recognize that since vowel sounds have fairly flexible acoustic targets in any given language, the acquisition of new vowel sounds is more than acquiring new mental representations of appropriate categorical distinctions of target language (TL) phonemes, which would fit within the PAM framework. Rather mental representations of interlanguage phonetic categories of vowel sounds evolve during the acquisition process to enable the language learner to perceive and produce sounds that eventually are closer to the TL vowel sounds, which are ideas expressed in several of SLM's seven hypotheses.

The concept of phonetic similarity is a crucial element in predicting how L2 learners will deal with new segment categories in both the PAM and the SLM. For vowels, phonetic distance or similarity could be accounted for in many different ways. A common way of comparing vowel categories is by comparing F_1 and F_2 frequencies within the vowel space of a speaker or group of speakers. Other dimensions crucial to vowel perception and production are duration and formant movement (diphthongization). Taking all of these dimensions into account, it is feasible to claim that all of the BP vowels in the current study fit the PAM's *both uncategorized* description for L1 English speakers. That is, each of the BP vowel pairs [a ɐ̃], [i ĩ], and [u ũ] are within (American English) native phonetic space, but not within any native category since at least some of the acoustic cues of vowel categories are different from those of their closest English counterparts. Since the PAM makes no specific prediction about segment categories that fit this description, the predictions in this model are not directly useful for the current study. However, two aspects of PAM are very important for the present study. First, Best's (1995) assertion regarding the continuation of perceptual learning into adulthood justifies research involving detailed phonetic comparisons between NSs and adult language learners. Second, the claims concerning the link between perception and production corroborate with the results of the accent perception experiment.

Overall, the SLM is germane to the present study in the sense that its foundational Hypothesis 1 informed the experimental design, i.e., the acknowledgement that perception is important at the position-sensitive allophonic level (rather than at the phonemic level) led me to use carrier phrases to control for as many environmental influences on the vowel segments being investigated. Also, the selection of tokens with target vowels controlled for lexical stress placement and word length as well as the selection of tokens with target vowels flanked by specific consonants was guided by Hypothesis 1 of the SLM. The proposals in the SLM regarding nonnative phonetic category perception (Hypothesis 2), feature weight adjustments (Hypothesis 6), and the link between perception and production (mentioned in Hypotheses 1, 3 and 5,) are all relevant for interpreting the results in of the production and accent perception experiments.

Comparative Studies with Portuguese Vowels and Spanish Vowels

Although cross-linguistic studies comparing allophonic or coarticulatory nasalization in English to other languages are relatively easy to find, Fails (2011) and Bailey (2012) are unique in their comparison of two closely related languages, Spanish and Portuguese. Since these languages have many cognates, both researchers found ways to compare forms of nasalization in Spanish and BP. Fails's work is unique in its use of nasometer readings to study nasalization. Likewise, the uniqueness of Bailey's research is that hers is the only literature I found that studied language learners in a foreign language context with Spanish/English bilingual participants learning Portuguese in the United States. Although the participants in the current study are primarily English L1 speakers, the setting and goals of Bailey's research are very similar to the current study.

Fails (2011) compared nasalization in eight different syllable types using cognates or homophones in Spanish and Portuguese. Informants were one speaker from the city of São Paulo and another one from Mexico City. A nasometer consists of an apparatus that fits on a person's head with a plate between the nose and mouth that separates the acoustic signal. A microphone is placed above the plate to capture the acoustic signal emanating from the nose, and another microphone is located below the plate to pick up the acoustic signal coming from the mouth. If all of the acoustic signal were to come from the nasal cavities, the nasometer would register 100% nasality; likewise if the entire acoustic signal came from the oral cavity, the device would register 0% nasality. In reality, a certain level of acoustic signal is captured from both sources since vibrations from either the oral tract or nasal cavities can cause a small amount of vibration in surrounding facial tissue. To account for the mixing of the oral and nasal signal that occurs in nasalized vowels, Fails used the term oronasal to refer to nasal vowels and oronasalized for nasalized vowels (such as in the case of coarticulatory nasalization). Another characteristic of the acoustic measures taken with the nasometer is that vowel segments are characterized by contours, not steady levels of nasality. After establishing baseline measurements for Spanish oral vowels and Portuguese nasal vowels, Fails offered observations about each token in Spanish and Portuguese and comparisons between the corresponding tokens in the two languages. A comparison of the nasality contour for Spanish *canta* and Portuguese *canta*, both meaning ‘to sing’, demonstrated the difference in contours and timing of gestures. The first vowel in Spanish *canta* began at around 6% nasality and increased gradually to about 35% followed by a rapid transition to 96% nasality for the coda nasal consonant. The same vowel in Portuguese *canta* began at 8% nasality with a rapid increase to 63% nasality, and then slowly transitioned to 74% nasality just before transitioning into the nasal consonant at about 95% nasality (Fails, 2011:453-454). The duration of the coda /n/ is an important difference between Spanish and Portuguese for *canta*. In order to circumvent any discrepancies caused by speech rate, /n/ was calculated as a percentage of the word duration. For Spanish, the nasal coda was 24% of total word duration and for Portuguese, only 13%. All of the Portuguese tokens containing vowels in stressed syllables followed by nasal consonants, whether tautosyllabic or heterosyllabic, were labeled oronasal (nasal) based on a level of nasality from 74% to 86%. In Portuguese tokens with a vowel in a stressed syllable preceded by a nasal consonant, the vowel was labeled as variable, in other words, the vowel was sometimes oronasal and sometime oral. For Spanish tokens, the only environment in which a vowel was judged to be oronasal all the time was the token *sin* 'without'. In some of the Spanish tokens with vowels in stressed syllables preceded and/or followed by nasal tautosyllabic and heterosyllabic consonants, vowels were labeled oral (for example, the first vowels in *ama* 'to love' [PRESENT 3RD SING.], *manto* 'cape', and *canta*). In other Spanish tokens (the second vowels in *amado* 'beloved' and *humano* 'human'), the label oral/oronasal indicated variable results, with the vowel sometimes being oral and sometimes nasal. In brief, Fail's study established that BP vowels exhibited a higher level of nasalization in more contexts than in Spanish; the two languages had very different contours of nasalization suggesting differences in gestural timing; and the languages exhibited different patterns of nasalization according to nasal environments. Fail's results are important for the current study in that they showed important differences between the way Spanish and BP deal with vowel nasalization. Also, nasal vowels cannot be described as steady state vowels, therefore the trajectory of nasal(ized) vowels is important to understand their perception and production.

In a master's thesis, Bailey (2012) reported on an experimental study of BP vowel nasalization. She recorded six BP NSs (three male and three female) and four L1 Spanish speakers (two male and two female) who knew English (their L2) and had studied Portuguese for at least two semesters. For the L1 Spanish speakers, Portuguese was considered their third language (L3). All participants were recorded in two production tasks in Portuguese. One task involved reading 27 sentences containing disyllabic words designed for acoustic analysis of oral and nasal BP vowels in stressed syllables. Another task involved reading of the same tokens in a carrier phrase. All target vowels were preceded by fricatives to facilitate vowel segmentation. A Spanish language task was recorded only by Spanish L1 speakers. They read a paragraph containing similar Spanish tokens designed to elicit the five oral vowels in oral and nasal contexts (nasalized vowels). The purpose of the Spanish recording was for making comparisons with the corresponding BP vowels. For each target vowel, Bailey recorded duration, F_1, F_2, and for nasal vowels, the first two anti-resonances. In a comparison of Spanish nasalized and Portuguese nasal vowels, only one statistically significant difference was found for F_1 frequencies. The BP low nasal vowel [ɐ̃] had a lower F_1 frequency than its Spanish counterpart, indicating a higher articulation for Portuguese speakers. For F_2 frequencies, one nasal vowel [ẽ] and one oral vowel [o] had significant differences. BP [ẽ] had a significantly lower F_2 frequency than its Spanish counterpart, indicating that BP's mid front nasal vowel was less fronted. BP [o] had significantly lower F_2, indicating that BP's mid back vowel was more posterior than its Spanish counterpart. All BP nasal vowels except for [ɐ̃] were significantly longer than BP oral vowels. When comparing BP oral vowels produced by L1 speakers, all oral vowels tended to be longer than those produced by L1 Spanish speakers; however, none of these group differences were statistically significant. In a comparison of nasal vowels based on L1 group, only [ĩ] and [ũ] were significantly longer for L1 Spanish speakers. Both groups produced significantly longer BP [ĩ] and [ũ] than their oral counterparts. Only L1 Portuguese speakers produced [ẽ] longer than [e]. The L1 Spanish group had longer nasal murmurs but the differences were not significant. Females in both groups tended to produce longer vowel segments and longer nasal murmurs than male speakers. L1 Spanish-speaking females produced significantly longer nasal murmurs for [ĩ] and [ũ] than L1 Portuguese-speaking females. In reference to the most significant results in describing BP nasal vowels, Bailey concluded, “Because of the high position of /i/ and /u/ have in the acoustic outskirts, duration may be a way of contrasting these vowels with their oral counterparts more than height or advancement. On the other hand, the opposite effect [is] seen for /a/, which contrasted from its oral counterpart more in height than duration or advancement” (2012:48).

Cross-Linguistic Research on Vowel Nasalization

A number of cross-linguistic studies on vowel nasalization have focused on coarticulatory and allophonic nasalization by examining vowel production in nasal contexts. Some examples of cross-linguistic studies include English versus Spanish by Solé (1992, 1995), English versus Korean by Seunghee and Kuehn (2006), and English versus French by Cohn (1993). However, Beddor and Strange’s (1982) experimental study stands out for its investigation of oral-nasal phonemic vowel category perception. I focus on this study in the following paragraphs.

In an investigation of the influence of linguistic experience on the perception of oral–nasal distinctions between vowels [a]–[ã] and consonants [b]–[m], Beddor and Strange tested Hindi and English speakers on identification and discrimination of speechlike sounds generated by an articulatory synthesis program from Haskins Laboratories. Hindi participants lived in the United States, but had been raised in India or Pakistan and reported using Hindi at home at the time of the experiments. English participants were American English speakers; all except for one had not studied any languages that had any oral–nasal vowel distinctions. The sound systems of Hindi and English both possess categorical distinctions between oral and nasal consonants. Thus, identification levels and discrimination accuracy between the syllables [ba]-[ma] were similar and categorical for both groups of listeners. However, Hindi and English differ on the phonemic status of oral-nasal vowel distinctions. English does not have phonemic nasal vowels, but oral vowels undergo allophonic variation when adjacent to nasal consonants. On the other hand, Hindi has phonemic nasal vowels that contrast with oral vowels in minimal pairs.

For the perception tasks, sounds with incremental differences were generated through articulatory synthesis by increasing the velo-pharyngeal port opening in eleven equal intervals from 0.0-mm^2 to 24-mm^2. In an oddity discrimination tasks, stimuli consisted of triads of two sounds that varied in three-step increments (for the consonant and vowel series) and four-step increments (only for the vowel series). Triads had two same and one different sound, and listeners were instructed to select the one sound that was different in each triplet. The identification tasks required listeners to label the syllable they heard as beginning with *b* or *m* (for the consonant series) or ending in *a* or *an* (for the vowel series). Cross-language similarities and differences were revealed based on language background. One cross-language similarity demonstrated:

> comparisons of the oral-nasal boundary for the consonant series […] and the vowel series […] indicated that labeling of the vowel stimuli as nasal required more velar port opening than labeling of the consonant stimuli as nasal. For both language groups, the crossover from [b] to [m] required less than 8.5-mm^2 velar port area, while the crossover for [a] to [ã] required more than 12-mm^2 velar port area. (Beddor & Strange, 1982:1555)

There were some meaningful cross-language differences in accuracy levels and oral-nasal discrimination boundaries. For Hindi listeners, discrimination accuracy for vowel pairs were most accurate for pairs whose members belonged to different phonemic identities (pairs which crossed the velar port opening boundary). Hindi participant vowel pair discrimination accuracy was low but above chance for vowel pairs within the same category for both the oral and the nasal ends of the spectrum. English listeners perceived the oral–nasal vowel distinctions continuously. They correctly discriminated vowel pairs within the oral category and in some of the cross-category region at similar levels of accuracy. But vowel pair stimuli on the nasal end of the spectrum received comparatively poor discrimination by English speakers. As expected, the results showed that discrimination between [ba]-[bã] was more categorical for Hindi participants and more continuous for American English listeners.

Structure of this Dissertation

The remaining chapters of this dissertation are organized in the following manner. Chapter 3 covers the methodology of the production and perception experiments in the current study. Chapter 4 reports on the results and statistical analyses of both experiments. Chapter 5 brings a discussion of the results, pedagogical implications, and conclusions.

CHAPTER 3

METHODOLOGY

This chapter covers the methods used to collect data for the production experiment and the accent rating experiment. Additional information regarding tasks, procedure, and informed consent forms are included in the appendices.

Research Design and Hypotheses

There are three main hypotheses motivating this study:

1. Nasal vowels produced by NSs will be longer than oral vowels produced by the same speakers due to partial or full vocalization of the nasal coda and the nucleation of the nasal feature (Medeiros, 2012).
    - Are nasal vowels longer than oral vowels for native Brazilian Portuguese speakers?
    - How does duration of oral and nasal vowels pattern for the two nonnative BP speaker groups?
2. Acoustic features, such as vowel quality and duration, of BP vowels produced by NSs and NNSs will be different, but some differences will be more significant than others.
    - Because of differences in speech rhythm (Shaiman, 2001; White & Mattys, 2007a; White & Mattys 2007b) between English and BP as well as word-final lengthening of English syllables (Culter & Butterfield, 1990), English L1 speakers of BP will lengthen word-final oral vowels more than NSs of BP. The difference between duration in native and nonnative production will be

more apparent for high vowels /i/ and /u/ than for the low vowel /a/ because low vowels and nasal vowels are intrinsically longer. Are word-final high vowels /i/ and /u/ produced by the two nonnative BP speaker groups longer than those produced by the native BP speaker group?

- Are there any significant differences among speaker groups for the two measures of vowel quality, height and advancement?
- The production of a nasal coda will be frequent and have more consonantal characteristics in the production of BP nasal vowels among NNSs. NSs will produce shorter nasal codas with more gradual spectral movement associated with glides rather than more abrupt movement associated with nasal consonants (Medeiros, 2012; Stevens, 2000).
- Is the difference in intensity between the vowel and nasal murmur smaller for native BP speakers?
- Do native BP speakers produce relatively shorter nasal murmurs when compared to the two nonnative BP speaker groups?

3. NSs of BP will perceive the accentedness level of L2 speakers that correlate with each L2 speaker's level of experience with BP.
    - How well do raters agree with one another in the task of assigning nativelikeness scores (inter-rater reliability)?
    - Do nativelikeness ratings correlate with level of experience with BP?
    - Do tokens with nasal vowels receive lower nativelikeness scores?
    - Do low-frequency tokens receive lower nativelikeness scores?

- How are accent ratings related to the acoustic characteristics of the speech produced by all participants?

Speakers in the Production Experiment

There were 34 participants in the production study: 12 NSs of BP and 22 NNSs enrolled or recently enrolled in university-level Portuguese as a foreign language classes. The recording of one NS participant was not usable due to poor quality of the recording, resulting in 11 NSs in the analysis. The 22 NNSs were divided into two groups based on their level of experience in Portuguese as a foreign language. Participants assigned to the inexperienced group had one to three semesters of college-level Portuguese classes, and participants assigned to the experienced group had four or more semesters of college-level Portuguese classes. One exception to the four-semester minimum in the experienced group was one participant who was enrolled in an upper-level (fourth year) Portuguese class at the time. Although he was only in his third semester Portuguese classes, his level of proficiency fit within the experienced group better than the inexperienced group; therefore, a decision was made prior to data analysis that he should be included in the experienced NNS group.

The composition of the three groups of participants was as follows: (A) 11 native BP speakers (5 male and 6 female); (B) 13 inexperienced L2 speakers (3 male and 10 female); (C) nine experienced L2 speakers (5 male and 4 female). The latter two groups were made up of students enrolled, or recently enrolled in, university-level Portuguese classes. NSs of BP included in this study were all university students or visiting scholars between the ages of 24-47 years at the time of the experiment. They were from four regions of Brazil: two from the South, two from the Northeast, five from the Southeast, and one from the Midwest (*Centro-oeste* in Portuguese) who also had lived in the Southeast for about 15 years. Table 3.1 below provides a more detailed account of the native-speaker participants based on a demographic questionnaire they completed before beginning the experiment.

Table 3.1 Native speaker participant demographics.

Participant	**Age**	**Gender**	**Region**	**Other languages in addition to Portuguese/English**
1	27	Female	Southeast	Spanish (basic)
2	24	Male	Southeast	Spanish (fluent), French (basic), Italian (basic)
3	28	Female	Southeast	Spanish (basic), French (basic)
4	34	Female	Southeast	Spanish (advanced)
5	27	Male	Southeast	Spanish (advanced), French (basic)
6	30	Female	Northeast	–
7	30	Female	Northeast	French (basic)
8	47	Male	Midwest	French (basic)
9	32	Female	South	Spanish (intermediate)
10	30	Male	South	Spanish (intermediate)
11	29	Male	Southeast	–

The 22 L2 speaker participants were university students between the ages of 18-33 years when the experiment was conducted. No participant had begun learning Portuguese before 18 years of age, but many participants had experience with other languages. Thirteen of the nonnative participants had not visited a Portuguese-speaking country. Eight participants had spent 2-10 weeks in a Portuguese-speaking country (Brazil or Portugal), and one participant had

lived in Brazil for 19 months. Table 3.2 below provides a more detailed account of the L2 speaker participants based on a demographic questionnaire administered before beginning the experiment.

Table 3.2 Nonnative speaker participant demographics.

Participant	**Age**	**Gender**	**Level**	**Current semester of Portuguese**	**Languages besides English/Portuguese**
12	20	Female	Inexperienced	3rd semester	Spanish (in high school)
13	23	Female	Inexperienced	1st semester	Spanish (bilingual), Italian (fluent), French (basic)
14	21	Male	Inexperienced	1st semester	Spanish (advanced), Arabic (intermediate)
15	19	Female	Inexperienced	1st semester	Spanish (bilingual)
16	20	Female	Inexperienced	3rd semester	Spanish (in high school), French (in high school), German (in high school)
17	20	Female	Inexperienced	2nd semester	Spanish (bilingual)
18	19	Female	Inexperienced	3rd semester	Spanish (in high school)
19	18	Female	Inexperienced	1st semester	Spanish (advanced)
20	32	Male	Inexperienced	1st semester	Spanish (bilingual), German (basic)
21	20	Female	Inexperienced	1st semester	Spanish (intermediate)
22	21	Female	Inexperienced	1st semester	Spanish (advanced)
23	19	Female	Inexperienced	3rd semester	Spanish (bilingual), French (basic)
24	29	Male	Inexperienced	2nd semester	Spanish (fluent)
25	20	Female	Experienced	5th semester	
26	20	Male	Experienced	4th semester	Spanish (bilingual)
27	27	Female	Experienced	5th semester	Spanish (advanced)

28	20	Male	Experienced	3rd semester (in upper-level Portuguese)	Spanish (fluent), Italian (conversational), German (conversational)
29	24	Male	Experienced	6th semester	Spanish (fluent)
30	20	Female	Experienced	5th semester	Spanish (advanced), French (basic)
31	19	Male	Experienced	4th semester	Spanish (bilingual)
32	24	Male	Experienced	4th semester	
33	33	Female	Experienced	20th semester	Spanish, French, Italian, Galician, Catalan (Intermediate to native-like)

Tokens of the Production Experiment

The tokens used in the production experiment were designed to elicit specific BP oral and nasal vowels. There were 12 tokens with target vowel sounds and 7 tokens designed to be distractors. Each token was disyllabic and contained a vowel being investigated in a syllable bearing primary stress since acoustic measures are more reliable and easier to obtain for vowels in stressed syllables. Tokens with target vowel sounds were divided evenly between words with penultimate stress and ultimate stress. Each vowel in each position was analyzed separately so that any acoustic influence due to word position could be detected.

