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Perception and Production of Canadian English Vowels by L1 Spanish Speakers

Santiago Barreda
Western University

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Santiago Barreda

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	Chet Creider

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Santiago **Barreda**

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Abstract

The present study investigates the perception and production of Canadian English (CE) vowels by L1 Spanish speakers who began acquisition of CE as adults. The objective was to determine which CE vowels will be difficult for Spanish speakers to discriminate and how this may affect the ability to produce the same vowel in a native-like fashion.

To this end, the perception and production of the CE phonemic monophthongs /i, ɪ, e, ɛ, ʌ, æ, ɑ, o, ʊ, u/ by two groups was compared: A group of L1 Spanish, L2 Canadian English (CE) end-state speakers who began acquisition of English as adults (n = 11) and a group of native English speakers (n = 9).

Participants were asked to perform a perception task and a production task. The perception task was a rhyming task in which participants were presented with an auditory stimulus word and asked to indicate which word from a list they felt the stimulus rhymed with. The list of possible response words contained one monosyllabic word of the type CVC for each of the ten CE vowels of interest. Both groups were asked to perform this task. The production task consisted of two reading lists, one of Spanish words and one of English words. The reading lists contained six words meant to elicit each of the ten CE monophthongs and each of the five Spanish monophthongs /a, e, i, o, u/. The L2 CE group was asked to read both lists and the L1 CE group was asked to read only the English word list.

Results indicate that production is not necessarily indicative of perception. In three cases, vowels were produced based on orthographic representation and not primary linguistic data. The CE vowels /ɪ, ɛ, ɑ/ are perceived as variants of Spanish /e, a, a/ respectively, yet they are produced as variants of Spanish /i, e, o/. In each case, the CE vowel is pronounced as an instance of the Spanish vowel which would be indicated by the vowel grapheme used in the English reading list.

These results call into question some vowel contrasts traditionally thought to be problematic, specifically /i/-/ɪ/ and /ɛ/-/e/. Also, the possibility of a paralinguistically motivated perception-production misalignment calls into question any phonological theory in which the symbolic units of representation are primarily auditory or gestural in nature.

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Chapter One

1. Theoretical Background

1.1 The initial condition

Theories of L1 phonological acquisition that depend on innate knowledge regarding features or articulatory specifications are not flexible enough to account for the adaptability of the human language faculty. When describing this adaptability, linguists frequently reference the fact that babies exposed to sign language babble with their hands in the same way that speaking children babble orally (Petitto et al 2004). Even though this connection is frequently made, linguists generally fail to account for how their descriptions of the acquisition of spoken language phonemes can be extended to include sign languages, which are themselves presumably governed by the language faculty common to all humans (Brentari 1998). Any phonological theory should also be able to account for whistled languages (Brusis 1972, Busnel 1976) and language conveyed through any medium which employs the human language faculty. Recent studies using brain imaging techniques have shown that the brains of speakers of whistled (Carreiras et al 2005) and signed languages (Hickok et al 1997) show activity in Wernicke's and Broca's areas when performing language acts. These areas of the brain are central to language processing; this suggests that the language faculty is independent of the particular medium through which language is relayed.

Any account of how minimally distinctive speech units are established and contrasted should be as flexible as the human language faculty itself. The assertion that a child is born with innate knowledge of the complete set of primitives (whether they be features, articulatory configurations or any other descriptive information) necessary to describe all phonemes[1] of spoken language entails that if sign language can be acquired in the same way, and using the same faculties with which spoken language is acquired, then all children must also be born with innate knowledge regarding the complete set of primitives necessary to describe sign language phonemes. It also follows from this that all humans must be born with innate knowledge regarding the complete set of primitives which exhaustively describe all possible phonemes across all methods of communication which humans could plausibly use to convey phonemes[2]. This is, in effect, to say that a child is born with the complete set of all primitives needed to describe all the actions that it can perform or experience which might be considered phonemes.

So what delimits the set of phonemes? All and only those phonemes that are describable in terms of primitives can exist. And what delimits the set of primitives? All and only the primitives necessary to describe all possible phonemes that exist. They are defined only in terms of each other. The set of phonemes and necessary primitives (or the set of primitives and resulting phonemes, depending on which part of the loop one begins) are possibly infinite and unquantifiable.

Apart from spoken, signed and whistled languages, the media through which language may be conveyed are, while not infinite, not clearly definable. Are proficient listeners of Morse code performing language by converting beeps into phonemes? It involves a simpler, yet similar, sort of auditory pattern recognition as that involved in orally produced speech. The case for body language being included in this discussion may be rejected by a majority of linguists but what about the interplay between sign language

[1] The term 'phoneme' will be used to refer to minimally contrastive speech units of language regardless of the medium.

[2] Plausibly as determined by the physiological limitations imposed by the body's sensory systems and language's requirement that the medium be able to transfer large amounts of information in whatever form it may appear. The necessary plausibility of the language conveying medium will be assumed in the discussion to follow.

and body language? Can a clear separation even be made? How can one make an empirical statement regarding the possible limits of human language?

The language faculty cannot assign primacy to any specific form of language which it performs; all must be equal. In fact, to say that, for example, non-spoken language is 'learned' in a way not facilitated by an innate disposition is an argument against any innate knowledge of language whatsoever. If a system capable of transmitting information with a level of complexity comparable to spoken language can be learned without innate knowledge in one case, recourse to innate knowledge should be unnecessary in other cases.

This means that if one primitive is innate, then necessarily, all primitives that exist must also be innate. In the end what is being posited is a possibly infinite and unquantifiable set of primitives, all of which are known innately. One way to get around this is to say that only some features, those that describe language across one or more particular mediums is innate. If it is true that all language is governed by the language faculty that is shared by all humans then this cannot be the case. A child cannot possibly know what environment it will be born into and yet a deaf child will acquire sign language, a normally-hearing child will acquire spoken language, and so on. Together the primitives can represent the complete set of things which can be interpreted as phonemes by humans, where phonemes are defined as minimal language units that can be defined in terms of primitives; this circular definition provides no way to delimit or constrain the set of possible primitives and phonemes.

It is unclear how this unconstrained set of innate primitives could possibly be a result of evolution. However, if primitives are innate, and they are a finite set flexible enough to describe *all* sensory input that may constitute a phoneme, these primitives impose no limits on language since only sensory input that may constitute a phoneme may constitute a phoneme. Because of this, the statements 'all primitives are innate' and 'all primitives are acquired' become functionally equivalent propositions since neither places any limits on the set of possible phonemes *per se*. None of the above is meant to deny the existence of primitives below the level of the phoneme but is simply an argument against the suggestion that they must be innate. However, a consequence of this is that no set of features is more or less 'correct' than any other except to the extent to which they fit a particular set of data.

If linguistics is to describe *all* human language and not simply *spoken language*, then all forms must be considered equally representative of the language faculty and only those theories that are potentially tenable across mediums can accurately describe the human language faculty as it really is. If the goal of phonology is to model psychological reality then this is a nontrivial consideration. Given that language exists only in the mind, if the goal is not to model psychological reality then it is unclear what exactly is being modeled.

The fundamental similarity between all forms of language conveyed through whatever medium is that any given language in any medium will have certain patterns which tend to appear frequently and other patterns which are seldom experienced at all. The following discussion will limit itself to spoken language and to vowels in particular but will be formulated in a way which could be extended to human language conveyed across any possible medium.

First, the ways in which the native language (L1) phonemes are established will be discussed. I will then discuss what kind of information constitutes our knowledge of the phoneme and how this may affect the acquisition of second language (L2) sounds. The vocalic and orthographic systems of the two languages will then be discussed followed by an overview of some relevant previous studies.