In a pilot study, phrases of 11 or more syllables were shown to be difficult for inexperienced NNSs of BP to reproduce in an elicited imitation task. To ensure the best and most consistent reproduction of tokens by all nonnative BP speakers, tokens were presented in carrier phrases with each phrase having a total of seven syllables. The tokens appeared in syllables three and four, that is each token was preceded by two syllables ['CV.CV] and followed by three syllables [CV(C)# 'CV.CV(C)]. The use of a carrier phrases is common in acoustic phonetic studies concerned with vowel length, amplitude and other measures such as formant frequencies (Lima-Gregio et al., 2010; Oh, 2008; Shaiman, 2001). Carrier phrases and carefully selected tokens allowed for greater control of the environment surrounding each vowel, such as consonantal environment, word length, prosody at the word level and phrase level, and placement of the token within the phrase to minimize effects caused by environmental factors such as coarticulatory assimilation and prosodic differences that could affect the vowel quality, length, and amplitude (van Santen, 1992).

Two carrier phrases were used, with the second carrier phase being repeated two times. Only the tokens in the second and third repetitions (same carrier phrase) were considered in the acoustic analysis. A set of carrier phrases with a token containing the target vowel /a/ in penultimate stress appears in (6). The target vowel is surrounded by voiceless stops.

6. Token: cata ['ka.tɐ] ‘to gather’ [3RD SING. PRESENT]

a. Diga cata, por favor.

‘Say gather, please.’

b. Diga cata de novo.

‘Say gather again.’ (repeated 2 times)

Another sample from the elicited imitation protocol appears in (7).

7. Token: patim [pa.ˈt͡ʃĩ] ‘skate(s)’

a. Diga patim, por favor.

‘Say skate please.’

b. Diga patim de novo.

‘Say skate again.’ (repeated 2 times)

A voiceless alveolar stop before the high front vowels [i] and [ĩ] does not occur in BP, except for in some dialects of Northeastern Brazil, and none of the NSs in this study were from this dialectal region. Therefore, all of the tokens with high front vowels that were preceded by an orthographic <t> were pronounced as a voiceless alveolo-palatal affricate [t͡ʃ]. Since the token in 6 carries ultimate stress, the target nasal vowel [ĩ] in the second and third repetitions were followed by a voiced alveolo-palatal affricate in the word ‘de’ [d͡ʒɪ] or a voiced stop [de] depending on regional dialect of the speaker. Only two NSs produced the alternate pronunciation with the voiced alveolar stop [d] and mid-close front vowel [e]. The form used as stimuli for the elicited imitation, as well as the most frequent pronunciation, was the voiced alveolo-palatal affricate [d͡ʒ] and the high front vowel [ɪ].

Tokens were carefully selected to control the environment around the target vowels as much as possible. In token selection, ease of sound file segmentation and subsequent acoustic analysis were considered as well. Ideally all of the tokens would have only voiceless stop consonants, but because of typical phonological processes that occur in BP, the consonants in tokens were a combination of voiceless stops and voiceless affricates. Tokens with penultimate stress contained vowels followed by voiceless stops, and tokens with ultimate stress contained vowels followed by the voiced alveolo-palatal affricate [d͡ʒ]. Appendix A contains a complete list of tokens with phonetic transcriptions and English translations.

Procedure of the Production Experiment

All participants signed the consent forms and filled out a brief demographic survey before beginning the experimental tasks. The demographic questionnaire is available in Appendix B and sample consent forms are in Appendix C. Participants were given code numbers, which were written on the demographic questionnaire and were used as part of the naming protocol for the sound files. To ensure participant confidentiality, only code numbers were used throughout the experimental procedures and analyses.

NS participants were recorded reading BP carrier phrases with tokens. Each participant received a different randomized list of sentences. Participants were instructed to read the sentences at a normal speaking rate and to avoid pausing within each sentence unless a punctuation mark was present. I told participants that if they thought they had made a mistake during the recording, they should go back to the beginning of the sentence in which they misspoke or stuttered.

All recordings took place in a sound attenuated booth in a phonetics laboratory at the University of Georgia. A unidirectional (cardioid) table microphone (Shur SM58) was used to record the participants' utterances. The recordings resulting from the first two native-speaker participants (one male and one female, both from the Southeast of Brazil) were used for the elicited imitation task in which the two L2 groups participated. Fifty-three percent of the stimuli for the elicited imitation task were from the male speaker and 47 percent from the female speaker. The elicited imitation task consisted of 19 sound (.wav) files which were played using the iTunes "shuffle" setting so that each participant would hear each token in a blocked random order, and each participant performed the task in a new random order. Each sound file (block) had three repetitions of the same token in the carrier phrases presented in examples 5 and 6 above. Three seconds of silence were added after each repetition allowing enough time for the sentence to be repeated in the elicited imitation task.

NNSs were recorded doing an elicited imitation task of repeating randomized sentences previously recorded by two of the NS participants (one male and one female). Snow and Hoefnagel-Höhle (1977) and Markham (1997) are two examples of previous studies that used a direct repetition technique. This technique was selected for this study because the alternative elicitation methods of reading or spontaneous speech present more drawbacks than advantages for less experienced L2 speakers. In a reading task, varying reading abilities may interfere with pronunciation. Additionally, in spontaneous speech, morphosyntactic or lexical errors could interfere with the NNSs' production (Patkowski, 1990; Piske; Mackay & Flege, 2001). All NNSs were recorded in the same sound attenuated booth as the NSs. The participants heard the recordings through a circumaural headphone (Semmheiser HD-280) and repeated what he or she heard through a unidirectional (cardioid) table microphone (Shur SM58).

Research Design of the Accent Rating Experiment

In the second phase of this study, 20 NSs of BP listened to and did accent ratings on a series of randomized phrases. The second repetition of each token from the production experiment was used in the accent rating experiment. Each phrase was approximately two seconds long. To minimize variations in volume among the various speakers and phrases, a volume normalization Praat script (Xu, 2002) was performed on all of the sound files used in the accent rating task. This script is designed to automatically adjust peak amplitude to maximum.

Listeners in the Accent Rating Experiment

There were 20 participants (11 male, 9 female) in the accent rating experiment. No participant reported having been diagnosed with a hearing impairment. Ages ranged from 19 to 43 years, with the mean age being 26 years. An effort was made to minimize the chances that the participants would recognize any of the voices in the stimuli. All participants were Brazilian university students not enrolled in the Department of Romance Languages, the department from which most of the participants in the production experiment came.

Tokens of the Accent Rating Experiment

Two versions of the accent rating task were used. Twelve participants did version A, and eight participants did version B. Tokens were divided into Token Group 1 and Token Group 2.

Token Group 1 consisted of three tokens with oral vowels (two with ultimate stress and one with penultimate stress) and three tokens with nasal vowels (one with ultimate stress and two with penultimate stress). Conversely, Token Group 2 consisted of three tokens with oral vowels (one with ultimate stress and two with penultimate stress and three tokens with nasal vowels (two the ultimate stress and two with penultimate stress). See Table 3.3 below for a list of the tokens divided into Token Group 1 and Token Group 2. Version A of the accent rating task had tokens from all 22 speakers: 11 speakers uttering phrases from Token Group 1 and the other 11 speakers uttering phrases from Token Group 2. Version B of the accent rating task was made up of the remaining tokens, and also included tokens from all 22 speakers. Each version had 192 experiment tokens resulting in a total of 384 tokens having received accent ratings.

Table 3.3 Tokens used in accent rating task divided into token groups.

Token Group 1			Token Group 2		
Stress position	**Vowel type**	**Token**	**Stress position**	**Vowel type**	**Token**
penult	oral	*cata*	ultimate	nasal	*cristã*
ultimate	oral	*está*	penult	oral	*tico*
penult	nasal	*canta*	ultimate	oral	*vesti*
ultimate	oral	*tutu*	penult	nasal	*tinto*
penult	nasal	*tunco*	ultimate	nasal	*patim*
ultimate	nasal	*atum*	penult	oral	*tuco*

Procedure of the Accent Rating Experiment

Before beginning the accent rating task, each participant signed a consent form and answered a confidential written demographic questionnaire. See Appendix B for demographic questionnaire and Appendix C for sample consent forms. The researcher explained the task orally and presented a sheet of paper with written instructions as well. The instructions were printed in English on one side of the sheet of paper and in Portuguese on the other side. A copy of the written instructions appears in Appendix D. Participants were informed that some of the speakers in the recordings were NSs of Portuguese and others were NNSs. The accent rating task was performed in quiet settings, either in the homes of participants or at locations on campus as requested by each participant.

Once participants understood the written instructions, they were fitted with circumaural headphones and a laptop with the experiment already loaded and ready to begin. Participants had a volume dial on the headphone and were instructed to adjust the volume during the practice session. Using a free display software program DMDX (Forster & Forster, 2002), each participant heard 200 individual stimuli consisting of a token in a carrier phrase. At the beginning of each experiment, participants were asked to listen to and rate eight practice phrases, which were presented in random order with a pause of one to two seconds in which the rater was instructed to type a number between 1 and 8, 1 meaning the phrase sounded very nonnativelike and 8 meaning the phrase sounded very nativelike. Once participants were ready to begin the actual experiment, they were instructed to hit the spacebar on the laptop. Each of the 192 experiment items were presented in random order with a pause of one to two seconds. The raters were instructed to continue the same rating procedure used in the practice session. The rating task lasted about 20 minutes, including the time needed to fill out the forms and go over the instructions.

The rating values were recorded by DMDX into a text file and imported to a spreadsheet for the purpose of data and statistical analysis.

CHAPTER 4

ANALYSIS AND DISCUSSION OF RESULTS

This chapter presents phonetic and statistical analyses of the acoustic data from the production experiment as well as a statistical analysis of the accent rating experiment. The following are the research questions discussed in the analyses presented in this chapter, repeated here in an abridged form from Chapter 3.

1. Nasal vowels produced by NSs will be longer than oral vowels produced by the same speakers due to partial or full vocalization of the nasal coda and the nucleation of the nasal feature.
    - Are nasal vowels longer than oral vowels for Brazilian Portuguese NSs?
    - How does duration of oral and nasal vowels pattern for the two BP NNS groups?
2. Acoustic features, such as vowel quality and duration, of BP vowels produced by NSs and NNSs will be different, but some differences will be more significant than others.
    - Are word-final high vowels /i/ and /u/ produced by the two NNS groups longer than those produced by the BP NS group?
    - Are there any significant differences among speaker groups for the two measures of vowel quality, height and advancement?
    - The production of a nasal coda will be frequent and have more consonantal characteristics in the production of BP nasal vowels among NNSs. Therefore,

    is the transition between vowel and nasal murmur characterized by more gradual spectral movement for native BP speakers?
    - Is the difference in intensity between the vowel and nasal murmur smaller for native BP speakers?
    - Do BP NSs produce relatively shorter nasal murmurs when compared to the two NNS groups?

3. NSs of BP will perceive the accentedness level of L2 speakers that correlate with each L2 speaker's level of experience with BP.
    a. How well do raters agree with one another in the task of assigning nativelikeness scores (inter-rater reliability)?
        - Do nativelikeness ratings correlate with level of experienced with BP?
        - Do tokens with nasal vowels receive lower nativelikeness scores?
        - Do low-frequency tokens receive lower nativelikeness scores?
        - How are accent ratings related to the acoustic characteristics of the speech produced by all participants?

Analysis of Acoustic Data

The recordings of the native-speaker and L2 speaker participants were analyzed using Praat, a free computer software program used in the analysis of speech sounds (Boersma & Weenink, 2012). The beginning and end of each vowel segment were delimited and labeled manually taking into consideration both the waveform and spectrogram when deciding where to place boundaries. In other words, boundaries were placed at the nearest zero-crossing on the waveform that agreed with the beginning or end of the vowel formants in the spectrogram.

How Acoustic Measures Were Taken

Since speech prosody is an important factor in accented speech, duration and intensity of each target vowel were measured (Huang & Jun, 2011; Kolly & Dellwo, 2014; Morrison, 2008; Trovimovich & Baker, 2006). Vowel quality is another significant factor in accented speech (Morrison, 2008; Piske, et al., 2002), which is measured with the frequency bands commonly labeled as F_1, F_2, and F_3.

Acoustic measures were recorded for the target vowels [i a u ĩ ẽ ũ] produced in the second and third repetitions in the recordings of NS and NNS participants. A Praat script (Hirst, 2012) was used to take measurements of the acoustic signal. Four of the five numeric values (variables) were derived from the acoustic signal at the temporal mid-point of each target vowel. The extracted variables were duration (in ms.) of segment, mean intensity (in decibels), F_1 frequency in Hz (inversely related to tongue height), F_2 frequency in Hz (indicating tongue backness), and F_3 frequency in Hz (lip rounding tends to lower this value).

Dataset Used in Acoustic Analysis

The target vowel in 24 tokens for each of the 33 speakers was analyzed resulting in 792 (24x33) tokens. The mean values of the two repetitions of each token produced by each speaker were calculated. After averages were calculated, there were 396 sets of numeric variables. For each speaker there were 60 numeric values (five measurements for each of 12 vowels) derived from the acoustic signal plus two categorical labels, gender and level, resulting in 62 variables per speaker. The 62 numeric values consisted of duration plus the remaining four values (intensity, F_1, F_2, and F_3) obtained from the temporal mid-point of each target vowel in stressed position of the disyllabic words. That is, in tokens containing target vowels in which primary stress falls in penultimate position /'CV.CV/, the first vowel was analyzed, and in tokens with ultimate primary stress /CV.ˈCV/, the second vowel (which is also a vowel in word-final position) was analyzed. The words with penultimate stress were *cata* ['ka.tɐ] ‘to gather’, *canta* ['kɐ̃^{n}.tɐ] ‘to sing (3RD SING. PRESENT)’, *tico* ['ʧi.kʊ] ‘whit’, *tinto* ['ʧĩ^{n}.tʊ] ‘tinted’, *tuco* ['tu.kʊ] ‘worker who removes the earth, in the conservation of the railway bed’, and *tunco* ['tũ^{ŋ}.kʊ] ‘colloquialism for kiss or clicking sound of tongue’. The words with ultimate stress were *está* [es.'ta] ~ [eʃ.'ta] ‘to be (3RD SING. PRESENT)’, cristã [kɾis.'tɐ̃] ~ [kɾiʃ.'tɐ̃] ‘Christian (FEM.)’, *vesti* [veʃ.'ʧi] ~ [ves.'ʧi] ‘to dress (1ST SING. PRETERIT)’, patim [pa.'ʧĩ], ‘skate’, *tutu* [tu.'tu] ‘tutu’, and atum [a.'tũ] ‘tuna’.

A Closer Look at Nasal Vowels

After a preliminary examination of the data, adjustments were made in order to answer some research questions regarding nasal vowels and nasal murmurs stated at the beginning of this chapter. Nasal vowels were divided into two segments, with the first part consisting of steady and strong vowel formants and the second part being characterized by weaker or missing vowel formants but still having evidence of voicing. The first part was identified as the nasal vowel and the second part as the nasal murmur. The transition between the vowel portion and the nasal murmur portion was sometimes abrupt and easy to find and other times the transition was gradual or almost nonexistent, especially for NSs.

To answer the question regarding how the trajectory and shape of nasal vowels differ among the nonnative and NS groups, we looked at waveforms and spectrograms of individual speakers. Since there is a great deal of variation among individuals as to how the waveform and spectrogram look, only some general observations are included here. The formant transitions and waveform differences between vowel and nasal murmur were easiest to see on the spectrogram for the [ɐ̃]. Sometimes the formant transitions were relatively easy to see for [ĩ], but the waveform differences were unpredictable. Often the formant transitions for [ũ] were not detectible and the waveform differences were unpredictable. Figure 4.1 is a screenshot of a spectrogram and waveform for a female NS saying “cristã” [kris.ˈtã] and Figure 4.2 is the same for a female inexperienced L2 speaker, both from this study. The [ɐ̃] of the NS has an almost undetectable nasal murmur with steady formant frequencies and intensity throughout most of the trajectory of the vowel. At the end of the nasal vowel segment, there is an increase in frequency of F_2. The waveform also seems to indicate only one segment with no abrupt breaks leading us to conclude that there is no nasal coda or nasal murmur in this example. The [ɐ̃] of the inexperienced speaker has two distinct segments, suggesting a nasal coda [n] rather than a nasal murmur. Regarding the vowel formants, F_2 and F_3 show abrupt movement and weakening at the same point at which the waveform also weakens suddenly. From the examples in Figures 4.1 and 4.2, we can conclude that sometimes there are clear differences among waveform and spectrograms of NNSs and NSs. However, generally these differences are unpredictable. Of the three nasal vowels in this study, [ũ] was the least predictable with the subtlest spectral changes.

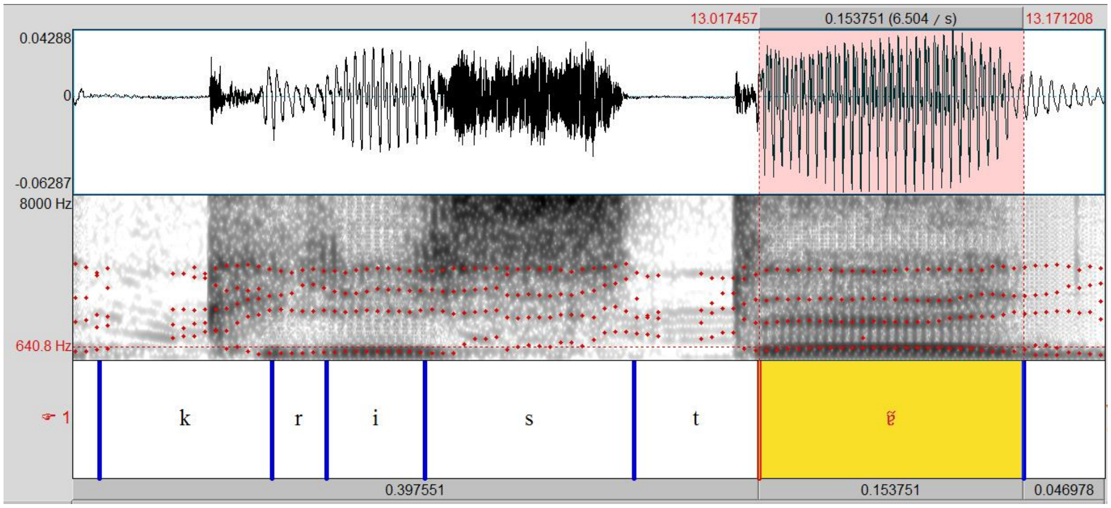

Figure 4.1 Waveform and spectrogram of “cristã” by a female native speaker.

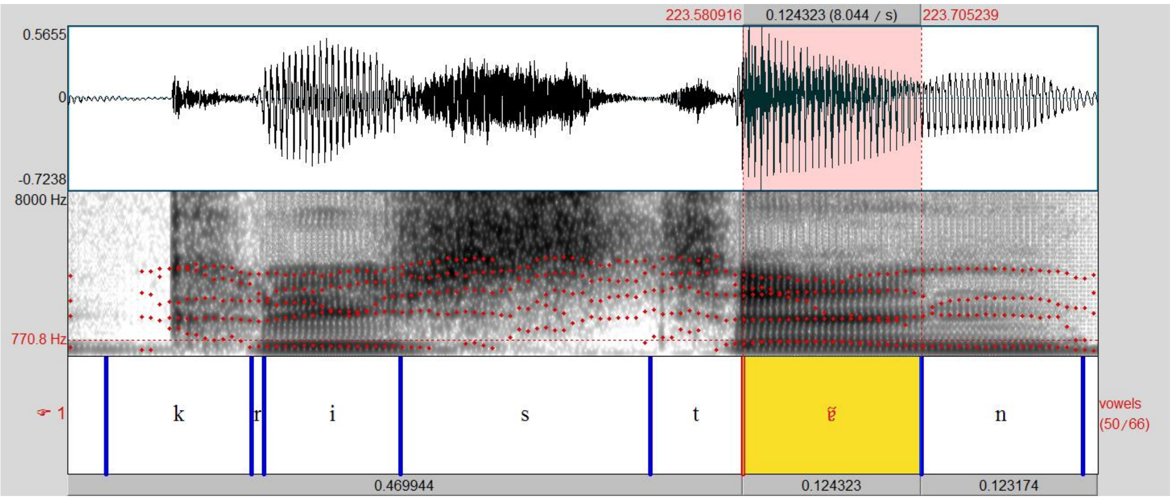

Figure 4.2 Waveform and spectrogram of “cristã” by a female inexperienced L2 speaker.

To ensure greater consistency in dividing the nasal vowel from nasal murmurs, every instance of a nasal vowel was examined during at least two different sittings. When formant movement occurred in more than one place during a nasal vowel, the place in which both formant movement and formant weakening occurred simultaneously was used as the boundary. In spite of some difficulties in separating the nasal vowel from the nasal murmur, the duration of each part was measured, and then the sum of the duration of both parts was divided by the nasal murmur duration to get a ratio. Additionally, the difference in intensity in the nasal vowel and the nasal murmur was calculated for each nasal vowel. Since intensity measures are sensitive to how loudly a person speaks and the distance between the speaker and the microphone, raw intensity values for both oral and nasal vowels were not used in the statistical analysis.

Vowel Quality Comparisons Among Speaker Groups

To understand how vowel quality attributes vary among inexperienced L2 speakers, experienced L2 speakers, and NSs, plots of the group mean values of F_1 and F_2 in Hz for each

BP oral vowel are presented in Figures 4.3 and 4.4. F_1 values correlate (inversely) with tongue height and F_2 values correlate (inversely) with the backness of the tongue of vowel articulation.

In Figure 4.3, mean formant values of oral vowels produced by male speakers are displayed divided into three speaker groups: inexperienced L2 (*n*=3), experienced L2 (*n*=5), and NSs (*n*=5). The orange circles represent mean formant values for inexperienced L2 speakers, the blue squares represent mean formant values for experienced L2 speakers, and dark green triangles represent mean formant values for NSs. Ellipses show one standard deviation around each point. Male experienced L2 speakers pronounced an /i/ that is slightly more fronted and lower than the male speakers in the inexperienced L2 and native-speaker groups. Counterintuitively, the inexperienced L2 group and the NS group have very similar means for /i/. The mean formant values for /a/ are similar for the three groups of male speakers, with the lowest /a/ mean being the native-speaker group and the highest being the inexperienced L2 group. Again, for /u/ the male inexperienced L2 group and the native-speakers' mean formant values are practically the same. Only the experienced L2 group shows slightly fronted and lower mean formant values for /u/.

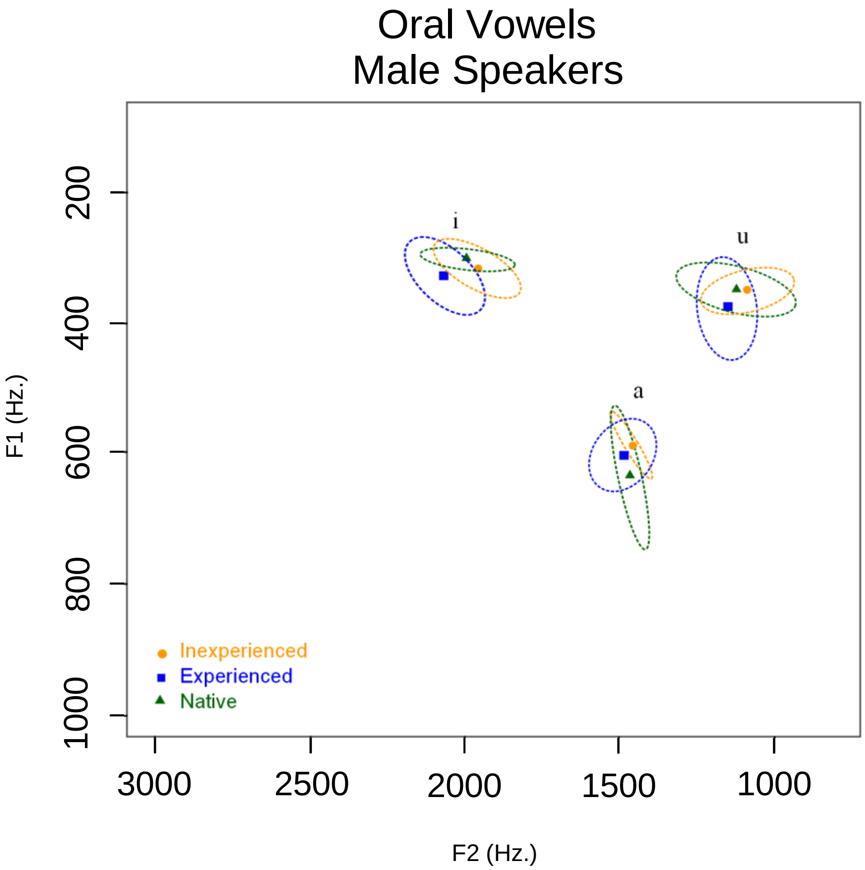

Figure 4.3 Oral vowels by male speakers. Points indicate mean for each group; ellipses show one standard deviation.

Figure 4.4 represents mean formant values produced by female speakers in the same three speaker groups: inexperienced L2 speakers (*n*=10), experienced L2 speakers (*n*=4), and NSs (*n*=6). For /i/ the mean formant values do not show much variation among the three groups. The native-speaker group produced /a/ with mean formant values that indicate a lower and more back articulation than the other two groups, with the inexperienced L2 group being the most centralized. The ellipses of the inexperienced and experienced L2 groups show greater dispersion for F_1 (vowel height) than the NS group. The inexperienced and experienced L2 groups produced /u/ with mean formant values that indicate a more fronted and slightly lower articulation than the

NS group. Overall, the /i/ formant values are the most similar among the three groups of speakers regardless of speaker gender. The greatest variation among speaker groups occurs for the formant values of /a/, and there is some fronting of /u/ by non-native speakers evidenced by F_2 values. Both differences observed for /a/ and /u/ are not surprising results when the vowel inventory of American English, the L1 of most L2 participants, is taken into consideration (Labov, Ash, & Boberg, 2005).

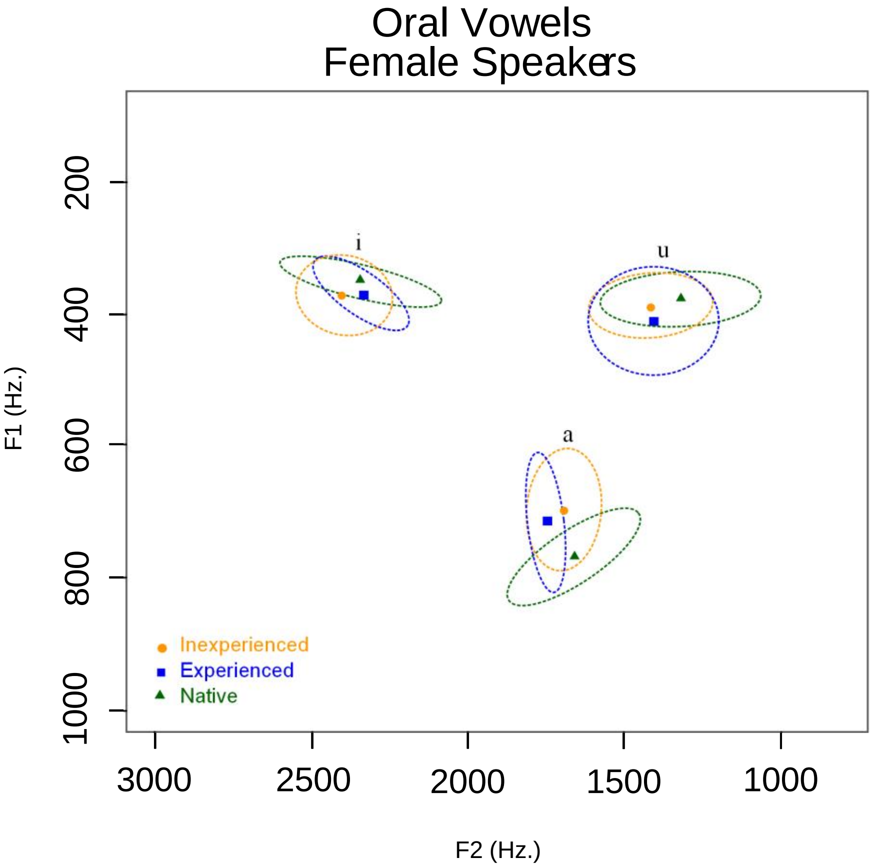

Figure 4.4 Oral vowels by female speakers. Points indicate mean for each group; ellipses show one standard deviation.

Mean formant values for nasal vowels produced by male speakers are displayed in Figure 4.5. As with the [i] in Figure 4.4, the values for [ĩ] seem counterintuitive in that the mean value for inexperienced L2 speakers suggests that their pronunciation of this vowel was more like the pronunciation of the NS group than the experienced L2 group. The ellipses that represent one standard deviation reveal that there was more variation in the production of [ĩ] within the experienced L2 group than within the other two groups. The male NS group produced [ɐ̃] with the mean F_1 value indicating a higher articulation. The experienced L2 group had a mean F_1 value indicating a lower articulation for [ɐ̃] and the inexperienced L2 group produced [ɐ̃] with a similar mean F_1 value to the NSs, indicating similarity in height. Both L2 groups produced [ɐ̃] farther back than the NSs. The mean F_1 values for /ũ/ indicate that the NS group produced [ũ] with the highest articulation and the inexperienced L2 group has the lowest [ũ], with the experienced L2 group falling in between the other two groups.

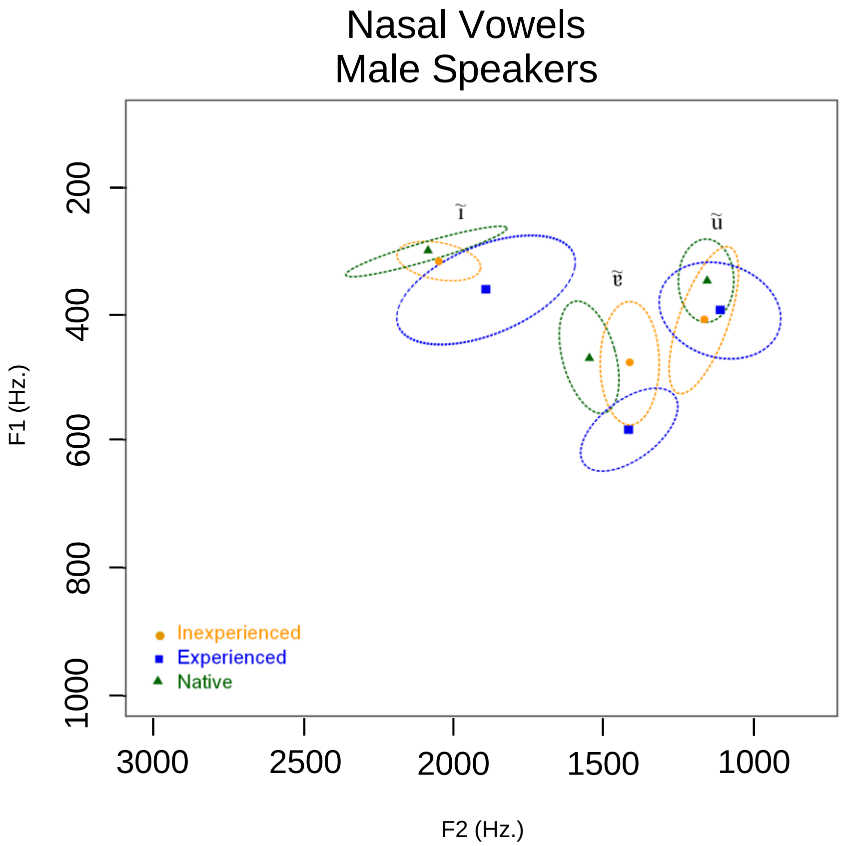

Figure 4.5 Nasal vowels by male speakers. Points indicate mean for each group; ellipses show one standard deviation.

Figure 4.6 displays results for nasal vowels produced by female speakers. The high vowels, [ĩ] and [ũ], had similar patterns with these vowels being farther back for female NSs than for the two L2 groups. The most fronted [ũ] was produced by the inexperienced L2 group, while on the other hand, the most fronted [ĩ] was produced by the experienced L2 group. As was true for the male NS group, the female NSs produced the highest [ɛ̃], but unlike the male speaker groups, the inexperienced L2 group had the lowest [ɛ̃] of the three groups and the experienced group fell between the other two groups.

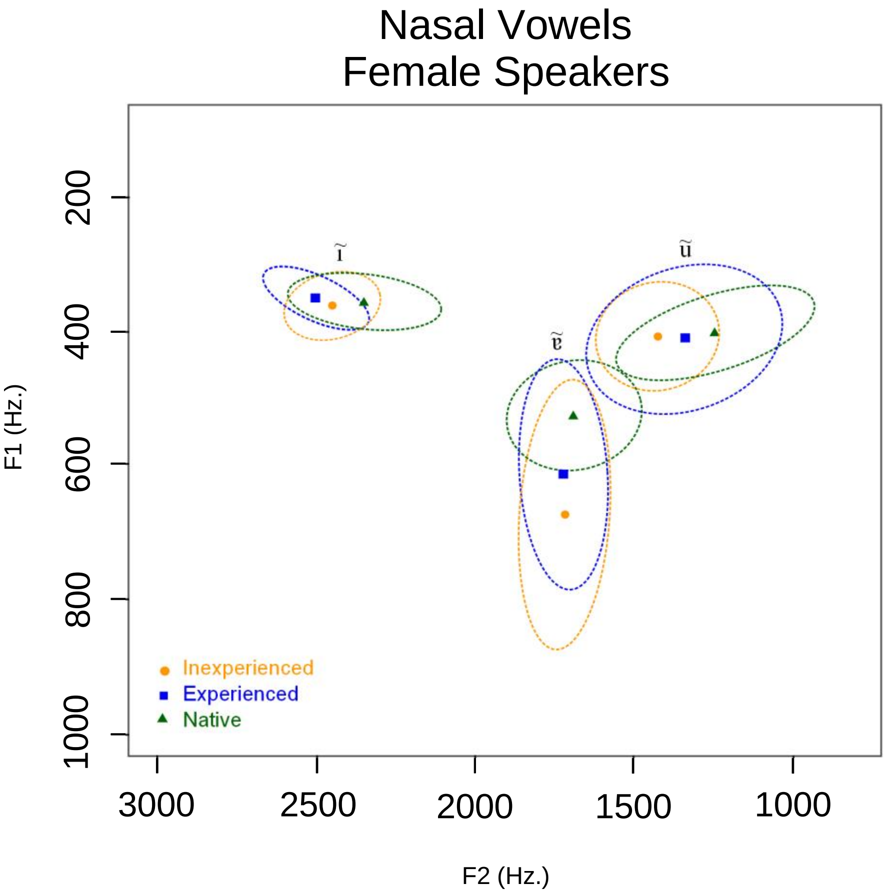

Figure 4.6 Nasal vowels by female speakers. Points indicate mean for each group; ellipses show one standard deviation.

Normalized Vowel Quality Comparisons

The vowel comparisons above were separated according to speaker gender since the vocal tract of female speakers is typically shorter than that of male speakers, resulting in higher frequency formants in speech produced by females. When comparing vowel production of mixed gender groups, a common practice in phonetics is to use vowel normalization. The goal of vowel normalization is to factor out “physical (i.e., acoustic) differences in vowel production resulting from anatomical differences between speakers” (Watts, Fabricius & Kendall, 2001:111). Female adults produce speech signals with an overall higher frequency than male adults, and children’s speech signals are even higher than those of female adults. A listener is thought to unconsciously compensate for formant frequency differences resulting from variation in vocal tract length. In spite of the variable acoustic signal, members of the same speech community are able to understand one another and distinguish one vowel phoneme from another. One way to normalize acoustic data is to use algorithms to convert linear measurements in Hz units into their psychoperceptual equivalents. One of these algorithms used for vowel normalization converts Hz into a nonlinear scale of Bark units which take into account human pitch perception. At lower frequencies, humans can differentiate simultaneous signals that are close in frequency and perceive these as separate tones. At higher frequencies, humans perceive simultaneous signals as a single tone if they are close in frequency (Reetz & Jongman, 2009). A vowel chart in Bark results in a vowel space at F_2 frequencies and higher that are compressed relative to the vowel space around F_1 frequencies.

In Figures 4.7 and 4.8 male and female speakers were grouped and Hz values converted to Bark, then values were plotted using the Bark Difference Metric (Thomas & Kendall, 2007; Syrdal & Gopal, 1986). In the Bark Difference Metric, Z represents the Bark converted values for F, in which F_1 or height is calculated by subtracting Z_1 from Z_3 (henceforth Z_3-Z_1). Likewise, advancement is modeled by subtracting Z_2 from Z_3 (henceforth Z_3- Z_2). A few advantages of using the Bark Difference Metric, which is a vowel-intrinsic method, are that physiological differences that cause differences in pitch are factored out, and differences in the phonological inventories of dialects or languages are preserved.

Inexperienced L2 speakers (*n*=13) are represented with orange circles and ellipses, experienced L2 speakers (*n*=9) are represented with blue squares and ellipses, and NSs (*n*=11) are represented with dark green triangles and ellipses. Oral vowels are shown in Figure 4.7. The mean value for [i] of the NS group was higher and less fronted than the other groups. The mean value for [a] of the NS group was lower and slightly fronted in comparison to the L2 speaker groups. Both L2 speaker groups produced [u] more fronted than the NS group.

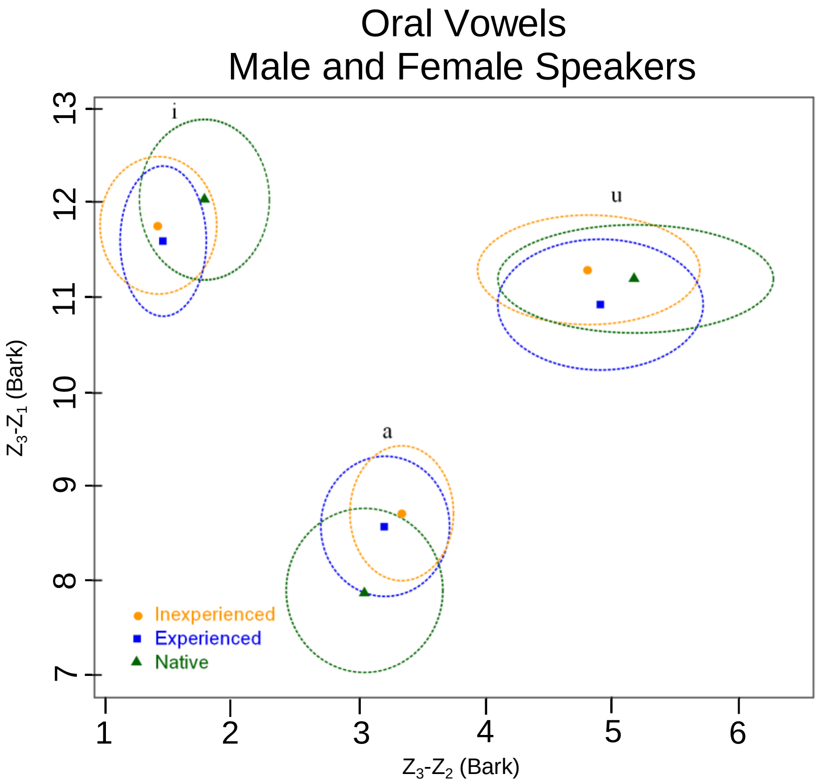

Figure 4.7 Oral vowels in Bark for all participants. Points indicate mean for each group; ellipses show one standard deviation.

Figure 4.8 plots the mean values of all participants for nasal vowels. The mean value of [ĩ] for NSs indicated a higher vowel than the [ĩ] of experienced L2 speakers. The [ĩ] for inexperienced L2 speakers was more fronted and lower than for the NSs. For [ɐ̃], NSs had a much higher articulation than both L2 speaker groups. The [ũ] of inexperienced L2 speakers was more fronted than the experienced L2 and the NS groups.