1.2 Acquisition of L1 phonemes

Kuhl (2007) suggests that the acquisition of phonemes in the L1 consists of the neural commitments of the brain's circuits. Children combine an acute sense of pattern recognition and statistical learning to categorize speech sounds in their environment into phonemes, "groups of non-identical sounds, called phonetic units, which are functionally equivalent in the language" (1). For example, on a physical level the vowel /i/ may vary in nearly infinite ways when produced by different people and in different contexts but all realizations of the phoneme will be treated as functionally equivalent to speakers of a language in which /i/ is a phoneme. The boundaries between phonemes are not accidental but dependant on the perceptual abilities of human beings (Kuhl 1991a). The infant then refines the boundaries between categories as it is exposed to the language. A phonemic representation is established and this phoneme exerts a 'perceptual magnet effect' in which the perceived dissimilarity of a phoneme and a phonetic realization is inversely related to the physical similarity of the two (Kuhl 1991b, 1995). The inverse has also been found, that listeners show increased sensitivity to differences between segments at or near their L1 category boundaries (Abramson & Lisker 1970).

On what basis might the phonemic categories be hypothesized? The distribution of speech sounds in a language tends to be such that phonetic realizations of phonemes tend to occur less frequently near phonemic boundaries (Kuhl 2007, Nearey & Hogan 1986). Infants as young as 6 months old show awareness of, and can make classifications based on, the distributions of the sounds patterns in their environment (Maye et al 2002). This is not to say that acquisition of phonemes is only simple pattern recognition, it also involves environmental factors that exert unknown pressures on the language faculty (Kuhl et al 2003).

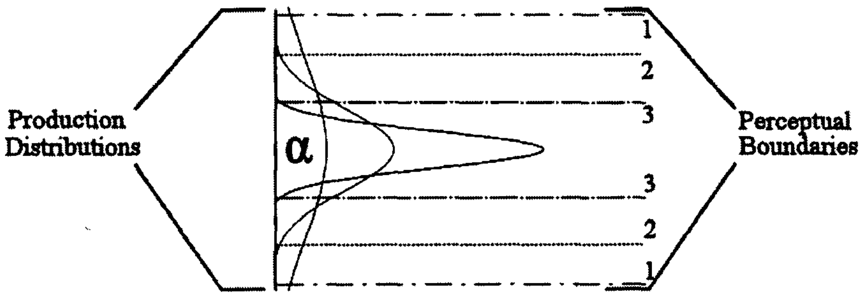


Figure 1.1- A visual representation of the interplay between the production distribution and the category boundary of a phoneme.

Figure 1.1 shows three different possible distributions for an acoustic cue. These three frequency distributions are those of the same phoneme, /ɑ/, along the same dimension across three different languages. As an example, the property could be tongue height in the specification of /i/. Languages with only one high, front vowel, such as Quechua, will see considerable variation in height in the phonetic realization of /i/; this will lead to a production distribution as in (1) in Figure 1.1, which will result in a wide tolerance of 'height' values. A language with several high front vowels, such as German, will have less variation in the height of any one particular vowel; a large deviation in height may cause a vowel to drift into the phonetic territory of a neighbouring vowel. In this case, the production distribution will resemble (3) in 1.1. The boundaries set around a cue are inversely related to the variance of the production distribution so that higher peaks result in tighter category boundaries. The 'weight' of a cue is the relative importance given to it by listeners when making a categorical decision. The acquisition of L1 phonemes requires not only awareness of which dimensions are contrastive for that phoneme but also an awareness of the relative weights given to each dimension for that phoneme by the L1; speakers of languages that give different weighs to the same cue, for example vowel length, will perceive vowels in systematically different ways (Munro 1992).

The complete description of a vowel could be thought of as an *n*-dimensional polytope where the boundary for each dimension is the result of the distribution properties of the cue along that dimension, for that phoneme, in that dialect. It is important to note that all dimensions along which a vowel may vary are present in all actualizations of a vowel, whether an appropriate setting is specified or not. For example, in a language in which length is not contrastive, the specification of vowels will not include clearly defined boundaries regarding the length of the vowel. However, this does not mean that vowels in this language do not posses length; for obvious reasons the realization of any vowel involves a length of time.

Since a phoneme is defined in terms of the distribution of its properties in the speech input, its boundaries are defined by the frequency distribution of the relevant properties; more typical tokens of the phoneme are more likely to occur and less typical tokens are progressively rarer. The listener then must categorize the phoneme based on the frequency distributions of all relevant contrastive dimensions.

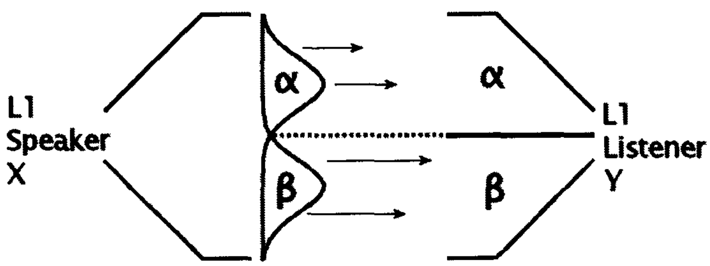


Figure 1.2– A two-dimensional representation of L1 communication. See text (adapted from Morrison 2006).

In Figure 1.2, we see communication between a speaker and a listener of the same language. The two vowels /α/ and /β/ differ along one dimension; this could represent tongue height or backness, length or any other dimension along which vowels can be contrasted. In this case, and in the case of all intra-language communication, there is an optimal, or near-optimal, alignment between the frequency distributions of phonemes, along all relevant dimensions, and the perceptual category boundaries that define those phonemes along the same dimensions.

1.3 L2 phonological acquisition

The acquisition of an L2 is different from the acquisition of an L1 in several important ways. By the time an L2 is learned, competence in an L1 has already been established. Since the L1 phonology is charged with categorizing speech sounds, the L2 is in a sense learned 'through' the L1. A consequence of this is that certain L2 sounds and contrasts will be more difficult to acquire than others.

The Speech Learning Model, or 'SLM' (Flege 1995, 2005) is a broad theory that accounts for all aspects of phonological L2 acquisition. SLM suggests that accurate production follows from accurate perception. Although this may not necessarily be true of consonants, it seems likely to be the case for vowels. For example, Canadian English /ε/ appears halfway between Spanish /a/ and /e/. Spanish speakers will pass through the necessary articulatory configuration to produce /ε/ when producing an /ae/ or /ea/ vocalic sequence, both of which are unexceptional in Spanish. Spanish speakers who do not produce Canadian English /ε/ in a native-like manner fail to do so only because they fail to place the tongue in the proper position and not because they lack the ability to do so. In these models, the failure to replicate an acoustic pattern is attributable to an inadequate mental representation of the same pattern and this is itself attributable to perceptual problems. An outline of the relevant proposals of the SLM is seen in Table 1.1 below.

The SLM proposes that:
• The processes and mechanisms that guide successful L1 speech acquisition remain intact and accessible across the life span. • Category formation for an L2 phoneme becomes less likely through childhood as representations for neighboring L1 sounds develop. • L1 and L2 phonemes exist in a common phonological space, and so mutually influence one another. • The greater the perceived dissimilarity of an L2 phoneme from the closest L1 phoneme, the more likely a new category will be formed for the L2 phoneme. • When a category is not formed for an L2 sound because it is too similar to an L1 counterpart, the L1 and L2 categories will assimilate, leading to a merged representation of the respective L1 and L2 phonemes.

Table 1.1 - An outline of SLM. Adapted from Flege (2005).

Perfect acquisition of a phoneme refers to perception and production of an L2 phoneme in a native-like manner along all relevant dimensions; it is up for debate whether this is ever possible. Regardless of that fact, second languages are acquirable at least to some degree. Although a foreign accent, no matter how slight, is evidence that a speaker's phonology is somehow different from that of a native speaker, if an L2 learner has learned to discriminate all minimal pairs in the target language in a significant proportion of cases, acquisition of the L2 phonemes has reached what I will call Practically Sufficient Attainment (PSA). Practical sufficiency is reached when a learner is sensitive to at least enough properties of every L2 phoneme to distinguish it from every other L2 phoneme.