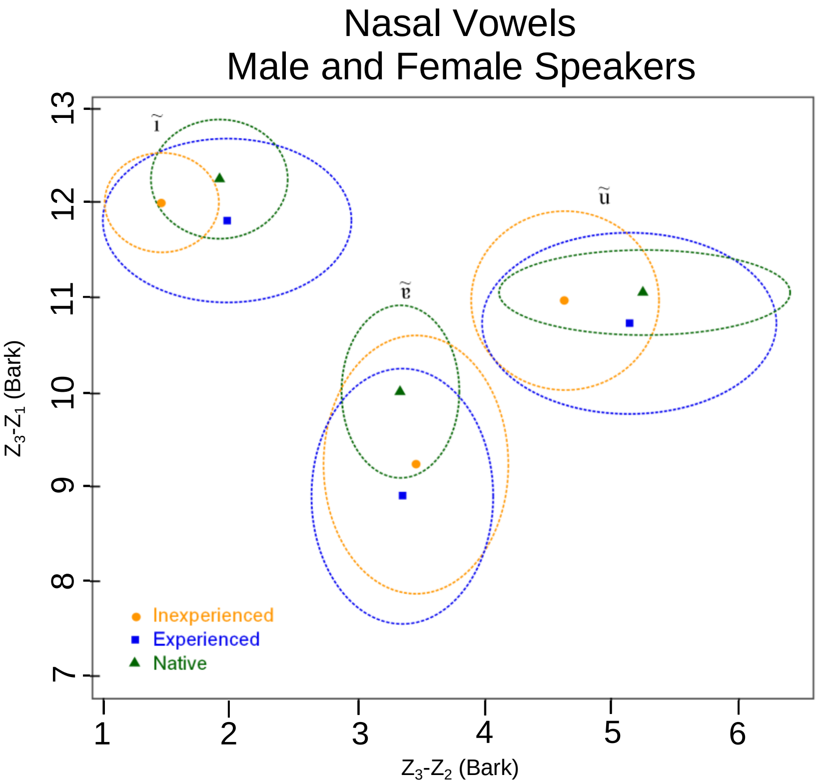

Figure 4.8 Nasal vowels in Bark for all participants. Points indicate mean for each group; ellipses show one standard deviation.

To visualize how vowel height and advancement are affected by nasalization, Figures 4.9, 4.10 and 4.11 plot the means of oral and nasal vowel counterparts of each group: native, experienced L2, and inexperienced L2 speakers, respectively. The most salient difference between the distribution of vowels within the NS vowel space and the vowel space of the other two groups is the difference in the height (Z_3-Z_1) mean values for [ɐ̃]. The significantly different Z_3-Z_1 values indicate a very different acoustic signal for [ɐ̃] than for the [a] produced by NSs. On the other hand, the difference between the L2 speaker Z_3-Z_1 mean values for [ɐ̃] and [a] are not nearly as great, suggesting that L2 speakers have not learned to use vowel height as an important cue to distinguish between the oral and nasal low vowels. Additionally, the standard deviations for the nasal vowels produced by the experienced and inexperienced L2 groups are higher, indicating a greater variety in how nasalization was produced by the L2 speakers.

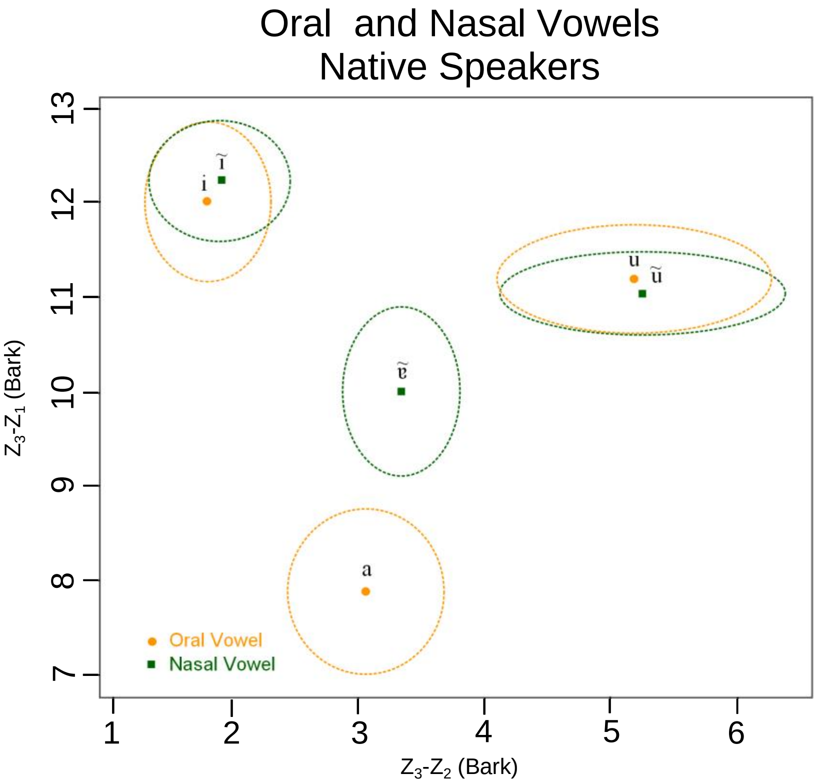

Figure 4.9 Oral and nasal vowels by native speakers.

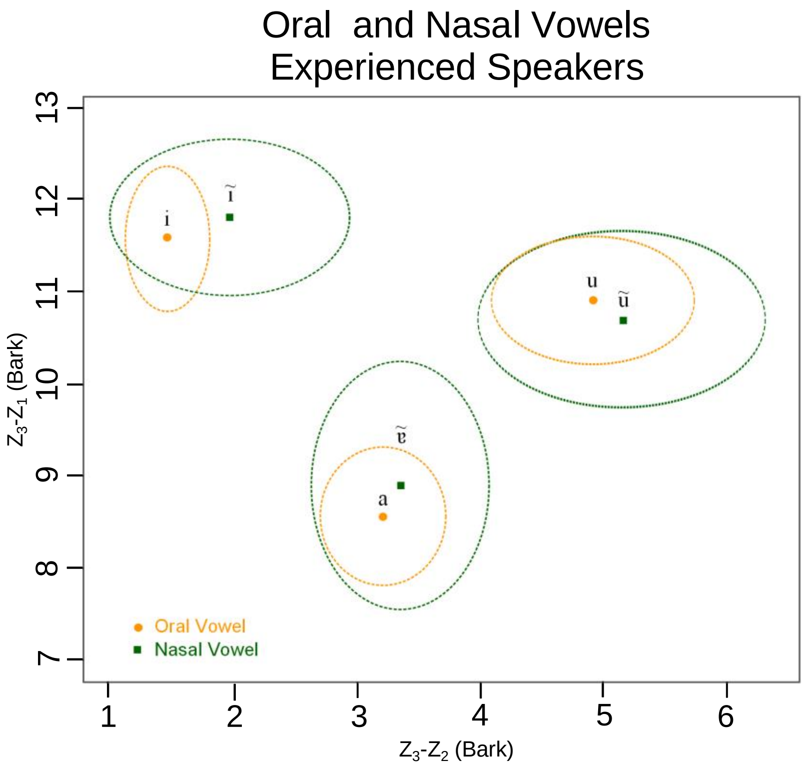

Figure 4.10 Oral and nasal vowels by experienced L2 speakers.

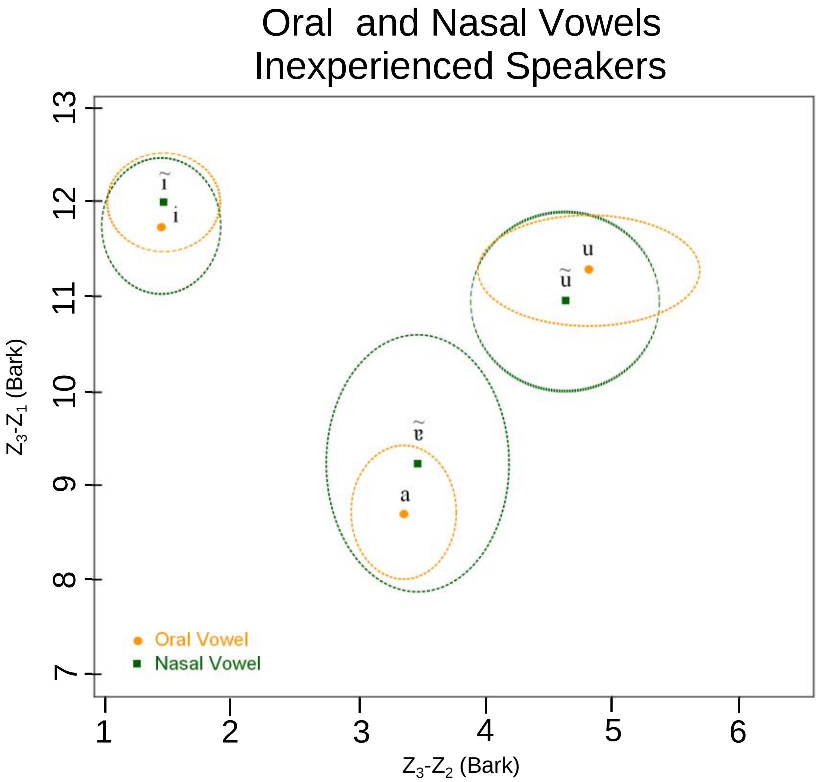

Figure 4.11 Oral and nasal vowels by inexperienced L2 speakers.

Statistical Analysis of Production Experiment

Although some vowel quality differences can be observed in vowel plots, statistical analyses are able to reveal the level of significance of these differences. Through statistical analyses, other measures, such as duration and accent rating are checked for significance. All statistical analyses (except for one noted exception) were performed using SAS 9.3.

Interaction of Duration with Speaker Group, Vowel Identity, and Syllable Position

Because the duration of vowel segments was established to be very important in an acoustic analysis of vowels produced by NSs and NNSs, special attention is given to duration in the statistical analyses (Franks & Barbosa, 2014). Each of the six vowels in syllables bearing primary stress is examined in penultimate and ultimate positions. Table 4.1 provides the mean and standard deviation of the duration in ms. of vowels by group, separately for each of the 12 syllable types. The means are the averages of the duration for each vowel for each group; the standard deviations are a measure of how much those durations are different from one another within a group.

Table 4.1 Mean and standard deviation of duration in ms. by participant group and vowel.

Vowel	Position	Inexperienced Mean	Inexperienced Std Dev	Experienced Mean	Experienced Std Dev	Native Mean	Native Std Dev
[a]	penult	127.73	26.28	118.56	17.24	127.05	26.43
[ɐ̃]	penult	188.50	27.00	177.11	12.44	165.82	39.93
[i]	penult	76.65	15.83	71.78	33.43	80.50	20.63
[ĩ]	penult	187.23	35.55	169.67	35.37	141.91	34.97
[u]	penult	100.27	19.08	85.78	26.94	100.64	32.21
[ũ]	penult	183.85	23.73	156.28	16.15	167.91	42.28
[a]	ultimate	219.92	49.58	174.33	43.43	172.05	44.41
[ɐ̃]	ultimate	219.88	33.06	220.78	36.23	161.55	30.64
[i]	ultimate	213.31	40.86	174.56	28.17	120.00	46.29
[ĩ]	ultimate	197.85	46.49	182.39	38.25	167.53	47.03
[u]	ultimate	183.12	31.49	178.89	50.27	123.32	36.60
[ũ]	ultimate	266.96	49.47	231.17	24.30	196.73	61.51

To analyze the differences in duration among the different groups of speakers, vowels, nasal versus oral vowel, and syllable position, we used a linear mixed-effects model. This model is similar to a four-way analysis of variance (ANOVA) in that four different categorical predictors are used to find the continuous measure of duration. The linear mixed-effects model is different in that a random effect, which takes into account the variability among the individuals, is included in the model. It is necessary to take into account variability among the individuals since one of the predictors, group of participants, is at the level of the individual, rather than each token. Each individual remained in the same group throughout the study. The other three predictors—vowel, nasal versus oral vowel, and syllable position—all vary within individuals, as each individual provided 12 different tokens for analysis. This within-group and between-group variability is the reason a mixed model was used.

The type III tests of effects in the linear mixed-effects model were used to determine whether each of the predictors and/or their interactions were statistically significantly related to duration. In the type III test, each predictor was considered after all other effects were accounted for to determine whether each individual predictor or interaction of predictors is significant with respect to the vowel duration. The numerator degrees of freedom (Num DF) are based on the number of different categories there are for each predictor; the denominator degrees of freedom (Den DF) are related to the number of participants (per group) and the number of total observations (for all other predictors). The F value can be thought of as a standardized measure of the effect of each predictor or interaction; the larger the F value, the more evidence there is of a relationship between the predictor or interaction of predictors and duration. The size of the F value is interpreted through the use of the p value. The p value is the probability that we would choose a random sample of individuals with differences based on the predictor at least as large as those in this sample, if there is no relationship between that predictor and duration in the population of BP speakers. The smaller the p value, the less likely it is that this sample could result from such a population, and the more evidence we have to say there is a relationship of the predictor to duration. The level of significance used throughout this study is 0.05, so a p value of 0.05 or less indicates a statistically significant predictor.

Table 4.2 provides results of Type III tests of significance of relationship of predictors to duration. Many statistically significant effects show up in Table 4.2. In particular, there is a statistically significant four-way interaction of participant group (level), vowel, oral versus nasal, and syllable position ($p = 0.0007$). This means that no overall conclusions can be drawn regarding the effects of speaker group (level), vowel, nasal versus oral, and syllable position; thus they must always be interpreted in the context of other effects. One way to interpret these results is to consider each of the 36 possible combinations of language learner level, vowel, nasal versus oral, and syllable position separately, and compare them each to one another.

Table 4.2 Type III tests of significance of relationship of predictors to duration. P values marked with asterisks indicate statistical significance.

Effect	Num DF	Den DF	F Value	P Value
Level	2	30	6.58	0.0043*
Vowel	2	330	26.05	<0.0001*
Level*Vowel	4	330	0.37	0.8276
NasalOral	1	330	349	<0.0001*
Level*NasalOral	2	330	1.03	0.3566
Vowel*NasalOral	2	330	16.82	<0.0001*
Level*Vowel*NasalOral	4	330	2.96	0.0201*
Position	1	330	381.41	<0.0001*
Level*Position	2	330	27.94	<0.0001*
Vowel*Position	2	330	4.44	0.0125*
Level*Vowel* Position	4	330	1.08	0.3646
NasalOral* Position	1	330	52.93	<0.0001*
Level*NasalOral* Position	2	330	5.59	0.0041*
Vowel*NasalOral* Position	2	330	14.26	<0.0001*
Level*Vowel*NasalOral* Position	4	330	4.96	0.0007*

High Nasal Vowels Are Longer Than Their Oral Counterparts in Penultimate Syllables

In Figures 4.12 and 4.13 the average duration for each of the 36 combinations of vowel, nasal versus oral, level, and position are presented in the form of bar graphs. Figure 4.12 shows all duration averages of vowels in syllables bearing primary stress in penultimate position. The upper case letters above each bar represent which Tukey groupings each combination belongs to. Combinations that are similar have the same letter above the bar. Combinations that are significantly different do not have the same letter next to them. As an example, all oral vowel average durations in penultimate position (Figure 4.12) belong to K, so we conclude that none of these are significantly different from one another across all groups of speakers. Similarly, all of the nasal vowel average durations in penultimate position belong to E, and again we can conclude that none of the nasal vowels in penultimate position are significantly different from one another. Inversely, we can observe that the oral vowel [i] belongs only to K and has no overlap with any of the nasal vowels in penultimate position. Since none of the Tukey groupings overlap between [i] and all the nasal vowels, we can conclude that these are significantly different. When comparing the average duration of the oral vowel [u] with its nasal counterpart, for each speaker group [u] is statistically significantly shorter than [ũ]. Since [a] and [ɐ̃] average durations for NSs both belong to Tukey groups F, G, and H, these durations are not statistically different. However, when average durations of [a] and [ɐ̃] are compared to each other within the inexperienced and experienced groups, the oral counterpart is statistically shorter than the nasal counterpart in the same group of speakers, but not outside each speaker group.

From this analysis, we can gather a few more general observations regarding average durations of syllable rimes in penultimate position. One can see the general trend of oral vowels being shorter than nasal, but not always significantly shorter. Also, each group of participants follow a similar trend, with [i] being the shortest. All duration averages are longer for the inexperienced group, then experienced, with the shortest averages being the native group, with the exception of [ũ] which is slightly longer for NSs when compared to experienced L2 speakers.

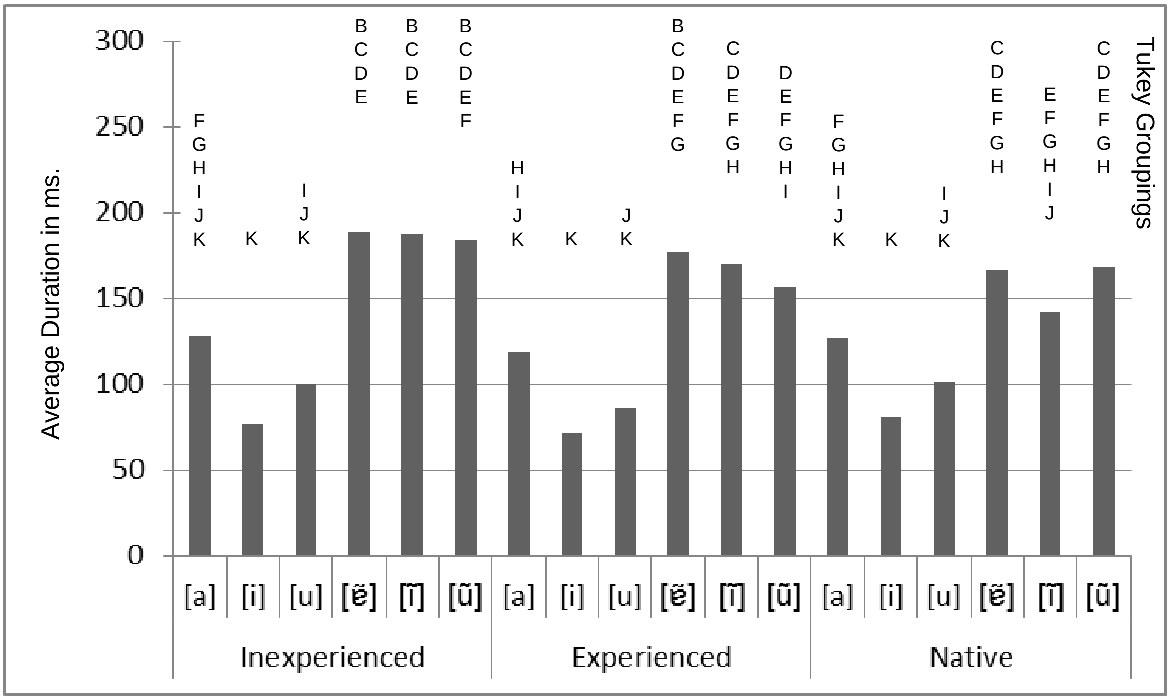

Figure 4.12 Tukey groups for duration of vowels in penultimate position.

Word-Final Vowels Are Generally Longer than Vowels in Penultimate Position

The average duration for vowels in syllables bearing stress in ultimate position is presented in Figure 4.13. An overall comparison of Figures 4.12 and 4.13 reveals that the vowels in ultimate position are generally longer than vowels in penultimate position. Two notable exceptions are the NS high oral vowels [i] and [u] in ultimate position in which average duration are more similar to high oral vowels in penultimate position. Since no Tukey groupings overlap for inexperienced L2 speaker high oral vowels and NS high oral vowels in ultimate position, we are able to state that these are significantly different. On the other hand, the average durations of high oral vowels of the experienced group are not significantly different from the ultimate high oral vowels of the other two groups even though the average duration for experienced high oral vowels lies somewhere between the inexperienced and native groups.

Nasal Vowels Are Not Longer Than Their Oral Counterparts in Word-Final Syllables

Regarding nasal vowels, [ẽ] in both positions for all three groups belong to overlapping Tukey groupings, so none of these combinations can be said to be significantly different. The same is true for [ĩ]. Although [ũ] for all three groups in penultimate position belong to overlapping Tukey groupings, average duration for [ũ] in ultimate (word-final) position tells a different story. Inexperienced speaker [ũ] average duration (266.96 ms.) belongs only to A and NS [ũ] average duration (196.73 ms.) belongs to B, C, D, and E, so these two groups have statistically different durations. Again, although the experienced speaker [ũ] average duration (231.17 ms.) falls between the other two speaker groups, this value belongs to both A and B, hence this average duration is not statistically different from the inexperienced or NS counterparts.

With the exception of high back [u] and [ũ] for NSs and inexperienced speakers, nasal vowels are not significantly longer than oral vowels in ultimate position. For the first research question, “Are nasal vowels longer than oral vowels?” we must answer, “Sometimes.” High nasal vowels in penultimate and the high back vowel [ũ] in ultimate position are significantly longer than their oral counterparts, especially for NSs.