PSA is different from simple 'attainment' or 'acquisition' in the following way. Imagine that two species of parrot are distinguished in two ways: one is blue and has a long beak, while the other is green and has a short beak. Two people, one who is colourblind and another who is not, will be able to distinguish these two parrots, the latter on the basis of colour and beak size and the former only on the basis of beak size. When describing these parrots, the colourblind person's description will not include contrastive colour information yet it will contain enough information to contrast the two parrots. The colour-discriminating person has a more 'complete' conceptualization of the two species of parrot, yet on a functional level, both have adequate knowledge to make the necessary distinctions. It can be said that although only the colour-discriminating person has a 'complete' conceptualization of the object, both people have practically sufficient knowledge of it.

Although PSA may mean different things for different levels of linguistic competence, the fundamental function of a phoneme is simply to be contrasted from every other phoneme. The following sections will deal with why cross language speech perception should be a problem, the different sorts of assimilatory processes that occur and the perceptual problems these processes lead to.

1.3.1 Why perceptual problems occur

There is general agreement that L2 speech sounds are, at least initially, perceived in relation to, or, in terms of, the L1 (see: Bohn 1995). The category boundaries of the L1 do not necessarily coincide with the category boundaries of the L2 because the distributional properties of the two languages may not coincide. Two languages may differentiate the same phoneme along different numbers of dimensions, also, each of these dimensions may be weighted differently in the two languages. A misalignment in any of these settings along any dimension may result in perceptual difficulties.

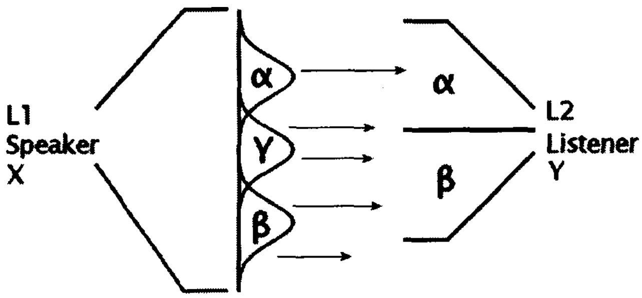


Figure 1.3 – A two-dimensional representation of L1-L2 communication. On the left are the production distributions, on the right are the perceptual category boundaries (adapted from Morrison 2006).

In the example above, three vowels, /α/, /β/ and /γ/ differ along one dimension in two different languages. Whereas the listener's category boundaries were perfectly attuned to the L1, the misalignment between the frequency distributions of the L2 vowels and the category boundaries of the L1 will result in problems in perception. In this case, most, if not all, instances of /α/ will be classified correctly. Although /β/ appears lower than it does in his L1, listener Y will be able to classify most instances. The classification, and as a result, the acquisition of /γ/ will be extremely problematic for listener Y. Most instances of /γ/ will be assimilated to /β/, some will assimilate to /α/ and some, those that fall on or close to the category boundary will be classified correctly at the level of chance.

1.3.2 How languages are assimilated into the L1

The Perceptual Assimilation Model or 'PAM' (Best 1995) offers an account of how an L2 is heard through the L1; it also provides a way to describe the different sorts of assimilatory processes seen in Table 1.1 above. PAM posits that all foreign speech sounds will be filtered through the L1. As a result of this, all foreign speech sounds will be categorized in terms of the native language. The result of this assimilation of foreign sounds into L1 categories will be one of three possibilities seen in Table 1.2.

Degrees of assimilation of L2 sounds:
1. Assimilated to a native category. a. a good exemplar of that category. b. an acceptable but not ideal exemplar of that category. c. a notably deviant exemplar of that category. 2. Assimilated as uncategorizable speech sound. In this case the sound is accepted as speech but is not categorizable in terms of any L1 phoneme. 3. Not assimilated to speech, interpreted as a non-speech sound.

Table 1.2 – PAM, adapted from Best (1995).

The PAM posits that the degree of discriminability between any two L2 sounds can be predicted based on the way in which each L2 sound has been assimilated in terms of the L1. An overview of the most common assimilation patterns is seen in Table 1.3 below.

Relative difficulty of discrimination of L2 phonemes depending on assimilation patterns:
1. **Two-Category Assimilation**: sounds are assimilated into two different L1 categories, discrimination will be <u>excellent</u>. 2. **Uncategorized vs. Categorized**: One sound is assimilated into an L1 category, the other falls in the phonetic space but outside any L1 category, discrimination will be <u>very good</u>. 3. **Nonassimilable**: Both sounds fall outside the phonetic space and are treated as non-speech sounds, discrimination will be <u>good to very good</u>. 4. **Category-Goodness Difference**: both sounds are assimilated into one L1 category but differ in goodness of fit. Discrimination will be <u>moderate to very good</u>, depending on the relative goodness of fit of the two tokens . 5. **Single-Category Assimilation**: both sounds are accepted as equally good exemplars of the same L1 category, discrimination will be <u>poor</u>. 6. **Both Uncategorizable**: both sounds fall within the phonetic space but do not assimilate into any L1 category, discrimination will depend on the nature of the sounds and the L1 categories.

Table 1.3 - PAM, adapted from Best (1995).

Using the SLM and the PAM one can describe the problems in acquisition that speakers of an L1 can expect to encounter when trying to attempting to reach Practically Sufficient Attainment in a particular L2. To know this one must find what the nature and degree of assimilation is for each L2 phoneme in terms of the L1. A discussion of how the chosen methodology will answer these questions can be found in § 2.5.

1.4 The Vowels of Spanish and of Canadian English

The vocalic systems of both Spanish and English are composed both of monophthongs and diphthongs; only the monophthongs of the two systems are relevant to this study. Spanish has five monophthongs /a, e, i, o, u/ which are relatively stable across all dialects. Morrison & Escudero (2007) conducted an acoustic study of the vowels of Peruvian and Peninsular Spanish, two very geographically and historically different dialects. The mean formant frequencies for the five vowels across 17 speakers of each dialect are given in Figure 1.4 below. Morrison & Escudero (2007) concluded that the vowels of the two dialects are similar enough that speakers of the two dialects could be pooled into a single experimental group without adverse effects.

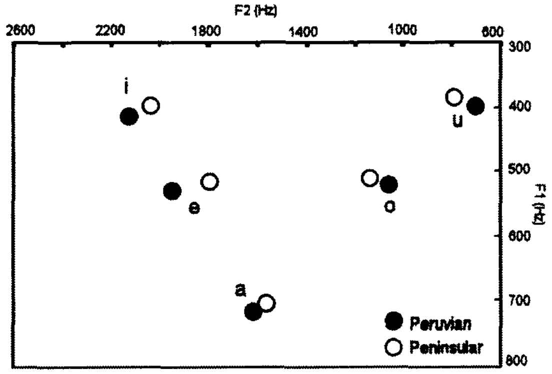


Figure 1.4- The vowels of Peruvian and Peninsular Spanish (Modified from Morrison & Escudero 2007)

North American varieties of English generally have the nine monophthongs /i, ɪ, ɛ, ʌ, æ, ɑ, ɔ, ʊ, u/ as in the words *bit, beet, bet, but, bat, cot, caught, book, boot.* There are also two phonetic diphthongs /e, o/ ([eɪ, oʊ]), as in the words *bait* and *boat.* These two vowels are realized with varying levels of diphthongization and are generally interpreted as being one single vowel by North American English speakers. Most North American English monophthongs are produced with a steady movement of the vowel nucleus; this movement is also crucial for the perception of vowels (Assmann et al 1982, Assmann & Katz 2005, Morrison & Nearey 2007). Despite this, on a phonemic level, the aforementioned vowels are treated as single units and so, for the remainder of this study, mention of the monophthongs of English will refer to all phonemic monophthongs, regardless of their varying levels of inherent spectral change.