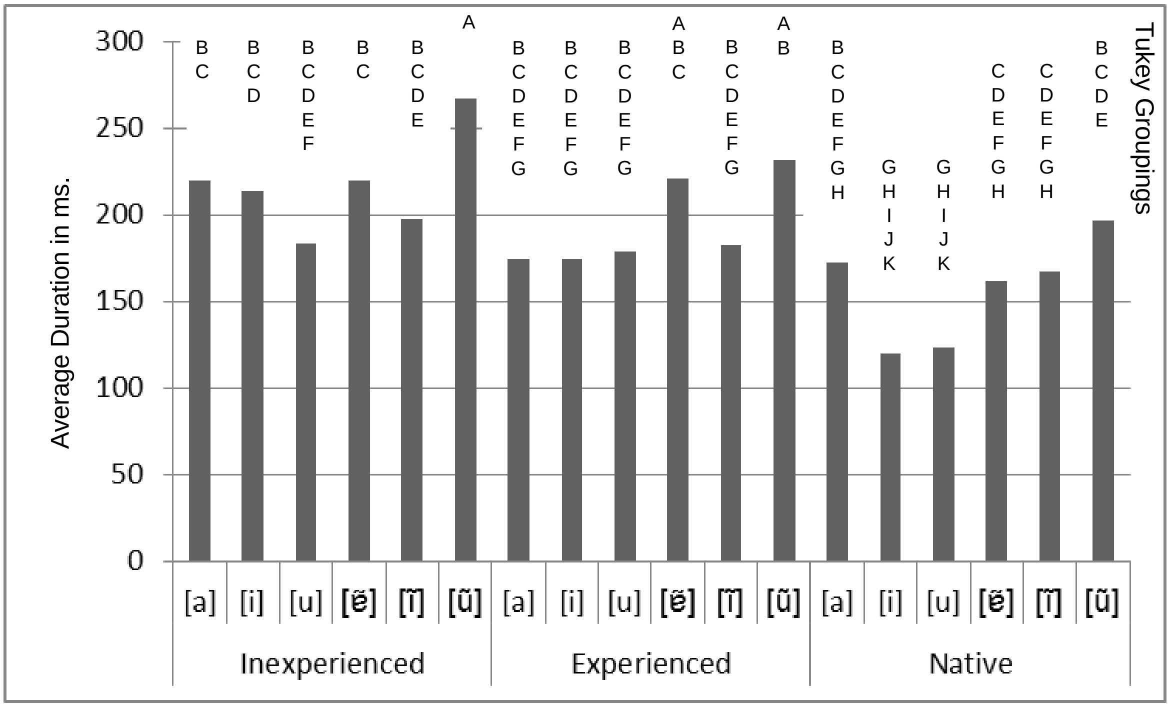

Figure 4.13 Tukey groups for duration of vowels in ultimate position.

Native Speaker Nasal Vowels Are Generally Longer than Oral Vowels

Another way to look at the results of the Type III tests of effects in the linear mixed-effects model is to sort according to different criteria in order to answer specific research questions. Are nasal vowels produced by NSs longer than oral vowels produced by the same speakers? Table 4.3 includes durations for NSs only, sorted by vowel, syllable position, and nasal versus oral. From the table, we can see that for [a] and [ẽ] durations are statistically similar for both penultimate and ultimate positions; for [i] and [ĩ], the nasal and oral durations are statistically significantly different in penultimate position (the nasal vowels are longer), but not in ultimate position. Finally, for [u] and [ũ], the nasal and oral durations are statistically significantly different for both penultimate and ultimate positions (the nasal vowels are longer in both cases). Again, for native BP speakers in this study, nasal vowels are sometimes longer than their oral counterparts, but vowel quality and syllable position must be taken into account.

Table 4.3 Tukey groups for native speaker average duration, sorted by vowel, position, and nasal versus oral.

Level	**Vowel**	**Nasal/ Oral**	**Position**	**Avg. Duration (ms.)**	**Tukey Groupings**									
Native	[ɐ̃]	N	penult	165.82		C	D	E	F	G	H			
Native	[a]	O	penult	127.05					F	G	H	I	J	K
Native	[ɐ̃]	N	ultimate	161.55		C	D	E	F	G	H			
Native	[a]	O	ultimate	172.05	B	C	D	E	F	G	H			
Native	[ĩ]	N	penult	141.91				E	F	G	H	I	J	
Native	[i]	O	penult	80.50										K
Native	[ĩ]	N	ultimate	167.53		C	D	E	F	G	H			
Native	[i]	O	ultimate	120.00						G	H	I	J	K
Native	[ũ]	N	penult	167.91		C	D	E	F	G	H			
Native	[u]	O	penult	100.64								I	J	K
Native	[ũ]	N	ultimate	196.73	B	C	D	E						
Native	[u]	O	ultimate	123.32						G	H	I	J	K

Duration Patterns Differ for Nonnative Speaker Groups

Since a pattern emerged for the NS group with regard to average duration of nasal versus oral vowels, it is interesting to look at the average duration results for the other two groups. For the inexperienced and experienced L2 speaker groups, a different pattern emerges, as seen in Tables 4.4 and 4.5. Unlike the native group, in penultimate position, average duration for all three nasal versus oral vowel combinations are significantly different for both L2 speaker groups. Concerning average duration of vowels in ultimate position, we see a parallel only between the native and inexperienced groups, in that only [u] versus [ũ] are significantly different. For the experienced L2 speaker group, none of the vowels in ultimate position are significantly different. From these results, we can conclude that the position of the syllable, penultimate versus ultimate in this study, affects the vowel length differently for NSs and L2 speakers. With regard to syllable position, average duration tends to vary more for L2 speakers, with word final vowels being relatively longer for this group. To answer the research question in regard to inexperienced L2 speakers, “Are nasal vowels longer than oral vowels?”, we answer, “Yes, for vowels in penultimate syllable position and for the high back vowel [ũ] in ultimate position.” In reference to experienced L2 speakers in the study, the answer to this question is slightly different. Nasal vowels are longer than oral vowels, but only in penultimate syllable position, not in ultimate position. Hence, we confirm that vowel duration of oral versus nasal vowels pattern differently for the NNS groups in this study when compared to the NS group.

Table 4.4 Tukey groups for inexperienced L2 speaker average duration, sorted by vowel, position, and nasal versus oral.

Level	Vowel	Nasal/Oral	Syllable	Avg. Duration (ms.)	Tukey Groupings										
Inexperienced	[ɐ̃]	N	penult	188.5		B	C	D	E						
Inexperienced	[a]	O	penult	127.73						F	G	H	I	J	K
Inexperienced	[ɐ̃]	N	ultimate	219.88		B	C								
Inexperienced	[a]	O	ultimate	219.92		B	C								
Inexperienced	[ĩ]	N	penult	187.23		B	C	D	E						
Inexperienced	[i]	O	penult	76.65											K
Inexperienced	[ĩ]	N	ultimate	197.85		B	C	D	E						
Inexperienced	[i]	O	ultimate	213.31		B	C	D							
Inexperienced	[ũ]	N	penult	183.85		B	C	D	E	F					
Inexperienced	[u]	O	penult	100.27									I	J	K
Inexperienced	[ũ]	N	ultimate	266.96	A										
Inexperienced	[u]	O	ultimate	183.12		B	C	D	E	F					

Table 4.5 Tukey groups for experienced L2 speaker average duration, sorted by vowel, position, and nasal versus oral.

Level	Vowel	Nasal/ Oral	Syllable	Avg. Duration (ms.)	Tukey Groupings										
Experienced	[ẽ]	N	penult	177.11		B	C	D	E	F	G				
Experienced	[a]	O	penult	118.56								H	I	J	K
Experienced	[ẽ]	N	ultimate	220.78	A	B	C								
Experienced	[a]	O	ultimate	174.33		B	C	D	E	F	G				
Experienced	[ĩ]	N	penult	169.67			C	D	E	F	G	H			
Experienced	[i]	O	penult	71.78											K
Experienced	[ĩ]	N	ultimate	182.39		B	C	D	E	F	G				
Experienced	[i]	O	ultimate	174.56		B	C	D	E	F	G				
Experienced	[ũ]	N	penult	156.28				D	E	F	G	H	I		
Experienced	[u]	O	penult	85.78										J	K
Experienced	[ũ]	N	ultimate	231.17	A	B									
Experienced	[u]	O	ultimate	178.89		B	C	D	E	F	G				

Inexperienced L2 Speakers Lengthen Word-Final High Oral Vowels More than NS

Another research question asks if L2 speakers lengthen word-final oral vowels more than native BP speakers. Table 4.6 includes only the average durations for word-final oral vowels (ultimate position), and is sorted by vowel and participant group (level). For [a] there are no statistically significant differences across the participant groups; for both high vowels [i] and [u], however, the inexperienced L2 speakers are significantly different from the NSs, that is, the inexperienced speakers tend to lengthen high vowels more word-finally than the NSs. As noted earlier, the average durations for the experienced group fall between the other two groups, but we cannot say whether they are more similar to the NS group or the inexperienced group. Regarding the research question, “Are word-final high vowels [i] and [u] produced by the two NNS groups longer than those produced by the NS group?” we conclude that the answer is “Yes, but only for the inexperienced group in this study.”

Table 4.6 Tukey groups for average duration of oral vowels in word-final (ultimate) position, sorted by vowel and participant group.

Level	Vowel	Nasal/ Oral	Position	Avg. Duration (ms.)	Tukey Groupings									
Inexperienced	[a]	O	ultimate	219.92	B	C								
Experienced	[a]	O	ultimate	174.33	B	C	D	E	F	G				
Native	[a]	O	ultimate	172.05	B	C	D	E	F	G	H			
Inexperienced	[i]	O	ultimate	213.31	B	C	D							
Experienced	[i]	O	ultimate	174.56	B	C	D	E	F	G				
Native	[i]	O	ultimate	120						G	H	I	J	K
Inexperienced	[u]	O	ultimate	183.12	B	C	D	E	F					
Experienced	[u]	O	ultimate	178.89	B	C	D	E	F	G				
Native	[u]	O	ultimate	123.32						G	H	I	J	K

Vowel Height Shows Significant Differences for Low Vowels [a] and [ɐ̃]

To take into account the physiological difference between the male and female vocal tract, F_1 values were transformed to the Bark Difference Metric for F_1. Table 4.7 provides the mean and standard deviations of Z_3-Z_1 for each vowel, syllable position, and participant level.

Table 4.7 Mean and standard deviation of Z_3-Z_1 (vowel height) by participant group and vowel.

		Inexperienced		Experienced		Native	
Vowel	Position	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
[a]	penult	8.53	0.69	8.19	0.57	7.61	0.64
[a]	ultimate	8.9	0.72	8.98	0.7	8.24	0.83
[ɐ̃]	penult	9.09	1.8	8.37	1	9.96	0.89
[ɐ̃]	ultimate	9.39	0.73	9.45	1.47	10.24	0.82
[i]	penult	11.29	0.61	11.23	0.57	11.5	0.87
[i]	ultimate	12.18	0.53	11.93	0.84	12.42	0.62
[ĩ]	penult	11.97	0.47	11.62	0.83	12.02	0.64
[ĩ]	ultimate	12.02	0.58	11.99	0.9	12.33	0.76
[u]	penult	11.15	0.57	10.61	0.74	11.06	0.61
[u]	ultimate	11.41	0.57	11.24	0.48	11.21	0.56
[ũ]	penult	10.91	0.89	10.48	0.84	11	0.39
[ũ]	ultimate	11.02	1.02	10.97	1.03	11.08	0.58

To analyze vowel quality the model used is a one-way ANOVA. Each vowel and nasal–oral combination is analyzed separately and the measure of interest is averaged over the examples in penultimate and ultimate position. There is only one predictor in each model, the participant group. Since the measure of interest is a continuous measure, the one-way ANOVA model is appropriate.

Table 4.8 includes the average Z_3-Z_1 for each vowel and participant group and provides the tests of significance of the relationship of participant group to average Z_3-Z_1. The last column, labeled “Significance,” indicates which participant groups are different from each other. Z_3-Z_1 are only statistically significantly different for [a] and [ɐ̃]. For [a], the native group had the lowest articulation. The inexperienced L2 speakers demonstrated a statistically significant higher articulation than the native group for [a] (p value = 0.0156). The experienced group falls between the native and the inexperienced group, but the differences are not statistically significant. For [ɐ̃], the native group had the highest articulation. The experienced group demonstrated significantly less height than that of the native group (p = 0.0382). The inexperienced group fell between the native and experienced group and the difference was not statistically significant.

Table 4.8 Tests of significance of the relationship of participant group to Z_3-Z_1 (vowel height).

					Average Bark Difference Metric (Z_3-Z_1)			
Vowel	Num DF	Den DF	F Value	P Value	Inexperienced	Experienced	Native	Significance
[a]	2	30	4.82	0.0154	8.72	8.59	7.93	inex > native
[ɐ̃]	2	30	3.74	0.0356	9.24	8.91	10.1	expe < native
[i]	2	30	1.08	0.3517	11.74	11.58	11.96	-
[ĩ]	2	30	0.91	0.4135	11.99	11.8	12.18	-
[u]	2	30	1.42	0.2586	11.28	10.92	11.14	-
[ũ]	2	30	0.48	0.6233	10.96	10.72	11.04	-

Vowel Advancement Not Significantly Different Across Speaker Groups

As was done with F_1 above, F_2 values were transformed to the Bark Difference Metric, then Z_2 was subtracted from Z_3 (Z_3-Z_2). Although advancement is probably a better term for the F_2 acoustic correlate, since backness positively correlates with Z_3-Z_2, this term is used throughout. Table 4.9 provides the mean and standard deviations of Z_3-Z_2 for each vowel, syllable position, and participant level.

Table 4.9 Mean and standard deviation of Z_3-Z_2 (backness) by participant level, vowel, and syllable position.

		Inexperienced		Experienced		Native	
Vowel	Position	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
[a]	penult	3.14	0.36	2.95	0.50	2.94	0.58
[a]	ultimate	3.57	0.36	3.49	0.35	3.12	0.49
[ɐ̃]	penult	3.52	0.66	2.99	0.16	3.55	0.59
[ɐ̃]	ultimate	3.41	0.81	3.73	0.87	3.34	0.39
[i]	penult	1.47	0.57	1.32	0.28	1.55	0.39
[i]	ultimate	1.42	0.35	1.63	0.34	2.03	0.47
[ĩ]	penult	1.38	0.43	1.64	0.56	1.76	0.51
[ĩ]	ultimate	1.55	0.47	2.32	1.20	2.10	0.54
[u]	penult	4.70	0.79	5.25	0.61	5.93	0.62
[u]	ultimate	4.93	0.97	4.58	0.88	4.36	1.06
[ũ]	penult	4.66	0.63	5.35	1.19	5.04	1.24
[ũ]	ultimate	4.61	0.86	4.94	1.16	4.81	1.06

Before performing the one-way ANOVA, Z_3-Z_2 values for the two syllable positions were averaged. Table 4.10 provides tests of significance of the relationship of participant level to average Z_3-Z_2, which is not significantly different across the participant groups for any of the vowels.

Table 4.10 Tests of significance of the relationship of participant group to Z_3-Z_2 (backness).

					Average Bark Difference Metric (Z_3-Z_2)			
Vowel	Num DF	Den DF	F Value	P Value	Inexperienced	Experienced	Native	Significance
[a]	2	30	2.06	0.1449	3.35	3.22	3.03	-
[ɐ̃]	2	30	0.12	0.8871	3.46	3.36	3.44	-
[i]	2	30	3.20	0.0552	1.45	1.48	1.79	-
[ĩ]	2	30	3.26	0.0524	1.47	1.98	1.93	-
[u]	2	30	0.73	0.4919	4.82	4.91	5.15	-
[ũ]	2	30	1.09	0.3503	4.63	5.15	4.63	-

In regard to two measures of vowel quality, height and advancement, only vowel height for the low vowels [a] and [ɐ̃] were significantly different for one NNS group but not for both. The direction and the participant group differed for each low vowel. The oral low vowel [a] was significantly higher for inexperienced speakers, but not for experienced speakers. The nasal low vowel [ɐ̃] was significantly lower for experienced speakers, but not for inexperienced speakers.

Trajectories from Nasal Vowels to Nasal Codas or Nasal Murmurs

Although the status of nasal vowels in BP is controversial, phoneticians and phonologists generally agree that the production of BP nasal vowels result in a vowel with increasing nasalization throughout the trajectory of their articulation and no nasal coda, or in many instances a short nasal murmur is present at the end of the nasal vowel. The L1s of the NNSs (English and Spanish) do not have phonemic nasal vowels and a nasalized vowel is often preceded or followed by a nasal consonant. Because of the difference in how nasal vowels and nasal codas are realized in the L1s of the NNSs, we expect the intensity to decrease more in the trajectory from “nasal” vowel to the nasal murmur for these speakers, that is, the nasal murmur would be more consonantal. Additionally, consonantal weakening may result in a shorter segment for NSs. If a nasal coda is weakened to a non-consonantal nasal murmur attached to the preceding nasal vowel, the nasal murmur would be relatively shorter. To investigate what happens acoustically with the syllable rimes containing nasal vowels, we consider two questions: (1) Do NNSs produce nasal murmurs with a weaker intensity relative to each preceding nasal vowel? (2) Are nasal murmurs produced by NNSs relatively longer in proportion to the syllable rime?

To operationalize the first question of whether NNSs produce nasal murmurs with a weaker intensity relative to the preceding nasal vowel, the intensity in dB was measured at the midpoint of the vowel and nasal murmur portions of the syllable rimes containing nasal vowels, then the intensity of the nasal murmur was subtracted from the intensity of the vowel segment. These results are labeled Δ intensity. Since intensity is sensitive to speaker volume and distance from the microphone, a difference measure between the two parts of the rime is preferred to comparing raw intensity values for each segment. Table 4.11 provides the mean and standard deviation of Δ intensity by group and vowel.

Table 4.11 Mean and standard deviation of Δ intensity by participant group and vowel.

		Inexperienced		Experienced		Native	
Syllable Rime	Position	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
[ɐ̃]	penult	2.31	3.28	4.22	2.54	2.95	2.72
[ɐ̃]	ultimate	2.54	2.38	4.44	2.32	3.09	3.42
[ĩ]	penult	1.58	1.96	2.89	1.67	2.68	2.56
[ĩ]	ultimate	0.46	2.30	1.39	0.65	1.27	1.85
[ũ]	penult	3.04	2.29	4.06	4.07	2.18	3.17
[ũ]	ultimate	2.77	1.94	3.06	1.76	0.36	3.61

A one-way ANOVA was performed on the average of the Δ intensity values in penultimate and ultimate position for [ɐ̃], [ĩ], and [ũ]. Table 4.12 gives the F tests for the ANOVA analysis for Δ intensity. Average Δ intensity is not significantly different across the participant groups for any of the vowels in this study. We hypothesize that if nasal murmurs produced by NNSs are more consonantal, Δ intensity will be greater for these speakers. Contrary to intuition, for [ɐ̃] and [ĩ], average Δ intensity is least for inexperienced speakers. The only vowel that exhibited the predicted result is [ũ] in which average Δ intensity is lowest for NSs. Therefore, the difference in intensity between the vowel and nasal murmur is not significantly smaller for the native BP speaker group in this study.

Table 4.12 Test of Significance of the relationship of participant group to Δ intensity.

					Average Δ Intensity			
Vowel	Num DF	Den DF	F Value	P Value	Inexperienced	Experienced	Native	Significance
[ẽ]	2	30	1.54	0.2308	2.42	4.33	3.02	-
[ĩ]	2	30	1.51	0.2365	1.02	2.14	1.97	-
[ũ]	2	30	2.65	0.0871	2.90	3.56	1.27	-

To address the second question regarding whether NNSs produce relatively longer nasal murmurs than NSs, the duration of the entire syllable rime and the duration of the nasal murmur by itself were extracted and calculated as a ratio, nasal murmur duration divided by total rime duration. The advantage of using a ratio rather than a raw duration measurement is that variation in speech rate does not affect the comparison among speakers and segments. Table 4.13 displays the mean and standard deviation of ratio of nasal murmur to rime duration.

Table 4.13 Mean and standard deviation of ratio of nasal murmur to total vowel duration.

		Inexperienced		Experienced		Native	
Vowel	Position	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
[ẽ]	penult	0.45	0.09	0.40	0.05	0.38	0.10
[ẽ]	ultimate	0.36	0.14	0.37	0.10	0.28	0.11
[ĩ]	penult	0.55	0.09	0.55	0.10	0.47	0.15
[ĩ]	ultimate	0.47	0.08	0.57	0.14	0.52	0.11
[ũ]	penult	0.55	0.14	0.48	0.20	0.54	0.19
[ũ]	ultimate	0.54	0.12	0.64	0.10	0.56	0.22

A one-way ANOVA was performed on the average ratio of nasal murmur duration to rime duration in penultimate and ultimate position for [ẽ], [ĩ], and [ũ]. Table 4.14 provides the F tests for the ANOVA analysis for this ratio. Average ratio of nasal murmur to rime duration is not significantly different across the participant groups for any of these vowels. From these results, we conclude that the native BP speakers in this study did not produce relatively shorter nasal murmurs than the two L2 speaker groups.

Table 4.14 Test of significance of the relationship of participant group to ratio of nasal murmur to vowel duration.

					Average Ratio of Nasal Murmur to Vowel Duration			
Vowel	Num DF	Den DF	F Value	P Value	Inexperienced	Experienced	Native	Significance
[ɐ̃]	2	30	2.31	0.1168	0.4	0.39	0.33	-
[ĩ]	2	30	1.31	0.2849	0.51	0.56	0.50	-
[ũ]	2	30	0.04	0.9604	0.54	0.56	0.55	-

Although differences may exist in the trajectory of nasal vowels among participant groups, the two measures investigated above, Δ intensity and ratio of nasal murmur to rime duration, do not reveal statistically significant differences.

Statistical Analysis of Accent Ratings

Accent ratings were recorded by 20 raters using an ordinal scale from 1 (meaning very nonnativelike) to 8 (meaning very nativelike).

Intraclass Correlation Coefficients Indicate Agreement Among Raters

To check the validity of the accent rating task, we are interested in knowing how closely the raters agree with one another with respect to the accent ratings. There were two groups of raters, one group with 12 raters and the other with eight. Each group was analyzed separately for reliability since each group heard a different set of tokens and therefore cannot be compared. A common measure of agreement among multiple raters is the intraclass correlation coefficient (ICC). This measure ranges from 0 to 1, where 0 means there is no agreement among the raters, and 1 means there is complete agreement among the raters. The ICC was calculated using the “psych” package in R (Revelle, 2014). The ICC for the group of 12 raters is 0.60 and is highly statistically significant ($F(190,2090) = 21$, $p < 0.0001$). The ICC for the group of eight raters is also 0.60 and is also highly statistically significant ($F(190, 1330)= 21$, $p < 0.0001$). The ICC of 0.60 in both cases is significantly different from random agreement, and indicates that the raters do generally agree on appropriate ratings for the various tokens.

Accent Ratings Correspond with Expected Participant Groups

To determine how the accent ratings vary across the participant groups and the different tokens, a two-way ANOVA was used. The accent ratings were averaged across the individuals who rated each token for each speaker. In order to keep the duration of accent rating procedure below 20 minutes for each rater, 32 speakers were rated and tokens were split into two groups. Although 33 speakers are included in the production data, one of the NS participants was not included in the accent rating experiment. Eight individuals rated half of each speaker’s tokens and 12 individuals rated the other half of the tokens by same group speakers. The results of the ANOVA are in Table 4.15. Both the participant level ($p <0.0001$) and the token ($p <0.0001$) are significantly related to the accent ratings, but there is no interaction of the two (p value = 0.5607). This means that for each token, the participant groups are ranked the same with respect to the accent ratings. Because of this, we can say with reasonable confidence that the tokens used in this experiment were equally effective for the raters to detect accent level that correspond to the three participant groups.

Table 4.15 Significance of participant group, token, and interaction in relationship to accent rating.

Variable	Num DF	Den DF	F Value	P Value
Group	2	29	63.81	<.0001
Token	11	319	5.00	<.0001
Group*Token	22	319	0.93	0.5607

Post-hoc Tukey pairwise comparisons were performed on the accent ratings. Table 4.16 provides the Tukey groups for accent rating. The different participant groups or levels are all significantly different from each other with respect to average accent rating. As expected, the highest average accent rating is for the NSs, and the lowest is for the inexperienced speakers. These results lead us to conclude that nativelikeness ratings positively correlate with level of experience with BP.

Table 4.16 Tukey groups for accent rating.

Group	Average Accent Rating	Tukey Grouping		
Native	6.98	A		
Experienced	4.46		B	
Inexperienced	3.06			C

Tokens Containing Nasal Vowels Score Higher, Low Frequency Tokens Score Lower

Table 4.17 provides the average accent ratings for each participant group for each token. The syllable rime of interest is underlined in this table, and Tukey groupings for the different tokens are provided. Here results are presented in order of highest average accent rating (averaged across the three groups) to lowest average accent rating. Though the average accent ratings for each token correspond to the expected ranking of native > experienced > inexperienced, a few observations regarding the tokens are appropriate. One unexpected result is that five of the six tokens containing nasal vowels are among the top seven tokens based on average accent rating averages of all speakers. These five tokens with nasal vowels are listed with rank based on average accent rating: (1) *cristã*, second; (2) *atum*, fourth; (3) *patim*, fifth; (4) *tinto,* sixth; (5) *canta,* seventh. We, therefore, conclude that although nativelikeness scores are not significantly different, tokens containing nasal vowels did not receive lower accent ratings that tokens with oral vowels.

A less surprising result of the accent rating task is that the three tokens with the lowest average accent rating are low frequency BP words, that is, words not part of a typical native BP speaker's active lexicon. Evidence for level of word frequency can be tested by searching a large corpus of digital texts of the language. To explore the frequency of the tokens used in the current study, a search was performed in a 45-million-word corpus of Portuguese (Davies & Ferreira, 2006). No examples of *tunco* or *tuco* (ranked eleventh and twelfth in the accent rating, respectively) were found in this corpus.[3] Although nativelikeness scores are not significantly different, these low frequency tokens received lower accent ratings. The differences among accent ratings for each token are not statistically significant, providing evidence that the choice of tokens were adequate for the accent rating experiment.

Table 4.17 Tukey groups for accent rating by token (syllable rime of interest is underlined).

	Average Accent Rating			Tukey Grouping			
Token	Inexperienced	Experienced	Native				
vesti [i]	3.64	5.39	7.11	A			
cristã [ɐ̃]	3.45	4.68	7.30	A	B		
está [a]	3.51	4.63	7.05	A	B	C	
atum [ũ]	3.20	4.64	7.30	A	B	C	
patim [ĩ]	3.29	4.73	7.05	A	B	C	D
tinto [ĩ]	2.94	4.82	7.01	A	B	C	D
canta [ɐ̃]	3.32	4.09	7.28	A	B	C	D
cata [a]	3.07	4.36	6.70	A	B	C	D
tutu [u]	2.93	4.23	6.70		B	C	D
tico [i]	2.69	3.97	6.65			C	D
tunco [ũ]	2.45	3.82	6.89			C	D
tuco [u]	2.17	4.17	6.68				D

Accent Ratings in Relation to Acoustic Characteristics

How are accent ratings related to certain acoustic characteristics of speech? A multiple linear regression model was used to analyze, for each of the six vowels [a i u ɐ̃ ĩ ũ], duration (in ms.), vowel height (Z_3-Z_1), vowel backness (Z_3-Z_2), and for the three nasal vowels [ɐ̃ ĩ ũ], Δ intensity (in dB). Speaker groups were not considered in this analysis so that the measurements derived from the acoustic signal can be compared more directly to the accent ratings. All measures, including duration, were averaged over the two syllable positions for each vowel. The model used here is a multiple regression model, which compares continuous measures to another continuous measure. In this analysis, both linear and quadratic terms were considered for each acoustic measure. This means that we do not make the assumption that the accent rating can only increase or decrease with increasing duration, height, advancement, and Δ intensity (linear relationship), but can do both; for example, there could be a particular duration that is associated with the highest ratings, and durations lower or higher than that may result in a decrease in accent ratings.

An example of a graph generated by a multiple linear regression model is provided in Figure 4.14; this graph pertains to [ɐ̃]. The circle points in the graph represent the 32 individuals; their horizontal position indicates the average height (Z_3-Z_1) of an individual's [ɐ̃], and the vertical position indicates the average accent rating of an individual's tokens containing the same [ɐ̃]. The solid line represents the overall relationship between the two. This line shows that, within this sample, as the average height increases, the average accent rating tends to increase as well.

Another example of a graph generated by a multiple linear regression model is given in Figure 4.15; this graph pertains to [u]. The line of regression in Figure 4.15 shows that, within this sample, as the average backness (Z_3-Z_2) increases, the average accent rating tends to increase as well. There were no clear outliers in the linear regressions.[4]

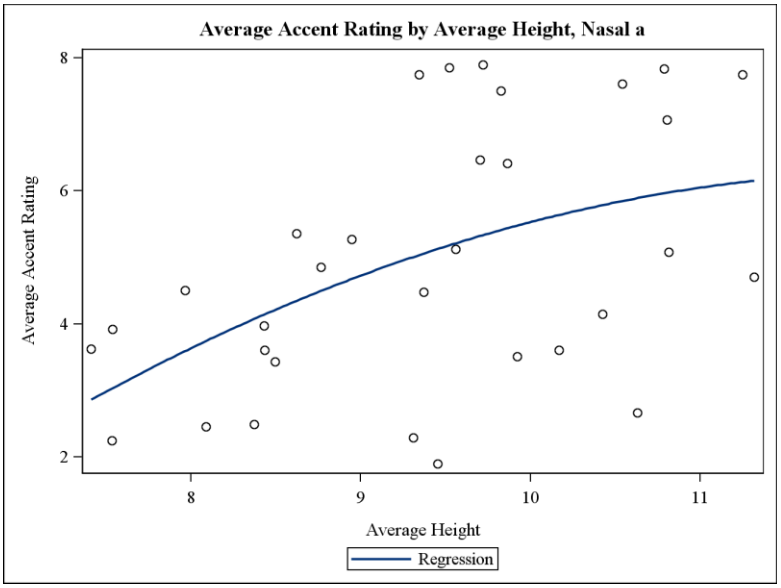

Figure 4.14 Graph of regression of average accent rating on average height for [ɐ̃].

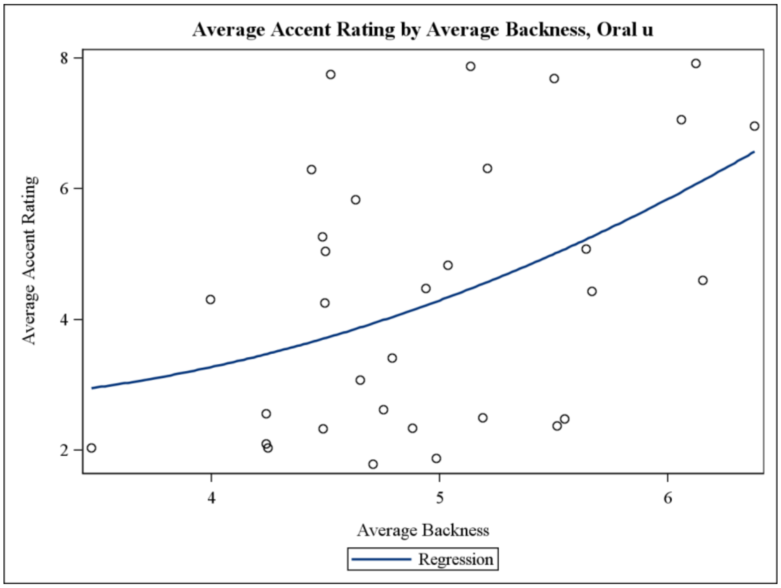

Figure 4.15 Graph of regression of average accent rating on average backness for [u].

We use regression analyses to explore which relationships are statistically significant, that is, qualities that represent a population trend rather than a sample trend only. To learn which acoustic measurements are significant, a stepwise selection process is used. Through this process, only the acoustic measurements that are statistically significantly related to the accent ratings are included in the statistical model**.** The most statistically significant acoustic measure enters the model first; if it is statistically significant at the 0.05 level, it remains in the model and the next most significant acoustic measurement enters. The process continues until no additional acoustic measurements are significant. If at any point an acoustic measurement that was previously included in the model becomes insignificant at the 0.05 level, it is removed.

Table 4.18 gives the estimated coefficients associated with each statistically significant acoustic quality for each vowel. The coefficients represent the change in the average accent rating based on a one-point change in the average acoustic quality, such as, a 1 ms. change in duration or a 1 Bark difference metric change in height or backness. Duration is statistically significant as a predictor for all vowels except [a] and [ũ], with average duration having a negative relationship with accent rating (the longer the average duration the lower the accent rating). In one case, [u], there is also a squared duration term. While it is statistically significant, the coefficient itself is very small, and despite being statistically significant does not have much bearing on the overall relationships of the duration of [u] to accent rating. Therefore, for all vowels except for [a] and [ũ] accent rating decreases as duration increases. There is no evidence that durations that are shorter than a particular value are related to poorer accent ratings.

For [a], only height (Z_3-Z_1) was significantly related to the accent rating; the negative coefficient indicates that as the height increase, the accent rating decreases. After accounting for the negative effect of duration on accent rating for [ɐ̃], height has a positive relationship with accent rating, so the greater the height, the greater the accent rating, which is the expected contrast between [a] and [ɐ̃] as NSs produce a greater contrast in height for these two vowels than NNSs.

Table 4.18 Estimated coefficients of relationships of acoustic measurements to accent ratings.

Vowel	Significant Acoustic Quality	Coefficient	Num DF	Den DF	F Value	P Value
[a]	Average Height	-1.038	1	30	6.63	0.0152
[ɐ̃]	Average Duration	-0.0296	1	28	12.74	0.0013
	Average Height	1.048	1	28	17.58	0.0002
	Average Δ Intensity Squared	0.0505	1	28	9.86	0.0040
[i]	Average Duration	-0.0298	1	30	11.61	0.0019
[ĩ]	Average Duration	-0.01848	1	30	4.20	0.0493
[u]	Average Duration	-0.16621	1	28	7.18	0.0122
	Average Duration Squared	0.000482	1	28	4.33	0.0466
	Average Backness Squared	0.184	1	28	21.58	<0.0001
[ũ]	No significant predictors	-	-	-	-	-

None of the vowels have an effect for Δ intensity, which is the difference of intensity in the nasal vowel and its nasal murmur. Only [ɐ̃] has an effect of Δ intensity squared, indicating that accent rating increases with greater Δ intensity. The greater the Δ intensity is, the greater the rate of the increase in the accent rating. This result is counterintuitive since we hypothesized that Δ intensity would be lower for NSs since their nasal murmur would be less consonantal.

In addition to the effect of duration for [u], there is a positive relationship of backness (Z_3-Z_2) squared with the accent rating. The higher the Z_3-Z_2 value, the more posterior the articulation. Although the square of average backenss is included for [u], the relationship does not indicate that low average backness (more tongue advancement) is ever related to higher accent ratings. So, the further back the articulation of [u] is, the higher the accent rating. Since American English [u] tends to be more fronted than BP [u], the higher accent rating for [u] that is farther back is expected.

Again, to answer the question concerning which acoustic characteristics are related to a higher accent rating, results from the linear regressions suggest that less fronted articulations of [u], lower articulations of [a] and higher articulations of [ɐ̃] result in higher accent ratings. Results also confirm that for four of the six vowels in this study, less duration correlates with higher accent ratings.

Summary

The statistical analyses that were performed fall into five general areas: duration, vowel quality, nasal murmur characteristics, accent rating, and inter-rater agreement. The results are summarized here.

With respect to duration, the overall finding was that it is not possible to make general conclusions about duration, as there is an interaction across all of the factors. In other words, the relationship of nasal–oral to duration may change, depending on the vowel, syllable position, and participant level. Keeping this in mind, some specific questions can be answered by comparing Tukey groupings, which are groups within the data that are statistically similar. For example, inexperienced L2 speakers have longer durations word-finally with respect to [i] and [u], but not [a]. Furthermore, similar but not identical patterns emerged for each participant group regarding penultimate versus ultimate syllable position and duration, as well as oral versus nasal vowels.

Regarding acoustic measures that correlate with height and advancement vowel qualities, the only significant relationship of participant level to these qualities was with respect to vowel height. Inexperienced L2 speakers tended to produce higher [a] than NSs; and experienced L2 speakers tended to produce lower [ẽ] than NSs. No other significant relationships for height and advancement were found. The analysis of nasal vowel trajectories by means of Δ intensity (change in intensity from nasal vowel to nasal murmur) and ratio of nasal murmur duration to rime duration did not reveal any significant relationships to participant groups.

With regard to inter-rater agreement, both groups of BP NS raters (the group of 12 and the group of eight) were shown to have statistically significant ICC, so that we can conclude agreement among the raters is stronger than random agreement.

Concerning accent ratings by BP NSs, for all 12 tokens uttered in identical carrier phrases, it was shown that NSs received higher ratings than experienced L2 speakers, who in turn received higher ratings than inexperienced L2 speakers. Aside from the participant levels, duration was shown to have a significant relationship to accent rating for every vowel except for [a] and [ũ], such that longer duration resulted in lower accent ratings, which means that longer segment duration correlates with sounding less nativelike. Backness was also shown to have a significant relationship with accent rating for [u], such that greater backness resulted in higher accent ratings. Vowel height had a significant relationship with accent rating for [a] and [ẽ], so that higher accent ratings resulted from lower [a] articulations and higher [ẽ] articulations. Hence, segment duration and vowel quality are important for the acquisition of BP speech, but each vowel, oral or nasal, has its own unique characteristics and presents the language learner with a different sets of challenges.

CHAPTER 5

DISCUSSION OF RESULTS AND CONCLUSIONS

This dissertation has investigated the production and accent perception of Brazilian Portuguese oral and nasal vowels in the three extreme corners of this language’s vowel space in order to deepen our understanding of the factors that influence the acquisition of L2 vowels. The acoustic part of this study was exploratory in nature, since to our knowledge no previous studies have compared BP NS production to English NS production of BP as an L2. The experimental study was limited to the three BP corner vowels /a i u/ and their nasal counterparts, [ɐ̃ ĩ ũ]. The perception portion of the current study involved 20 BP NSs who listened to tokens in carrier phrases previously recorded for the production experiment. Listeners were instructed to assign an accent rating from very native to very nonnative sounding.

A comparison of English vowels to the BP vowels in this study is relevant in view of the discussion and conclusions in this chapter. English has two high front vowels /i/ and /ɪ/ compared to BP /i/, which in terms of vowel quality has more in common with English /i/, at least in word-internal tonic syllables. When comparing the high back vowels, English has /u/ and /ʊ/ and BP only has /u/. English /u/ is closer to BP /u/ than English /ʊ/; /u/ in both languages has lip rounding and advanced tongue root (tense). However, neither English high back vowel is as far back as BP /u/. The contrasts between English and Portuguese low vowels are more complex since English has a low front /æ/ and a low back /ɑ/, as well as a diphthong that begins with a low central [a] to form /aɪ/ and /aʊ/. The first part of English these diphthongs is the closest to

BP /a/, but English does not have an equivalent /a/ monophthong, except for some speakers of southern dialects who do not produce the glide in /aɪ/.

Concerning the BP nasal vowels in the present study, the initial assumption would be that since English does not have contrastive nasal vowels, BP nasal vowels should pose an extra challenge for English L1 speakers learning BP. Yet, a well-known phonetic process in English is coarticulatory nasalization, in which vowels are nasalized when preceded and followed by nasal consonants (Beddor, Krakow & Goldstein, 1986; Beddor & Krakow, 1999). Could English coarticulatory nasalization provide positive transfer to L2 BP speakers? For the BP high nasal vowels [ĩ] and [ũ], positive transfer from English may in fact contribute to better L2 production. Furthermore, even though assimilatory nasalization may transfer from English for the BP low nasal vowel [ɐ̃], BP contrastive nasalization of this vowel involves significant vowel raising in addition to nasalization. BP [ɐ̃] is in fact closer in height to /ʌ/ as in the English word *tongue* [tʰʌ̃ŋ].

This chapter highlights the findings of the dissertation by thematically contextualizing its results in terms of several topics of interest to second language acquisition research. These themes are as follows: (1) aspects of BP vowel segment duration, their relationship to prosody, and L1 transfer; (2) BP vowel quality, vowel height interactions with nasalization, and L1 transfer; (3) considerations on the correlation between acoustic signal and accent perception; (4) theoretical implications of results; (5) pedagogical implications; (6) limitations and future directions; and (7) conclusions.