The following description of General Canadian English (GCE) is from the *Atlas of North American English* (Labov et al 2006) and pertains to the variety of English generally spoken between Vancouver and Ottawa. The GCE vocalic system is characterized by the low back vowel merger and the resulting Canadian shift. The vowels /ɑ/ and /ɔ/, as in *cot* and *caught*, have merged in GCE so that all cases of /ɔ/ have been replaced with /ɑ/. Speakers of GCE will pronounce and perceive the pair *cot* and *caught* as two instances of the same vowel. This merger resulted in empty space in the inventory which, it is assumed, caused the Canadian shift. The back vowel merger allowed /æ/ to move back which allowed both /ɛ/ and /ɪ/ to move down. (For more information on the Canadian shift in Vancouver, Winnipeg, Montreal and St. John's see: Clarke et al 1995, Hagiwara 2006, Boberg 2005, Hollett 2006.)

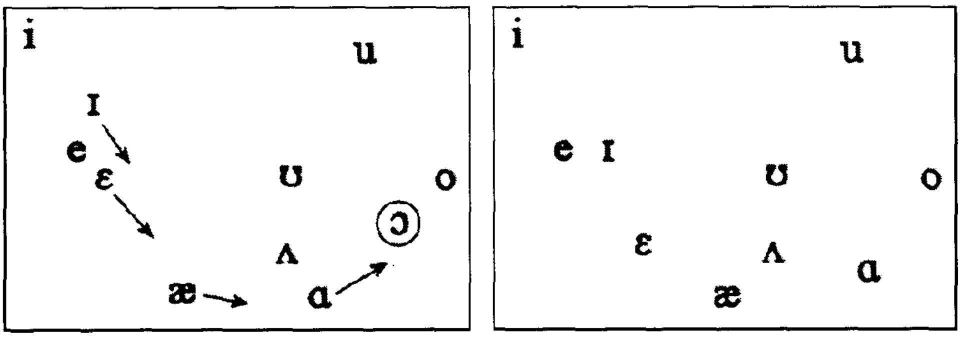


Figure 1.5 – On the left, the back vowel merger and resulting drag chain are represented. On the right, the resultant GCE inventory.

The systems of both English and Spanish include rounded back vowels and unrounded front vowels; therefore rounding is not a contrastive feature. Although nasal vowels are sometimes the result of phonological processes, nasality is not contrastive either in either language. English vowels have inherent length differences, for example, in identical contexts /æ/ will tend to be longer then /ɛ/. The length of a vowel is subject to phonologically conditioned changes, for example, vowels tend to be longer when a voiced stop is in the coda relative to a voiceless one. This can result in the masking of the inherent length differences of vowels, for example (where quantity refers to length): /bɛt/ ≤ /bɛd/ ≈ /bæt/ ≤ /bæd/. Gottfried & Beddor (1999) and Bohn & Flege (1990) have found that English speakers only use length distinctions to classify vowels in the most spectrally ambiguous of cases. Length is not contrastive in Spanish.

Although the systems of the two languages are quite different in some ways, they are quite similar in others. The spectral characteristics of a vowel are the primary source of information for identification of vowels in both languages. Because of this, a comparison of the two vocalic systems using an F1-F2 plane is thought to convey enough information to investigate Practically Sufficient Attainment. A brief overview of F1-F2 planes can be found in § 2.4.3.

1.4.1 The Spanish and English Writing Systems

The orthographic systems of both Spanish and English are based on the Roman alphabet. Vowels in both writing systems are generally represented with one, or a combination of the five vowel graphemes of Latin 'a, e, i, o, u' (English also uses 'y'). Spanish has a one-to-one grapheme to phoneme relationship in which each of the five phonemes /a, e, i, o, u/ is consistently represented with the each of the graphemes 'a, e, i, o, u' respectively. Although it uses the same graphemes, English has a fairly inconsistent and opaque writing system. The most common written representations for each of the CE vowels can be seen in Table 1.4 below (Edwards 2003).

æ	
a	97%

ɑ	
o	94%

ɛ	
e	91%

ʌ	
u (-e)	86%

ɪ	
i	68%
y	23%

o	
o	73%
o (-e)	14%
oa	5%

i	
e (-e)	70%
ee	10%
ea	10%

e	
a	45%
a -e	35%
ai	9%

ʊ	
u	54%
oo	31%
ou	7%

u	
oo	38%
u	21%
u -e	7%

Table 1.4 - Most common orthographic representations of GCE vowels.

Even where generalizations can be made about one vowel (97% of cases of /æ/ are spelled by 'a'), they often conflict with trends observed for others (45% of cases of /e/ are also spelled by 'a').

1.4.2 Distinctive features

This section will briefly outline the idea of distinctive features as used to describe phonemes. The idea behind features is that phonemes have an internal structure, in fact, phonemes can be thought of as a bundle of features. Features are either present in a signal (+) or they are not (-). Specific combinations of features present in the signal elicit the sensation of having perceived the phoneme defined by the set of those features.

The features used to describe the vowels of Spanish and English are seen in Table 1.5 below. The features 'high', 'front', 'low' and 'back' relate to the position of the tongue during articulation of the vowel; 'rounded' refers to whether the vowel is produced with a rounding of the lips or not. The 'tense' feature is "not unambiguous" (Kluender & Lotto 1999, 509) and is supposed to specify vowels produced with "considerable muscular contraction in the tongue" (Edwards 2003, 38). To my knowledge there is no one definition of what specifically this means in terms of the acoustic realization of the vowel.

It can be seen as a feature used to denote that a vowel is more salient than a similar, 'lax' vowel. A less charitable description is that 'tense' is a catch-all used to differentiate two vowels which cannot be distinguished using only the features already in the proposed set.

English											Spanish				
i	**ɪ**	**e**	**ɛ**	**æ**	**ʌ**	**ɑ**	**o**	**ʊ**	**u**		**i**	**e**	**a**	**o**	**u**
+	+	+	+	+		+	+	+	+	Front	+	+			
+	+							+	+	High	+				+
				+		+				Low			+		
						+	+	+	+	Back				+	+
							+	+	+	Rounded				+	+
+		+			+		+		+	Tense	+	+	+	+	+

Table 1.5 – Feature matrices of American English (Edwards 2003) and Spanish vowels.

The feature matrix seen above is for the vowels of American English which are slightly different than the vowels of GCE. How different the matrix of GCE vowels should be is not an easy question to answer. For example, if the Canadian shift has caused /æ/ to move backwards for the average speaker of GCE, how far can it more back before it is no longer considered to be [+front]? Despite this, features are used to classify vocalic systems with the working assumption that, since phonemes are bundles of features, different phonemes that share the same set of features should be interpreted in the same way.

1.5 Previous studies

Most studies regarding the L2 acquisition of English vowels by L1 Spanish speakers primarily focus on the front vowels. Most studies have been carried out based on the assumption that the feature-based classifications traditionally used to describe vowels are not only adequate but also correct. This has led to the assumption that certain vowel contrasts will be problematic; I have not been able to find any experimental justification for the predetermined contrasts used in most studies.

Flege et al (1995) conducted a multidimensional scaling study to determine how L1 Spanish speakers compared each of /æ/, /ɛ/, /ɑ/, /ʌ/, /e/ and /i/ of General American English and /a/, /e/ and /i/ of Spanish, both within and between languages. Multidimensional scaling (MDS) allows for similarity judgments to be represented visually along any number of dimensions. The dimensions may correlate to properties that are unknown or unquantifiable; for example, MDS is used to compare perceived similarities of taste and smell. The results of the judgments of the L1 Spanish who were 'non-proficient' in English are in Figure 1.6 below.