Relevant Aspects of Vowel Segment Duration

Speech Rhythm and Vowel Segment Duration

The rhythmic pattern of spoken English is said to be characterized by stress-timing (Abercrombie, 1967; Fant, Kruckenberg & Nord, 1991; Ramus, Nespor & Mehler, 1999). The two main factors that influence a language's rhythmic patterns are (1) the amount of variation in syllable structure; and (2) the amount variation in vowel duration resulting from vowel reduction in unstressed syllables and vowel lengthening due to lexical stress as well as the prosodic structure of an utterance. In addition to lengthening due to stress placement, syllable duration interacts with speech rate, intonation, vowel quality, (Cagliari & Massini-Cagliari, 1998) and word boundaries (Cutler & Butterfield, 1990). Firstly, English has a wide variety of permissible syllable structures and allows many consonant clusters in onset and coda positions. Secondly, English has a great deal of variation in vowel duration resulting from phonological processes influenced by prosody. Both of these factors contribute to English's stress-timed rhythm.

A wide range of rhythmic characterizations have been proposed for Portuguese. Cagliari (2012) and Major (1985) argue in favor of stress-timing of Portuguese (Brazilian and European varieties). However, Barbosa (2000) and Bisol (2000) describe BP as a syllable-timed language. Frota and Vigário (2001) support the view that both syllable and mora-timing characterize BP. Some of the confusion arises from methodological differences among scholars. A look at BP's syllable structure and vowel system can explain in part why a clear account of BP's rhythmic characterization is far from being straightforward. The syllable structure of BP suggests a tendency toward syllable-timing. In onset position, the only consonant clusters allowed are obstruents + liquids. In coda position only 4 archiphonemes are allowed /S/, /R/, /L/ and /N/. The only coda with more than one segment is /NS/, in which the status of /N/ as a consonant is often questioned (Cristófaro-Silva, 1998). Certainly when compared to English, BP’s syllable structure demonstrates a strong preference for CV syllables, thus having more syllables with simpler syllable structure than in English. Regarding duration, BP vowel segments are longer in tonic syllables, undergo vowel reduction in pre-tonic syllables, and drastic vowel reduction postonically, which are all more typical of stress-timing languages.

Although the purpose of the current study is not to describe BPs rhythmic structure, data from the acoustic study revealed an important durational difference in word-final syllables containing high vowels [i] and [u], but not for those with the low vowel [a]. Both English and BP syllables undergo durational variation due to the prosodic structure of utterances, but this study highlights that word-final lengthening in English results in longer high vowels than in BP.

Oral Versus Nasal Vowel Duration

In BP, high nasal vowels are longer than their oral counterparts in penultimate position, but in word final position, only the [u]–[ũ] contrast showed a significantly longer nasal vowel. In English, vowel duration is significantly affected by the consonants that follow the syllable nuclei. In an experiment using monosyllabic English words uttered by American English speakers, Peterson (1960) attested that vowels are shorter when followed by voiceless consonants, and longer when followed by voiced consonants. Nasal consonants in coda position had approximately the same influence on vowel length as did voiced plosives. The ratio of the duration of vowels preceding voiceless and voiced consonants (including nasals) was 2:3. Therefore, vowel lengthening due to coarticulatory nasalization in English may contribute to positive L1 transfer for learners producing BP nasal vowels.

Duration Based on Prosodic Position of Oral Vowels

Another issue revealed by the data in the present study was that oral vowel duration differences among native and nonnatives speakers vary significantly only in word-final (stem-final) position. Since [a] is inherently longer as a low vowel, lengthening in either prosodic position was not statistically significant. However, word-final high vowels [i] and [u] by inexperienced participants were significantly lengthened compared to those of NSs. Experienced BP NNSs demonstrated lengthening, but the difference was not statistically significant for this group, suggesting that a few extra semesters of exposure and practice in the L2 tended to improve this aspect of pronunciation. A look at English lexical phonology brings to light two factors that influence the lengthening of these high vowels in word-final open syllables. Halle and Mohanan (1985) refer to these as stem-final Tensing and stem-final Lengthening. Hammond (1997) affirms that all American English vowels in unreduced open syllables are bimoraic, suggesting that any vowel in syllables bearing primary stress must be longer than vowels in syllables not bearing stress. Therefore, it is reasonable to acknowledge that an English NS's BP [i] and [u] in stressed syllables will be affected by lengthening in this prosodic context. However, the results also indicate that L2 speakers are able to shorten word-final duration with exposure and/or practice.

Vowel Quality, Nasalization, and L1 Transfer

High Vowels: Evidence for L1 Negative Transfer in Accent Rating But Not in Acoustic Analysis

In the acoustic analysis of vowel quality measures that indicate vowel advancement, none of the numeric results were significantly different across speaker groups. However, in the accent rating task, fronting of [u] negatively correlated with nativelikeness scores. In other words, the more advancement revealed for [u] from acoustic measures of an individual speaker, the lower the accent rating score was for that speaker. According to Clopper and Pisoni (2005), American English speakers from the South, Midland, West, and Mid-Atlantic typically produce fronted [u], more so than the other two dialect groups they studied. The L2 speakers in the current study were either from the South or had lived in the South for part of their lives, meaning their English high back /u/s were likely to be fronted. Although no vowel advancement differences were revealed in the acoustic analysis, the accent rating task suggested the presence of some negative L1 transfer for advancement which only influenced the high back oral vowel [u].

Low Vowels: Acoustic and Accent Rating Evidence of L1 Negative Transfer

The most interesting and significant results concerning vowel quality in the present study are related to height of low vowels. In addition to nasalization, it is clear that another important cue to contrast BP [a] and [ɐ̃] is vowel height. For NSs [a] was much lower than [ɐ̃]. The data show that both groups of NNSs did not make this oral–nasal distinction in the same way that NSs did, since the height of these two vowels were not as distinct for these groups. Inexperienced BP NNSs tended to pronounce a higher [a] than NSs based on the mean values for Z_3-Z_1. Experienced participants pronounced [a] lower, thus were more similar to NSs than the inexperienced. On the other hand, the experienced group’s [ɐ̃] was less nativelike in the height, while, inexperienced speakers had a higher articulation for [ɐ̃], hence more nativelike than the experienced group. The accent rating task corroborated the acoustic findings by confirming that both a lower [a] and a higher [ɐ̃] correlated with higher accent ratings.

A possible explanation for these results is that students succeed at lowering the articulation of [a] before they are able to raise its nasal counterpart to achieve a more nativelike [ɐ̃]. In this case, the two groups, inexperienced and experienced, clearly showed different stages of acquisition. In light of the NNSs' inability to raise [ɐ̃] sufficiently, a look at vowel height consequences of coarticulatory nasalization is in order. In a cross-linguistic study, Schourup (1973) determined that vowel raising was the typical result of coarticulatory nasalization. In an acoustic study of the effects of nasalization on English vowels, Carignan, Shosted, Shih, and Rong (2011) demonstrated that the tongue is raised for [ĩ] when compared to [i], but not for [ã] when compared to [a], corroborating with the idea that L1 negative transfer contributes to the difficulty of producing BP [ɐ̃]. Furthermore, in a perception study involving English NSs and degrees of nasal coupling in /ɛ/ and /æ/, Beddor and her colleagues (1986) concluded that nasalization lowered perceived vowel height. From these findings, it is reasonable that L1 English speakers would not be able to discern the vowel raising associated with nasalization of BP [ɐ̃]. Explicit instruction regarding oral–nasal and vowel height contrasts is pedagogically valuable since L2 learner perception and intuition are likely not sufficient to achieve this distinction with nativelike accuracy.

No Clear Pattern for Nasal Vowel Trajectories Emerged

In this study, the relative duration of a nasal coda or nasal murmur was entirely random and none of the results were statistically significant. In a study of BP NSs, Jesus (2002:217) observed that the duration and/or existence of a nasal murmur following nasal vowels appeared to vary randomly among and within speaker samples. Difference in intensity between nasal vowels and nasal murmurs also appeared to be random and no statistically significant differences were found. An issue in measuring and analyzing the trajectory of nasal vowels to nasal murmur is that the division between nasal vowel and nasal murmur proved problematic because of the inconsistency of the appearance of the spectrogram of the nasal vowels. Vowel formants moved and varied in intensity at unpredictable times within the nasal vowel trajectories. Since the spectrograms varied a great deal with each occurrence, a consistent pattern for segmenting these was hard to determine. Albano (1999) and Medeiros (2012) agree that the timing of the vocal tract gestures in the trajectory from nasal vowel to nasal coda (or nasal murmur) is asynchronous. This asynchrony explains the confusing spectrogram results. While spectrogram/acoustic analyses are good for detecting the movement of articulatory constriction (although nasal–oral coupling somewhat muddy the results), articulatory instruments, such as palatography or MRI, are better at detecting velo-palatal gestural timing.

In the absence of clear durational patterns for the nasal vowel to nasal murmur trajectory, conclusions regarding duration of the portion referred to as nasal murmur are more useful in terms of language acquisition and pedagogy. Medeiros (2012:117) found that the coda nasal, or more literally translated as nasal appendage (Portuguese: *apêndice nasal*), was shorter than nasal consonants in onset position in tokens containing [ɐ̃] and [ĩ]. The mean values reported by Medeiros were as follows: onset nasal consonants in syllables bearing stress, 104 ms.; onset consonants in unstressed syllables, 77ms.; and coda nasal, 44ms. In regard to the remaining BP coda consonants, /S/ is shorter in coda position than in onset, /R/ often disappears completely, and /L/ tends to be realized as a glide [w] (Galea & Wertzner, 2010). These findings demonstrate the extent of the effects of weakening on BP coda nasals in comparison to the robustness of nasal consonants in onset position. In light of these findings, a study using both acoustic and articulatory data would be more suited for studying the trajectory of BP nasal vowels. At the least, BP learners would benefit from an explanation and demonstration that nasal consonants at the end of syllables, especially word-finally are very short.

Correlation Between Acoustic Analysis Results and Accent Rating Results

The perception part of the present study involved native BP listeners giving accent ratings to tokens in a carrier phrase. Listeners were not given any specific instructions to listen for the tokens or for specific vowels so that ratings would be based on a listener's overall perception of each utterance. A comparison of accent ratings, tokens, and participant levels showed that ratings correlated to the level of experience each group had with the language, that is, the experienced group received ratings higher than the inexperienced group but lower than the NS group. Each group was significantly different from the other groups. Tokens with nasal vowels were not perceived as being less nativelike than tokens with only oral vowels. To the contrary, five of the six tokens containing nasal vowels in stressed position ranked among tokens with higher nativelikeness scores. Word frequency was a more likely explanation for differences in accent ratings. The three tokens that received the lowest accent ratings across all groups are words that do not belong even to many BP NS's active vocabulary, but thus, may have caused listeners to think that the words were mispronunciations of similar, more frequent words. The token in eighth place for accent rating was *cata* 'gather, pick up' [3RD PERSON SING, PRESENT PERFECT], could have been confused with *carta* 'letter' [the kind sent in the mail]. Ranked in ninth place was *tutu* 'tutu', which is an English cognate, but not a very common word. Being a cognate may have caused extra negative L1 transfer for NNSs in the experiment. Even though, the stressed syllable in English 'tutu' falls on the penultimate syllable and in BP it falls on the ultimate syllable, speakers did not appear to misplace the stress in the production task. The last three tokens, *tico* 'whit' (ranked tenth), *tunco* 'Northeastern colloquialism for kiss or clicking sound of tongue' (eleventh), and *tuco* 'worker in charge of the maintenance of a railroad' (twelfth), are all quite obscure. A general principal that these observations allude to is that exposure to vocabulary items (including listening and oral practice) improve pronunciation. Overall, none of the tokens received statistically higher accent ratings than the others, so that generally speaker pronunciation is likely to improve with exposure to a language.

The most noteworthy results from the accent rating experiment were the close correlation to the acoustic results in the production experiment. Higher accent ratings correlated with shorter duration for most vowels, with the exception of [a] and [ũ]. Higher accent ratings also correlated with more native like vowel height for [a] and [ɐ̃], results that matched the acoustic analysis of the same vowels. Higher accent rating also correlated with less fronting of [u]. Although these results did not correspond with any statistically significant results in the acoustic analysis, evidence of /u/ fronting by American English speakers may explain the tendency for NNSs to front this vowel in L2 contexts. The only significant result in the multiple linear regression model used to compare accent rating with acoustic findings that defied explanation was change in intensity (Δ intensity) from nasal vowel to nasal murmur for [ɐ̃]. Greater Δ intensity resulted in a higher accent rating contrary to the hypothesis that NSs would produce the nasal vowel/nasal murmur sequence with lower Δ intensity. Intensity of the acoustic signal may be too crude of a measure to be useful for the purposes of studying nasal vowel trajectories. But overall, several acoustic cues in fact do affect a NS's perception of a talker's nonnative accent, and sometimes these cues are evidence for L1 negative transfer. The parallels between acoustic features and accent ratings are linguistically significant and statistically robust.

Theoretical Implications of Results

Theories of Speech Science and Experimental Phonetics

The findings in this dissertation support the idea that acoustic analysis is useful for learning more about the effects of L1 transfer. Also, parallels between acoustic features and accent ratings in the current study reinforce the long-standing issues that revolve around the link between perception and production. Three main theoretical camps exist regarding speech science, all of which address the relationship between perception and production in slightly different ways.

A group of speech science theories often referred to as motor theory ascribe a high level of importance to the role of movement or its sources. One such motor theory proposes that utterances are perceived in terms of intended gestures. Liberman and Mattingly used the phrase “intended gesture,” understanding that “gestures are not directly manifested in the acoustic signal or in the observable articulatory movements” (1985:3). Motor theory recognized a link between acoustic manifestations and articulatory gestures and proposed that the link is innately specified, Liberman and Mattingly acknowledged a mismatch between the two for many different reasons, one of which is coarticulation.

Other views have been classified as acoustic-auditory theories. These theories presuppose that perception and production are indirectly linked by way of shared “acoustically defined targets and auditory feedback mechanisms that operate during speech production” (Bradlow et al., 1997:2299). Instead of linking the acoustic medium to articulatory gestures, a fairly direct process of decoding sound into a representation of distinctive features is proposed. Within the sphere of acoustic-auditory theories there is the theory of acoustic invariance. Stevens and Blumstein “hypothesize that properties of speech *can* be uniquely and invariantly specified from the acoustic signal itself and that these properties are closely related to the distinctive features" (1981:2). It is said that these invariant acoustic properties are primary cues, while context-dependent cues are secondary cues. By using synthetically generated speech sounds, features boundaries are tested in the search for cues that cause listeners to recognize distinctive features. Within the theory of acoustic invariance, some promising areas of study concerning the so-called nasal murmur/tail of BP nasal vowels are the consonant-vowel and oral-nasal contrasts discussed by Stevens and Blumstein (1981 and references therein).

A third view is known as the direct-realist approach to speech perception. Contrary to motor theory, this view claims there is no specialized phonetic module. Perception and production are linked by a common communicative goal. The direct-realist approach asserts instead that the integrated perceptual systems of humans directly perceive sufficient information of events that coincide with reality from stimuli that originate from the world and from the listener's active attention to it (Best, 1995). In the case of human speech, these stimuli would originate primarily from the acoustic signal and, if a listener is looking at the speaker, from visual cues to articulation.

An example of an experimental study that demonstrated the value and efficacy of perceptual training is by Bradlow and colleagues. After three to four weeks of training on the perception of English /r/ and /l/, perception and production significantly improved for most Japanese L1 participants in the study. The results obtained, which indicated that perceptual learning transferred to improvement in production in the absence of any explicit instruction in /r/-/l/ production, point to "a unified, common mental representation that underlies both speech perception and speech production" (1997:2308). These findings are consistent in one way or another with all three theories of speech perception/production. Although the present study did not test the perception of non-native contrasts, the parallels between the acoustic analysis and NS accent rating task suggest a direct link between perception and production. With this in mind, we reaffirm the usefulness of acoustic analysis and perception tasks as complementary in the study of the acquisition of L2 sound systems.

Second Language Acquisition Theories

Best's (1995) Perceptual Assimilation Model (PAM) predicts that as listeners become more attuned to articulatory differences, their production improves. On the other hand, Flege's (1995) SLM emphasizes that improvement in production is due to a reorganization of the auditory-phonetic space (the underlying system for perception and production) which results in perceptual learning. Experienced participants in the current study showed greater progress in acquiring some of the phonetic differences between their L1 and L2, evidenced by a shorter and less fronted, thus more nativelike [u] word-finally. Improvement in the production of [u] may be due to better perception of phonetic differences in word-final vowel length and backness between the L1 and L2 sounds as proposed in SLM's Hypothesis 2. On the other hand, experienced learners may also have improved the timing and position of articulatory gestures resulting in a shorter and less fronted word-final [u].

In the present study, some vowel segments appeared to benefit from positive L1 transfer, such as high front [i] and [ĩ], in that no significant acoustic differences were found among the three groups of participants. Other vowels were influenced by negative L1 transfer, such as [u], [a] and [ɐ̃]. The vowel quality and average duration of the oral vowels [u] and [a] produced by experienced speakers were acoustically closer to the NS participant averages than were those of the inexperienced group, suggesting that level of experience in BP resulted in more nativelike pronunciation for these two vowels. On the other hand, the average vowel height for [ɐ̃] produced by experienced L2 speakers was less similar to the NS group average for the same vowel, and in fact, inexperienced L2 speakers exhibited an average vowel height for [ɐ̃] closer to that of the NSs. An explanation for this apparent “less accurate” production by the experienced speakers may not be possible from the current data. Since both [a] and [ɐ̃] were higher for inexperienced NNSs, perhaps speakers were simply mimicking the phonetic details they heard in the elicited imitation task without associating the sounds with vowel phonemes, or they may have been associating what they heard with a central English vowel, such as [ʌ]. Some plausible explanations are found in Flege’s SLM Hypothesis 6 which concludes that “the bilingual’s representation is based on different features, or feature weights, than monolinguals” (1995:239). Therefore, in regard to the contrast between [a] and [ɐ̃], the results show that neither group of L2 speakers had perceived the importance of the phonetic differences of vowel height in the oral–nasal contrast for the low-central BP vowels.

Pedagogical Implications

The second language acquisition community has frequently acknowledged the impossibility or rarity of adult L2 learners being able to achieve nativelike pronunciation in the L2. Unfortunately, some language teachers have used this knowledge as an excuse to ignore or minimize the importance of pronunciation instruction. Pronunciation instruction may have a variety of goals, intelligibility, comprehensibility, or (reduction of) accentedness. Derwing and Munro define these three terms.

> [Intelligibility is] the extent to which a listener actually understands an utterance. [Comprehensibility is] a listener’s perception of how difficult it is to understand an utterance. [Accentedness is] a listener’s perception of how different a speaker’s accent is from that of the L1 community. (2005:385).

The general consensus appears to be that comprehensibility and intelligibility are more important and attainable than accent reduction or eradication; however, a more nativelike accent has important social implications as well (Derwing & Munro, 2005; Hummel & French, 2010). No matter which goal a classroom instructor has in mind, sound teaching practices and pedagogical techniques can aid students in the process of moving toward both comprehensibility and accent reduction. The results in the present study evoke several pedagogical implications, some in the form of general principles; others are proposed as global or specific techniques.

Explicit teaching of phonological form can benefit L2 student pronunciation, especially when explanations help learners notice the differences between their own production and the speech of native or proficient speakers (Derwing & Munro, 2005). In an experimental study involving three treatment types: segmental pronunciation instruction, global prosodic instruction, and no explicit pronunciation instruction, L2 English students were recorded performing two speaking tasks at two different times: before the treatment period and after 11 weeks of classes. In the sentence reading task, both the segmental group and the global group improved their comprehensibility scores. In fact, the segmental group improved more than the prosodic group. In the picture description task, only the global group improved comprehensibility. All three groups showed improvement in accentedness for the sentence reading task and none of the groups showed improvement in accentedness in the picture description task (Derving, Munro, and Wiebe, 1998). This and other similar studies (such as Flege & Wang, 1989; Lima Júnior, 2010; and Saito, 2011) suggest that students need help realizing what they are doing and that explicit phonological instruction results in better L2 pronunciation.

Dealing with Vowels in Minimal Pairs

One general principle for foreign language teachers is that each vowel "type" (for example, high versus low, front versus back vowels) has its own inherent qualities, so contrasts such as oral versus nasal, short versus long, and so forth are best learned and practiced individually. Since BP does not contrast vowel length phonemically, the oral versus nasal contrast is most relevant here. Minimal pairs or near minimal pairs with corresponding oral and nasal vowels are more useful than explanations about the five nasal vowels in opposition to the seven oral vowels. Some possible minimal pairs are in Table 5.1.

Table 5.1 Minimal pairs for contrasting oral–nasal contrasts for five nasal vowels in penultimate and ultimate position.

Oral Vowel	Gloss	Nasal Vowel	Gloss
fá	'fa' [musical note]	*fã*	'fanatic'
prato	'plate'	*pranto*	'loud cry'
que	'what'	*quem*[5]	'who'
lebre	'hare'	*lembre*	'to remember' [3RD SING. IMPERATIVE]
ri	'to laugh' [3RD. SING. PRESENT PERFECT]	*rim*	'kidney'
Tito	'Titus' [name]	*tinto*	'tinted'
bobó (de camarão)	'(a shrimp) stew'	*bombom*	'bonbon'
lobo	'wolf'	*lombo*	'loin'
Itu	'city name'	*atum*	'tuna'
tuba	'tuba'	*tumba*	'tomb'

Although Table 5.1 presents several minimal pairs, all examples should not be covered in one sitting. To give students a chance to focus on one aspect of pronunciation, only one or two vowel contrasts should be practiced at a time, following Lee & VanPatten's (2003) proposition that teachers should focus on one structure at a time. Special attention should be paid to the vowel height changes in the [a/ɐ̃] and [e/ẽɪ̯] alternations. After hearing and repeating words in citation form, words from minimal pairs can be inserted in simple phrases, as in (8), and later into longer utterances.

8. Eu falo ____.

   'I say _____'

   Ele fala ____ também.

   'He says ____ too.'

A combination of visual and tactile techniques could be used to demonstrate and practice the vowel height difference between [a] and [ɐ̃]. Using a sagittal section of the vocal tract, a slightly lower jaw and tongue are shown for [a], then students are instructed to feel their jaw lower when pronouncing [a] in a word, such as *prato* [ˈpɾa.tu] 'plate'. Next, another sagittal section is used to show the opening of the velo-palatal port for [ɐ̃] in *pranto* [ˈpɾɐ̃ⁿ.tu] 'loud cry'. To explain that [ɐ̃] has a different vowel quality, an L1 example can be given, such as in English *pun* /pʌn/. With the *fá/fã* contrast, students can use a small mirror under their noses to test whether they are nasalizing *fã*. More condensation should show up on the mirror when saying *fã*.

For other contrasts, such as *ri* [xi] 'to laugh' versus *rim* [xĩ] 'kidney', teachers can show visually how *ri* is shorter than *rim* by drawing lines below each word as shown in (9).

9. ri

   ___

   rim

   _____

Although no clear patterns emerged in the acoustic analysis of nasal vowel trajectories, increased vowel nasalization and consonantal weakening of coda nasals should be addressed pedagogically. The timing between nasal vowel and nasal murmur do not seem to be as important as emphasizing the shortness and weakness of the nasal “appendage” or tail. This principle is easiest to demonstrate with words that end in an orthographic “m” by showing that the lips do not meet. A subsequent explanation of syllable division and then the existence of “incomplete” nasal consonants at the end of syllables would at the least raise learner awareness.

The incomplete closure of the orthographic <m> can be demonstrated visually and by putting a finger in one’s mouth to show that the lips do not close when saying *rim*. Although the articulations are not identical, the tongue movements for BP *rim* feel more like English *ring* than English *rim*.

To explain the difference between *Itu* [i.ˈtu] ‘a city in São Paulo’ and *atum* [a.ˈtũᵑ] ‘tuna’, the shortness of [u] in *Itu* can be demonstrated as it was for *ri*. Another aspect of the [u/ũ] contrast is that [u] has lip rounding, but less than for English /u/, whereas [ũ] has even less lip rounding. Although a velar nasal consonant is not present at the end of atum, the superscript [ᵑ] shows that there may be some tongue movement in the direction of the velum at the end of the word. The suggestions regarding the velar approximation or partial closure are based on articulatory evidence in research by Albano (1999) and Medeiro (2012). The purpose of the examples covered in this section is to demonstrate that each vowel contrast requires its own unique set of explanations.

Duration and Rhythmic Patterns

Since rhythmic patterns depend on speech rate and the duration of surrounding syllables, global techniques are useful for raising awareness and enabling useful practice. These involve the use of visual, tactile, and kinesthetic aids to demonstrate and perform rhythmic patterns (Celce-Murcia, Brinton, & Goodwin, 1996). An example of a visual aid designed to help students achieve proper word and phrasal stress placement is in Figure 5.1

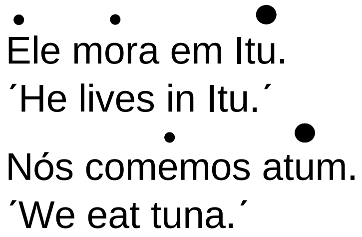

Figure 5.1. An example of a visual aid to show word and phrasal stressed syllables. English translations could be omitted in a language classroom.

The examples in Figure 5.1 are only for illustration purposes and are based on suggestions in Celce-Murcia, Briton, and Goodwin’s book. The focus of future research could be the elaboration of better visual models based on acoustic data from spontaneous speech.

Other tactile and kinesthetic techniques can be used to help students become more aware and able to produce BP prosody, such as tapping out the rhythm while listening and then speaking a phrase, using hand motions to feel stress placement, and stretching a rubber band based on syllable length within a phrase. Students can hold a rubber band or stretchy object with both hands. When a stressed or long syllable is heard or uttered, the object is stretched in proportion to the length of those syllables (Celce-Murcia et al., 2003).

Limitations and Future Directions

In the current study, the duration of some vowel segments based on prosodic location in a word uncovered some L1 and L2 language differences that cause nonnative accents. Many more vowel segments/contrasts and variations of prosodic position were not included. This study looked at six different vowel segments (3 oral and 3 nasal), but in fact, BP has a large vowel inventory including monophthongs, diphthongs, and possibly triphthongs, which all merit the attention of SLA research. This study used only disyllabic words with stress on the ultimate and penultimate syllables. Trisyllabic and longer words could be studied in the future, while looking at vowels in stressed and unstressed syllables. In addition to ultimate and penultimate stress, BP words can also have antepenultimate stress, presenting yet another variation for a future study. Furthermore, since BPs lexical stress involves a relatively complex system, future experiments will investigate the acquisition of speech rhythm by measuring and analyzing segment duration and/or vowel quality in tonic, pre-tonic, and post-tonic medial and final syllables.

Any claims regarding vowel segment duration, speech rhythm, and prosody should be considered with caution since this study only measured vowel segments in stressed position. The rhythm characterization of BP is another rich source for future studies since there is a great deal of disagreement as to how to classify BP's rhythm, a stress-timed, syllable-timed, or a combination of syllable and mora-timed. A look at BP vowel reduction may lead to more insight on the language's rhythmic characteristics as well as understanding of the challenges L2 speakers face in understanding and producing BP.

Another issue that is ripe for future work in SLA concerns the timing of the gestures between the vowel and nasal murmur. The data in the current study varied to the extent that no clear pattern emerged. We can only assume that native BP listeners have a high tolerance for a variety of nasal vowel articulations. Future studies could manipulate the timing of the nasal vowel and nasal murmur transitions to test for native-speaker acceptability.

No literature was found on the functional load of BP's oral–nasal vowel contrasts.[6] Investigations on the functional load of each possible combination of oral–nasal contrasts may yield new insights into the phonemic status of nasal vowels as well as their acquisition (Renwick, 2012).

Conclusions

The results in the present study do not indicate which one of the two theories, perceptual learning (Flege's SLM) or articulatory learning (Best's PAM), is more fitting. In fact, both modes of learning were probably at play. Notwithstanding whether L2 production improves as a consequence of a better understanding and assimilation of articulatory differences or as a reorganization of the auditory-phonetic space, the current study showed that more time of exposure to BP tended to improve production of most BP segments and features that were investigated.

The results of the acoustic analyses and accent ratings showed that each individual oral and nasal vowel presents its own level of difficulty. The accent ratings demonstrated that nasal vowels produced by NNSs do not sound any less nativelike than their oral counterparts. To the contrary, oral [u] tended to get lower accent ratings, maybe because of fronting and a slightly diphthongal nature of American English /u/. Contrary to this researcher's intuition, BP nasal vowels are not necessarily harder for L2 speakers to acquire than some oral vowels, confirming Derwing and Munro's (2005) assertions that it is unfair to expect teachers to rely entirely on intuition. As a matter of fact, curricula and teaching techniques need to be informed by empirical phonological and phonetic research.

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ENDNOTES

Chapter 2

1. A superscript [n], [m], [ɲ], or [ŋ] is sometimes used in phonetic transcription to show that the nasal coda or nasal murmur following a nasal vowel is very short and may not undergo complete closure, especially when a nasal vowel is followed by a stop or affricate but sometimes word-finally as well.

2. For a breakdown of percentages for nasal vowel configurations in tonic and pretonic syllables, see Seara (2000).

Chapter 4

3. Number of occurrences of each token in a Portuguese corpus of 45 million words (Davies & Ferreira 2006).

Tokens	Number of Occurrences
vesti [i]	53
cristã [ɐ̃]	725
está [a]	47,295
atum [ũ]	144
patim [ĩ]	33
tinto [ĩ]	155
canta [ɐ̃]	1,045
cata [a]	255
tutu [u]	278
tico [i]	52
tunco [ũ]	0
tuco [u]	0

4. In reference to outliers in the linear regressions, Love-Myers wrote, “I reviewed residual plots and histograms of the residuals from those regressions, and found no strong evidence of outliers that should be taken into special consideration in the analysis. One slightly more technical method is to check the standardized residuals and look for absolute values greater than 2 (95% of standardized residuals should have absolute values less than 2); in each case, only one or two of these was found with values not much larger than 2, which is actually expected when you have 30 observations (5% of standardized residuals would reasonably be outside this range)” (K. Love-Myers, personal communication, November 21, 2014).

Chapter 5

5. Although all nasal vowels have some diphthongal quality to them, for the nasal counterpart of the /e/ and /ɛ/ it is especially important to emphasize that the nasal from [ẽɪ̯] ends with a glide obligatorily in word-final position and often in word-internal syllables, depending on regional accent.

6. Regarding the functional load of the oral–nasal vowel contrasts, in Portuguese grammar, the diphthong represented by either <ão> (in a tonic syllable) or <am> (in an atonic syllable) is an important part of inflectional morphology in distinguishing between 3rd person singular and 3rd person plural of several verb tense/aspect inflections. Here are two examples:

1. *falar* (PRESENT INDICATIVE)

fala	[ˈfa.lɐ]	‘s/he speaks’	(3RD PERSON SING.)
falam	[ˈfa.lɐ̃ɯ̯]	‘they speak’	(3RD PERSON PL.)

2. *falar* (FUTURE)

falará	[fɐ.lɐ,'ɾa]	‘s/he will speak’	(3RD PERSON SING.)
falarão	[fɐ.lɐ.'ɾɐ̃ɯ̯]	‘they will speak’	(3RD PERSON PL.)

APPENDIX A

TOKENS IN THE PRODUCTION AND ACCENT RATING EXPERIMENTS

Translations and Pronunciation Guide for Portuguese

Every Participant Heard this Token First

1. *quinta* /'kĩ.tɐ/ ‘Thursday, fifth’

Tokens with Target Vowels

2. *cata* /'ka.tɐ/ ‘to gather’ 3RD SING., PRESENT INDICATIVE

3. *canta* /'kɐ̃ⁿ.tɐ/ ‘to sing’ 3RD SING., PRESENT INDICATIVE

4. *tuco* /'tu.kʊ/ ‘worker in charge of the maintenance of a railroad’

5. *tunco* /'tũᵑ.kʊ/ ‘Northeastern colloquialism for kiss or clicking sound of tongue’

6. *tico* /'t͡ʃi.kʊ/ ‘tiny bit’

7. *tinto* /'t͡ʃĩⁿ.tʊ/ ‘tinted’

8. *está* /es.'ta/ ~ /eʃ.'ta/ ‘to be’ 3RD SING., PRESENT INDICATIVE

9. *cristã* /kris.'tɐ̃/ ~ /kriʃ.'tɐ̃/ ‘Christian’ FEM.

10. *tutu* /tu.'tu/ ‘a dish made with beans, or tutu (ballerina’s skirt)’

11. *atum* /a.'tũ/ ‘tuna’

12. *vesti* /ves.'t͡ʃi/ ~ /veʃ.'t͡ʃi/ ‘to dress onself' 3RD SING., PRETERIT

13. *patim* /pa.'t͡ʃĩ/ ‘skate’

Tokens Used as Distractors

14. *sofá* /so.'fa/ 'sofa'

15. *olá* /o.'la/ ‘hello’

16. *aqui* /ɐ.'ki/ ‘here’

17. *tudo* /'tu.dʊ/ ‘everything’

18. *maçã* /mɐ.'sɐ̃/ ‘apple’

19. *data* /'da.tɐ/ ‘date’

APPENDIX B

DEMOGRAPHIC QUESTIONNAIRE

For researcher use

Research Code:

Instrument 1

Questionnaire

Gender: ______ Male ______ Female Age _______ First language(s) ____________________

How many semesters have you studied Portuguese? ____________________

Are you a heritage speaker or were you exposed to Portuguese before you started taking Portuguese as an academic subject? If yes, please explain. ______________________________

____

Why are you taking Portuguese? ____

My overall average grades in Portuguese are (check one)

____ A ____ A- ____ B+ ____ B ____ B- ____ C+ ____ C ____ C- ____ D or lower

How would you rate yourself at the following Portuguese language skills?

	Novice	Intermediate	Advanced	Native-like or Native
Reading				
Writing				
Listening				
Speaking				

What other foreign languages do you know or have you studied? __________________________

____

How well do you know these other languages? ____

Have you ever been to a Portuguese-speaking country? __________________________________

If yes, which one? ____

How long were you there? ____

What did you do there? ____

____

Have you ever been diagnosed with a hearing impairment? ______________________________

Is there any other information that you would like to add to this questionnaire?

APPENDIX C

SAMPLES OF CONSENT FORMS

Consent Form for Production Experiment

CONSENT FORM

I, _________________________________, agree to participate in a research study titled "The acquisition of Brazilian Portuguese sounds" conducted by Suzanne Franks from the Linguistics Program at the University of Georgia (706-542-5099) under the direction of Dr. Don McCreary, Linguistics Program, University of Georgia (706-542-2231). I understand that my participation is voluntary. I can refuse to participate or stop taking part at anytime without giving any reason, and without penalty or loss of benefits to which I am otherwise entitled. I can ask to have all of the information about me returned to me, removed from the research records, or destroyed.

The reason for this study is to investigate the acquisition of certain Brazilian Portuguese sounds. If I volunteer to take part in this study, I will be asked to do the following things:

1) **Answer a short questionnaire about the languages I know and have studied.**
2) **Listen and repeat sentences in Portuguese, which will be recorded for acoustic analysis**

The procedures will take 30 minutes or less.

All of the information collected will be confidential and will only be used for research purposes. This means that my identity will be confidential; in other words, an identifying number will be assigned to my questionnaire and data, and no one besides the researcher will know my name. Whenever data from this study are published, my name will not be used. The data will be stored on a computer, and only the researcher will have access to it.

There are no specific benefits for participating in this experiment. There is no risk involved in participating in this experiment.

I will not be paid for participating in this study.

The investigator will answer any further questions about the research, now or during the course of the project. If I have any questions about the research, I may contact Suzanne Franks by telephone at 706-352-9397, by email scfweb@uga.edu**, or in person at the office in 102 Gilbert Hall.**

I understand that I am agreeing by my signature on this form to take part in this research project and understand that I will receive a signed copy of this consent form for my records.

Suzanne Franks **Name of Researcher** **Telephone: 706-389-6484** **Email:** scfweb@uga.edu	______________________ **Signature**	__________ **Date**
Dr. Don McCreary **Supervising Professor** **Telephone: 706-542-2231** **email:** mccreary@uga.edu	______________________ **Signature**	__________ **Date**
________________________ **Name of Participant**	______________________ **Signature**	__________ **Date**

Please sign both copies, keep one and return one to the researcher.

Additional questions or problems regarding your rights as a research participant should be addressed to The Chairperson, Institutional Review Board, University of Georgia, 629 Boyd Graduate Studies Research Center, Athens, Georgia 30602; Telephone (706) 542-3199; E-Mail Address IRB@uga.edu.

Consent Form for Accent Rating Experiment

CONSENT FORM

I, __________________________________, agree to participate in a research study titled "The acquisition of Brazilian Portuguese sounds" conducted by Suzanne Franks from the Linguistics Program at the University of Georgia (706-542-5099) under the direction of Dr. Don McCreary, Linguistics Program, University of Georgia (706-542-2231). I understand that my participation is voluntary. I can refuse to participate or stop taking part at anytime without giving any reason, and without penalty or loss of benefits to which I am otherwise entitled. I can ask to have all of the information about me returned to me, removed from the research records, or destroyed.

The reason for this study is to investigate the acquisition of certain Brazilian Portuguese sounds. If I volunteer to take part in this study, I will be asked to do the following things:

3) Answer a short questionnaire about the languages I know and have studied.

4) Listen to words and/or phrases in Portuguese and make judgments about the sounds I hear.

The procedures will take about 20 minutes.

All of the information collected will be confidential and will only be used for research purposes. This means that my identity will be confidential; in other words, an identifying number will be assigned to my questionnaire and data, and no one besides the researcher will know my name. Whenever data from this study are published, my name will not be used. The data will be stored on a computer, and only the researcher will have access to it.

There are no specific benefits for participating in this experiment. There is no risk involved in participating in this experiment.

I will not be paid for participating in this study.

The investigator will answer any further questions about the research, now or during the course of the project. If I have any questions about the research, I may contact Suzanne Franks by telephone at 706-352-9397, by email scfweb@uga.edu**, or in person at the office in 102 Gilbert Hall.**

I understand that I am agreeing by my signature on this form to take part in this research project and understand that I will receive a signed copy of this consent form for my records.

Suzanne Franks **Name of Researcher** **Telephone: 706-389-6484** **Email:** scfweb@uga.edu	______________________ **Signature**	__________ **Date**
Dr. Don McCreary **Supervising Professor** **Telephone: 706-542-2231** **email:** mccreary@uga.edu	______________________ **Signature**	__________ **Date**
________________________ **Name of Participant**	______________________ **Signature**	__________ **Date**

Please sign both copies, keep one and return one to the researcher.

Additional questions or problems regarding your rights as a research participant should be addressed to The Chairperson, Institutional Review Board, University of Georgia, 629 Boyd Graduate Studies Research Center, Athens, Georgia 30602; Telephone (706) 542-3199; E-Mail Address IRB@uga.edu.

APPENDIX D

INSTRUCTIONS FOR THE ACCENT RATING TASK

You will be presented with a series of short sentences in Portuguese spoken by native or non-native speakers.

Please select a number between 1 and 8 to rate how **nativelike** the phrase sounds to you.

Press 1 on your keyboard to rate a phrase that sounds very non-native.

Press 8 on your keyboard to rate a phrase that sounds very native.

Press a number between 1 and 8 for phrases that are somewhere between very non-native and very native.

How native does this phrase sound to you?

Very Non-native			←	→			**Very Native**
1	2	3	4	5	6	7	8

While the sound files are playing, nothing of importance is displayed on screen.

Press the SPACEBAR to start the PRACTICE session.

You will hear 8 practice sentences for you to rate.

Then you will see:

Press the SPACEBAR to start the EXPERIMENT.

When the experiment is finished, a dial tone will play.

(TRANSLATION TO PORTUGUESE)

INSTRUÇÕES PARA ATIVIDADE DE AVALIAÇÃO DE SOTAQUE

Você ouvirá uma série de frases em Português faladas por falantes nativos e não nativos de Português.

Por favor, selecione um número entre 1 e 8 para classificar quão **nativa** a frase soa para você.

Pressione 1 no teclado para classificar uma frase como **muito não nativa.**

Pressione 8 no teclado para classificar uma frase que soa **muito nativa.**

Pressione um número entre 1 e 8 para frases que caem em algum lugar numa escala de muito não nativa e muito nativa.

Quão nativa esta frase soa para você?

Muito Não nativa			←	→			**Muito Nativa**
1	2	3	4	5	6	7	8

Enquanto as frases estão tocando, nada de importante aparecerá na tela do laptop.

Pressione a BARRA DE ESPAÇO para começar a sessão de PRÁTICA.

Você ouvirá 8 frases para serem classificadas durante a sessão de prática.

Depois você verá:

Pressione a BARRA DE ESPAÇO para começar o EXPERIMENTO.

“Press the SPACEBAR to start the EXPERIMENT.”

Quando o experimento terminar, você ouvirá um aviso sonoro (bipe).