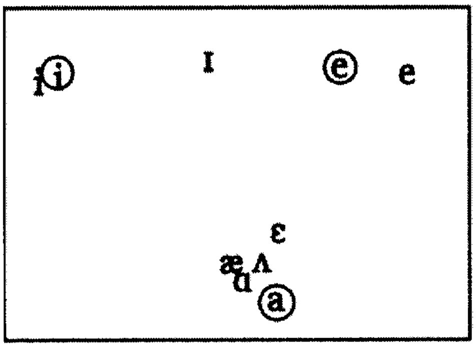


Figure 1.6- perceived similarities of Spanish and English vowels. Spanish vowels are circled. Modified from Flege et al (1995).

The author suggests that /ɪ/ is being assimilated to Spanish /i/; presumably this is based on their traditional feature classification of both vowels as [+high]. The fact that /ɪ/ appears closer to Spanish /e/ than English /i/ suggests that L1 Spanish speakers who are not proficient in English assimilate /ɪ/ as a poor exemplar of Spanish /e/, or perhaps that /ɪ/ falls near the border of Spanish /i/ and /e/. They also grouped /æ/, /ɛ/, /ɑ/, /ʌ/ close to Spanish /a/ suggesting that they are all assimilated into Spanish /a/. Again this is not in line with the traditional classification of /ɛ/ as [+mid, +front] as it would be expected that it would sound very similar to Spanish /e/ since they share these feature specifications.

The /i/-/ɪ/ contrast is considered to be particularly difficult for L1 Spanish speakers and it has been the focus of study (Perez-Gamboa 1999, Garcia Perez, 2003). Escudero (2000) tested the acquisition of the /i/-/ɪ/ contrast of L1 Spanish L2 Scottish English (SE) speakers. Escudero tentatively concluded that Spanish speakers initially assimilate English /i/ and /ɪ/ into Spanish /i/ and /e/ respectively but cautioned that these results are specific to SE. Morrison (2006) found that peninsular Spanish speakers initially assimilate GCE /ɪ/ to Spanish /e/ while Morrison (2008) found that Mexican Spanish speakers initially assimilate GCE /ɪ/ to Spanish /e/. Morrison (2008) attributes this difference to possibly different /i/-/e/ boundaries in the two dialects.

A possible motivation for the focus on certain pre-determined contrasts may be the pronunciation errors that L1 Spanish L2 English learners typically commit. However, it is not necessarily the case that production errors are indicative of perceptual performance. An example of the confounding influence the English orthographic system may have on this connection in terms of perception and production tasks will be outlined below.

Although vowel perception and production may be related, errors may not be parallel. Flege (1997) states that "[if] the Spanish subjects identified realizations of English /ɛ/ as instances of Spanish /e/ and realizations of English /æ/ as Spanish /a/, then they might produce even larger spectral differences between /ɛ/ - /æ/ than do [native-English] subjects" (444). Although this may be true, it is not bidirectional; large spectral differences between /ɛ/ - /æ/ do not necessarily indicate that /ɛ/ assimilates to Spanish /e/ (the results of Flege et al 1995 suggest that /ɛ/ is assimilated to Spanish /a/). The fact that English /ɛ/ is denoted by the grapheme 'e' in almost all cases, the same grapheme that denotes Spanish /e/ in all cases, may very well influence the pronunciation of second language learners (Birch 2007, Young-Scholten 1995).

Morrison (2006) and Escudero (2000) concluded that the apparent /i/-/ɪ/ problem could be an artifact of a misalignment of the orthographic systems of the two languages. If participants pronounce /ɪ/ as /i/ and /ɛ/ as /e/ because of the way words containing these vowels are spelled then the sorts of identification tasks used in some studies may be ill-suited to test the discrimination abilities of participants, especially those in an early stage of acquisition. A representation of why this could be is seen in Figure 1.7 below.

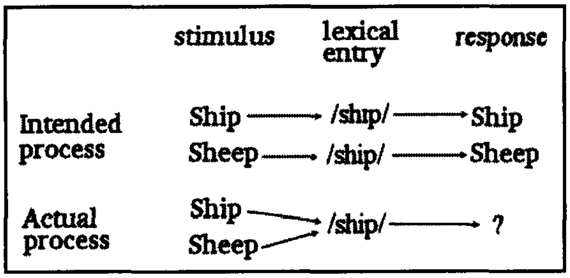


Figure 1.7 - A flow chart of the typical labelling task. See text.

The preferred methodology to test the ability to discriminate /ɪ/ and /i/ is to present participants with a written or visual representation of an /ɪ/-/i/ minimal pair, for example, a drawing of a sheep and another drawing of a ship. Participants then hear one of the words aloud and are asked to select the visual representation of the word they have just heard (Perez-Gamboa, 1999, Garcia Perez, 2003, Escudero 2000). This methodology is ideal if it is certain that production accurately reflects perception; this may be assumed to be the case for the L1 but there are too many possible interfering factors in L2 acquisition. If participants pronounce /ɪ/ as /i/ because of the way it is spelled then they will pronounce 'ship' and 'sheep' identically but this will have no bearing on their ability to discriminate the two vowels.

If a participant produces both words of a minimal vowel pair with the same vowel, meaning the lexical entry for both is identical, then on what basis can discrimination be made? For example, this methodology would probably lead to the conclusion that speakers of GCE cannot discriminate /ɔ/ and /ɑ/ for the simple reason that a speaker of GCE has all words containing both vowels stored as /ɑ/. A speaker of GCE has no way to know which subset of their /ɑ/ words should be labeled /ɔ/ and which ones should remain /ɑ/. If the production of a vowel is incorrect for any reason other than inaccurate perception then results of perceptual tests of this type may not reflect true perceptual performance. There is no reason to assume that the connection between perception and production is indirect, however, it does not seem that its directness can be taken for granted either.

Chapter Two

2. Methodology

The experiment consisted of two distinct tasks: a perception task and a production task. The perception test was a rhyming categorization task. The production task consisted of reading lists in English and Spanish. An L1 English control group was asked to read only the English word list; the L1 Spanish L2 English group was asked to read both. The following sections will outline the procedures and materials used for the production and perception tasks. Section 4 will discuss the methodology used in the analysis.

2. 1 Participants

Participants were divided into two groups: an L1 English control group and an L1 Spanish L2 English group. The L2 group was composed of 11 end-state speakers who began learning English as adults upon arrival to Canada. These participants are assumed to be end-state by virtue of their age and the fact that they have, on average, twenty years of experience speaking English. The L1 English group was composed of 9 native speakers. None of the members of the L1 group had any significant experience with another language or had ever lived abroad. Eight participants in both groups were residents of southern Ontario; one was a permanent resident of British Columbia.

Native control group

Participant	1	2	3	4	5	6	7	8	9	Avg.	SD.
Age	20	24	24	24	24	22	23	20	21	22.4	1.7
Gender	f	m	m	m	m	m	f	f	f		

L2 Group

Participant	1	2	3	4	5	6	7	8	9	10	11	Avg.	SD.
AOA	28	35	28	34	29	37	34	32	35	37	32	32.8	3.3
YOE	18	18	19	19	28	20	20	19	19	14	19	19.4	3.3
Age	46	53	47	53	57	57	54	51	54	51	51	52.3	3.52
Gender	f	m	f	f	f	m	f	m	m	f	f		

Table 2.1 – Participant information, age of arrival (AOA) and years of experience (YOE).

2. 2 Production Task

Two word lists were created, one in Spanish and one in English. A word list was chosen to minimize the vowel reduction that occurs in English casual speech which would have a centralizing effect on the vowel system. Following Johnson et al. (1993) it was decided that a word list would result in the most careful reading, and therefore, the most accurate representation of the phoneme.

Participants were recorded in a quiet room using a Samson C01U condenser microphone. The Samson C01U is a USB microphone which allowed the recordings to be made directly onto a laptop computer as WAV files using Audacity. The files were recorded with a 44.1 kHz sampling rate and with 16-bit sampling resolution. The microphone has a frequency response range of 40 Hz to 18 kHz.

The English words are all monosyllabic and end in /d/, /t/ or /k/. They all have simple onsets and codas and have a basic CVC structure. Each consonant appeared twice with each of /i, ɪ, e, ɛ, ʌ, æ, ɑ, o, ʊ, u/ for a total of 60 words. Common English words with simple onsets and the appropriate final consonant were selected. The Spanish words were all disyllabic words with the structure CV.CV. Each Spanish monophthong /a, e, i, o, u/ appeared 6 times for a total of 30 words. The second consonant in all words were either voiceless fricatives or stops; this was done to facilitate segmentation. Materials used in these tasks can be found in Appendix A.

Rather than have participants read the words off of a sheet, a series of HTML pages were created for each of the reading lists. Each of the pages contained one word in the middle of it; clicking on the word would take a participant to the next word on the list. This was done to ensure participants did not rush through the list, looking ahead to the next word as they read the current one. Participants were all instructed to read the words carefully, as if they were repeating them to someone who had misunderstood.

The frequencies of the first two formants were measured with Praat[3] using a five millisecond Gaussian window. The first two formants were considered to adequately describe the vowels of Spanish and English (Halberstam & Raphael 2004). Frequencies were taken from a stable part of the midpoint of the vowel. In the case of English /e/ and /o/, which tend to be diphthongized, frequencies were taken of the formants before the lowering of F1 and drop in amplitude which signal diphthongization (Fant 1970, pg 58). Several speakers produced /u/s with a clear onglide; in these cases frequency measurements were taken from a stable portion of the vowel with special attention paid to amplitude of the signal.

2. 2.1 Normalization method

No two speech events will ever be identical. Not even the same vowel produced by the same speaker twice in a row will result in identical sound waves. The lexicon cannot

[3] Praat is software for performing acoustic analysis that is freely available from the University of Amsterdam.

be accessed directly with the sound input, it is too varying. Therefore, the intervening phonemic level provides the unstable acoustic signal with a stable phonemic representation with which the lexicon may be accessed. The specific conversions required will be dependant on the inventory and phonology of the language; this process of data to sound conversion, or its inverse, is similar to the process by which modems allow personal computers to communicate.

A modem (**mod**ulator-**dem**odulator) turns digital information into an analog signal that can be transmitted via telephone. On the receiving end, the modem turns the analog signal back into the corresponding digital data. This process will only work if the two modems modulate and demodulate the data using the same algorithm. Incompatible methods will result in miscommunication.

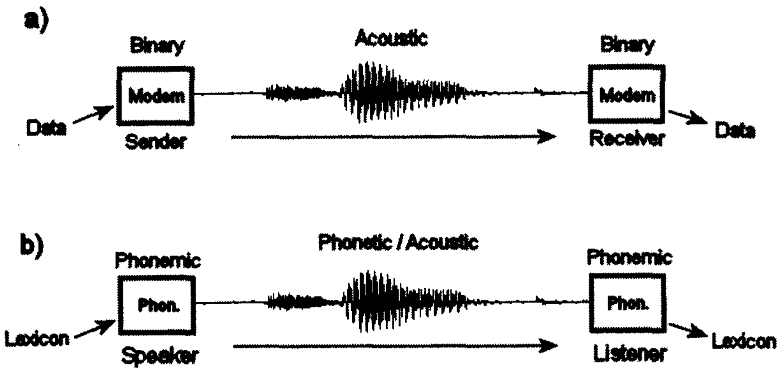


Figure 2.1 – Comparison of the data transmission processes of humans and computers.

If speakers of a language share a common method with which they decipher and encode the speech signal, this method should be definable in some way. The goal of vowel normalization methods is, to some extent, to mimic this conversion of acoustic to phonemic information by reducing speaker contingent and situational variation so that phones are roughly sorted by category. The methods are not meant to be representations of how humans achieve the task; they simply need to arrive at similar results.

Vowel normalization methods usually classify vowels using the first and second formants; it is standard practice to plot vowels on an F1-F2 plain. Halberstam & Raphael (2004) found that low-pass filtering vowel stimuli at 100 Hz above F2, thereby removing all of the upper formants, did not affect the ability of native speakers to classify phonated English vowels. There are also physiological reasons to believe that the position of the formants is the most important piece of information in the classification of vowels (Soeta & Nakagawa 2006, Zwicker et al 1957, Zwicker et al 1961). Standard vowel normalization techniques use the frequencies of the centers of the first two formants to classify and arrange vowels; durational cues are usually not represented.

The frequencies of the first two formants are mostly determined by the position of the tongue and the lips (Behrman 2007). Since the tongue cannot be compressed, a movement into one area of the mouth or pharynx causes the vacation of another area. Usually, the first formant is said to be inversely related to the height of the tongue during articulation. The height of the second formant is directly related to a vowel's frontness. The position of the tongue is not split into height and frontness but is instead a singular configuration represented along two axes. References made to the height and frontness of vowels have to do with the result of articulation and how this result is perceived rather than any specific position of the tongue or lips.

The position of the tongue can be directly related not only to the way vowels are produced but also to how they are perceived (this would only account for oral vowels where purely durational contrasts do not exist). Because of this, the classification of

Spanish and English vowels based on the frequencies of the first two formants is considered to be sufficiently descriptive.

The most effective methods are vocal chord scaling normalization methods (Adank et al 2004, Disner 1980). Nearey's (1978) and Lobanov's (1970) are the best two methods according to the two studies cited above; however, they work best when comparing speakers of only one language. Nearey's method performs a logarithmic transformation to the base of ten on all frequency values before proceeding. The resultant value is the frequency of a particular vowel's formant minus the arithmetic mean frequency of only that formant across all vowels. Lobanov's method further divides this by the standard deviation of the frequency of each formant across all vowels, in effect returning a standard score for each formant for each vowel. Both of these measures pool data across vowels, separating the data by formant instead. The formulas for these two methods are seen in Figure 2.2 below, where the result *v* for speaker *s* for formant *i*, is a function of the input frequency *f*, the mean μ, and the standard deviation σ. Values may be log-transformed (*L*).

$$v_{si} = f_{si}^{L} - \mu_{si}^{L} \qquad\qquad v_{si} = \frac{f_{si} - \mu_{si}}{\sigma_{si}}$$

Figure 2.2 - Formulas for two common normalization methods, Nearey (1978) on the left and Lobanov (1970) on the right.

As mentioned earlier, these methods are not as effective for the comparison of different languages and dialects. The mean formant frequency produced by a speaker will largely be a product of the particular vowel inventory of a language. The standard deviation, also dependant on the mean, will artificially increase the distance of vowels not clustered around the mean. Disner (1980) summarizes the problem encountered by normalization methods which use the mean when comparing vowels across languages:

> [It] does not necessarily follow that [the] results are indicative of the actual position of the vowels in the phonetic space [...] it is evident that languages with different phonological systems are likely to have different mean values for their vowel formants [...] Under such circumstances as these, scaling techniques such as those of Nearey or Wakita [1977] would assign different multipliers to the formants of different languages; hence, two vowels with identical formant frequencies (and identical phonetic quality), pronounced by speakers with identical vocal tracts, would result as different. This is a procedural effect which must be avoided.

The mean and standard deviation are descriptors of, and so dependant on, the population they describe. They do not directly describe the speaker. For example, if one needed to describe the acoustic range of a children's harmonica capable of playing one octave, there are two basic ways it could be done. If one studied the distribution of notes by calculating the average frequency and standard deviation of notes played in a song, the result would be a description of only the frequency range of that song. If one played a different song whose tendency was to use a different range in the octave, one might end up with a very different mean or standard deviation. Notes could be described only in terms of the population to which they belong; they could be compared only as a function of the song they belong to.

Any two songs that use the entire octave, or an adequate range of it, will have the same midpoint, defined as the point halfway between the smallest and largest members of the set. It is important to note that the midpoint is different from the median in that it does not have to be a member of the set. The set of values [0, 3, 7, 8, 10] has a median of 7 but a midpoint of 5. Using the midpoint, the notes of two songs can be compared as a function of the instrument that produces them and not only in relation to the song to which they belong. If the standard deviation is calculated, not from the mean, but from the midpoint, it becomes a measure of the proportion of the range used by the average note and not the distance to the average note.

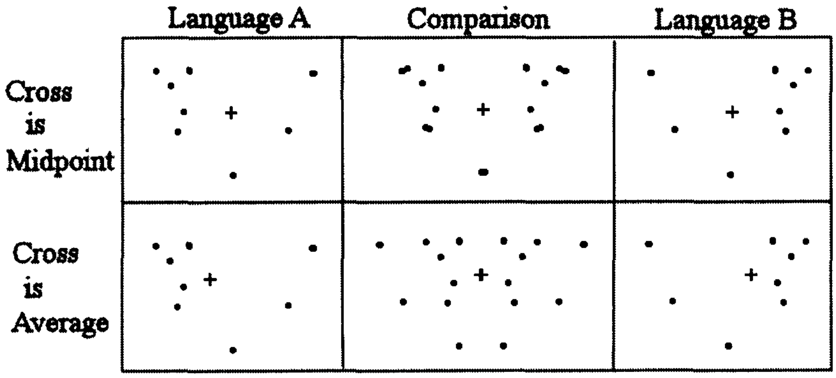


Figure 2.3 – Overlay of two possible vowel inventories. Crosses were placed at an approximation of the appropriate value. In (b), the inventories of (a) and (c) are aligned so that the measures of interest overlap.

In Figure 2.3 above, language (a) has many high, front vowels and language (c) has many high, back vowel; the inventories are mirror images of one another. The top row shows that the midpoint remains stable regardless of inventory. This stability results in a correct alignment of the inventories of the two vowel systems. This midpoint is not necessarily the center of the ranges that a person is capable of producing; the same speaker might well use quite different frequency ranges for different languages. This will not affect the usefulness of the midpoint as a reference point that is independent of a particular language's vowel inventory. If the standard deviation is calculated from the midpoint and not the mean, it will come to represent the average frequency range used by a speaker in relation to his or her total observed range in a language.

What is proposed is a modification of Lobanov's method. Instead of the mean frequency for each formant, the midpoint will be calculated. The midpoint will be one half the sum of the minimum and maximum frequencies for each formant, across all vowels, for each speaker. Instead of the standard deviation, the standard deviation from the midpoint (SDMid) will be calculated. The SDMid will be the average distance between each formant from the midpoint for that formant for that speaker. This method, and its resultant, will be referred to henceforth as the standard deviation from the centroid (SDC). The result of this is something like a z-score for each formant. The resultant should be interpreted in this way: For formant *i* and value *v*, formant *i* is *v* standard deviations away from the midpoint of the acoustic space used by speaker *s*.

$$mid_{si} = \frac{min_{si} + max_{si}}{2} \qquad \sigma'_{si} = \sqrt{\frac{\Sigma(f_{si} - mid_{si})^2}{N}} \qquad V_{si} = \frac{f_{si} - mid_{si}}{\sigma_{si}}$$

Figure 2.4 – Formulas for the midpoint, SDMid (σ′) and modified standard score.

The question of what, if any, transformation of the frequency measurements might be appropriate was considered. Generally, formant frequencies are transformed using either a logarithmic scale or a psychoacoustic scale. Nearey's (1977) method log-transforms all frequency values. Logarithmic transformation has been found to most accurately scale prosodic F_0 shifts between different speakers (Traunmuller & Eriksson 1995, Nolan 2003).

Psychoacoustic scales, such as the Mel scale (Stevens & Volkmann 1940) and the Bark scale (Zwicker et al. 1957, 1961), try to account for the fact that larger changes of frequency in high frequency sounds are perceptually equivalent to smaller differences in lower frequency ones. The bark scale was chosen due to the success it has had representing subjective pitch measurements (Healey & Bacon 2006, Iivonen 1994, Soeta & Nakagawa 2006). Distances between Barks represent subjective distances in pitch regardless of the absolute difference in hertz. Since the bark scale was originally represented in graphic form, Traunmuller's (1990) equation will be used.

$$z = \left[\frac{26.81f}{1960 + f}\right] - .53$$

Figure 2.5 – Traunmuller's (1990) equation for Hertz-Bark conversion where *z* is the resultant, in barks, and *f* is the frequency in Hz.

2.2.2 Comparison Using Data from Different Languages

Before using the proposed normalization method in the current study, it was decided to run a comparison of how well the different normalization methods mentioned above are able to compare the vowels of different languages. Frequencies of the first and second formants of the vowels of Quechua (Pasquale 2001), German (Iivonen 1987), Spanish and English (Bradlow 1995) and North Frisian (Bohn 2004) were taken from several studies for comparison. The Quechua vowels were from a single, female speaker, the German frequencies were averaged across five female speakers, the North Frisian vowels were averaged across ten male speakers, and the Spanish and English vowels were averaged across four male speakers per language. All vowels are stressed monophthongs.

The vowels of all five languages were normalized using Nearey's and Lobanov's methods. They were also normalized using SDC, once with the Hz frequency values and once with the Bark-scaled frequencies to make sure that Bark-scaling the data would not drastically alter the position of the vowels.

Each Language's entire vowel inventory, as seen in Table 2.2, was considered in each case. To make the results easier to read, only the point vowels /i, a, u/ (or the closest vowel present in the inventory) will be plotted.

Frisian	i	ɪ	ʏ	y	e	ɛ	ø	œ	æ	a	ɒ	o	ɔ	ʊ	u
English	i	ɪ			e	ɛ			ʌ	æ	ɑ	o	ɔ	ʊ	u
German	i			y	e	ɛ	ø			a		o			u
Spanish	i				e					a		o			u
Quechua	i									a				ʊ	

Figure 2.6 – Vowel inventories of test languages. The point vowels have been underlined.

The results are provided on a single page at the end of this subsection (Figure 2.7) to allow for comparison. Lobanov's method results in tighter grouping of the point vowels compared to the Hertz values. However, the low vowels in Frisian and German are exceptionally low, 2 and 2.5 standard deviations away from the mean respectively. This is a result of the high number of high vowels in these languages and is a 'procedural effect' to be avoided; it does not reflect any extra 'lowness' of the low vowels. The larger space given to the low vowels will result in a cramping of the vowel space for high vowels and a stretching out of the vowels space for low ones.

Nearey's log-mean method also results in languages with many high vowels having disproportionately low vowels. The similarities between the arrangements of the vowels between the two methods are probably a result of the use of the mean as a reference point by both methods. Nearey's method maintains the extra 'lowness' of the

German low vowels, but it erases differences in frontness of front vowels and exaggerates differences in height of the high vowels.

Both SDC methods avoid these problems, tightly grouping all point vowels. The use of bark-scaled frequency values has not distorted the positions of the vowels. The majority of vowels after SDC normalization will be within 1.5 standard deviations of the centroid; within a square with corners at (-1.5, -1.5) and (1.5, 1.5).

SDC better categorizes vowels across languages than other vocal chord scaling methods, even these extreme cases. In aligning the acoustic spaces based on the range used by a speaker, SDC normalization seeks to mimic the process by which listeners adjust their perceptual space based on the stimuli they are presented with (Bradlow 1993). The vocalic systems of Spanish and English are not as different as those used in this trial run, and so the 'procedural effects' may not be as significant, but it was still deemed prudent to use the method which resulted in best alignment of participants' acoustic space.

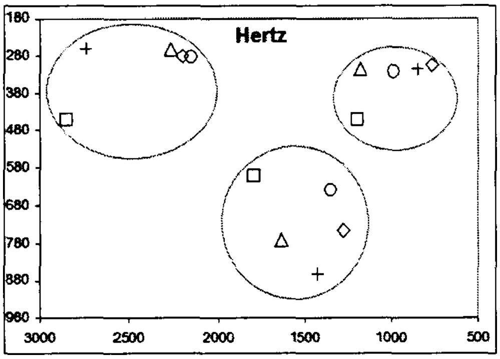
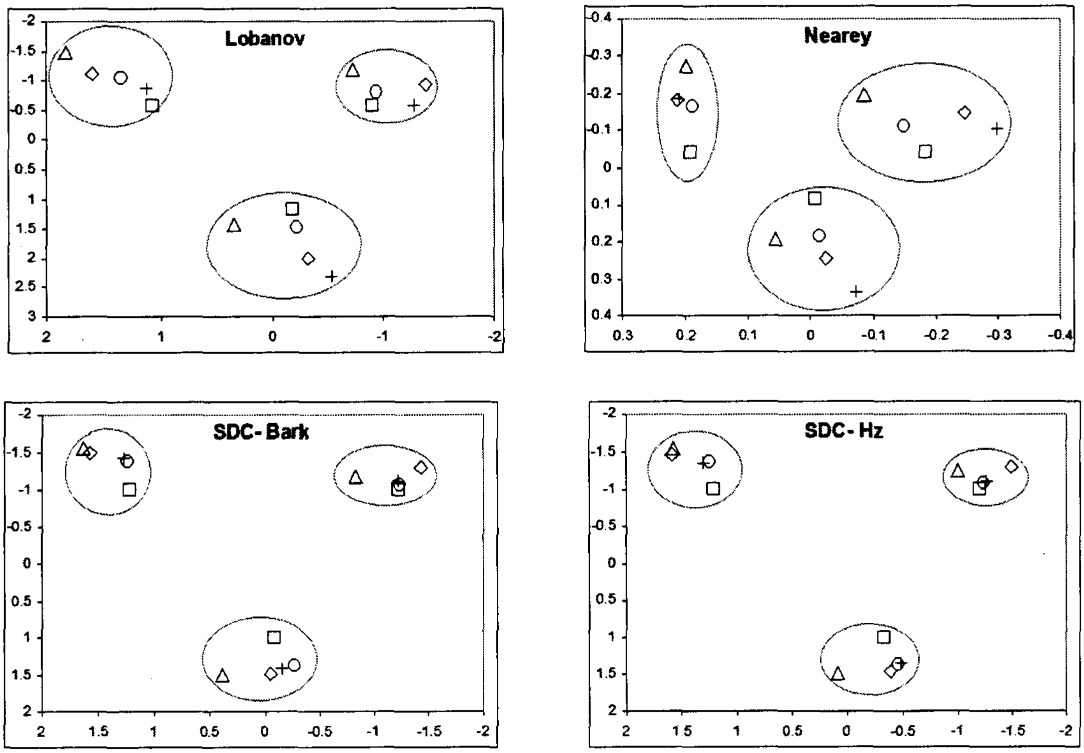


Figure 2.7 – Results of normalization method comparison. On the left, the vowels in their original frequency values. Below, the results of the methods tested. The same shapes will be used to represent each language in the following figures: Square (Quechua), Triangle (English), Diamond (Frisian), Circle (Spanish) and Cross (German). Ellipses are meant only to make the categories clear.



2.3 Perception task

A rhyme task was chosen to judge how well speakers could identify the vowels of English. In a rhyme task, participants are presented with a stimulus and a number of possible responses. Participants are then asked to indicate with which response word the stimulus word rhymes. Rhyme tasks have been shown to work with children as young as four (Lenel & Cantor 1981); even with children who cannot read or perform other cognitively simple tasks. People with pictographic alphabets (Read et al 1986) and illiterate adults (Morais et al 1979) have been shown to have difficulty with certain phonemic awareness tasks, such as phoneme removal tasks. Illiterate adults have been shown to have no difficulty with rhyme tasks suggesting that conscious awareness of the rhyme may be an early and universal skill (Morais et al 1986). Since the rhyme task requires categorization, it allows for a ten-way distinction at each question. In this way each question required the participant to choose the appropriate rhyming vowel out of the set of all ten vowels, not only the ones which the experimenter deemed similar enough to warrant comparison.

2. 3.1 Stimulus and response words

Thirty nonce words were used as stimulus words. Each of the ten English vowels appeared once with each of /d/, /t/ or /k/ in the coda, resulting in a total of thirty stimulus words. The words were all in a /hVC/ format. The stimulus words were read seven times each by a female, monolingual, native-speaker of English in a sound-proof recording booth. This native speaker was given all of the stimulus words on a sheet of paper. Some of the combinations of English vowels and the /hVC/ environment resulted in actual English words and some did not. Where actual English words corresponded to a required stimulus word, the appropriate word was used. Where no common, English word was available, an approximate spelling was given and similar, rhyming words were provided. A copy of this sheet can be seen in Appendix A. The recording was done using a condenser microphone and recorded directly onto a personal computer at 44.1 kHz with a 16-bit sampling rate using Ableton Live.

Measurements of the frequencies of the first two formants of each of the seven readings were made with Praat, using the same methodology used to analyze the production of the L2 and control groups. The average value for each formant of each vowel was found and the Cartesian distance between each vowel and the average vowel within its own category was found. In each case, the vowel which was closest to the average was chosen to be the stimulus word for use in the test. After the native speaker control group performed the production task the stimulus vowels were normalized using SDC normalization and compared to the vowels of the control group to see if they were good representatives of their respective phonemes. Results can be seen in Figure 2.8.

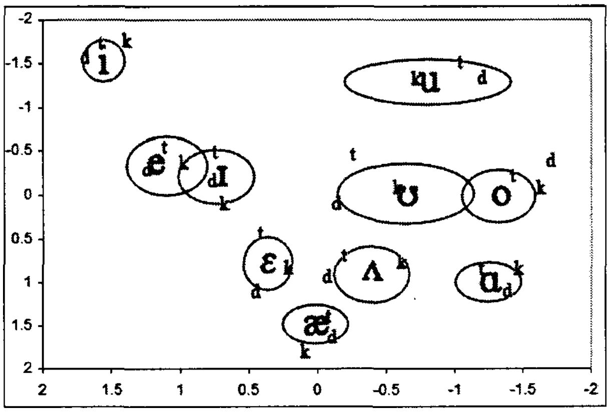


Figure 2.8 – An overlay of stimulus and native control vowels. Letters are coda consonants.

Thirty individual WAV sound files were created, one for each of the stimulus words. The thirty sound files were then normalized to maximum amplitude so that they would all play at relatively the same volume during the task. The sounds were grouped by final consonant into three groups of ten and arranged so that, whenever possible, high vowels did not follow high vowels, low vowels did not follow low vowels, and so on.

This was done to prevent participants from making comparisons based on stimuli stored in short term memory. Participants listened to the stimuli using headphones and iTunes.

The response words were all monosyllabic, CVC words. There were thirty words in total, one corresponding to each possible pairing of the ten vowels with /d/, /t/ or /k/ in the coda. The words were presented in two columns of five on html pages. At each stage only the ten words with the appropriate final consonant were displayed. These were displayed in a fixed order within-consonant to facilitate responses. The exact structure of the web pages will be discussed in the following section.

2.3.2 Response sheet design

The response sheets were a series of HTML pages. Each page displayed the appropriate response words in two columns of five. Each response word was a link which took the participant to the next question when it was clicked on. There were ten HTML pages for each of the thirty questions. Each of these pages was given a title with the format "*n*- *a*" where *n* is the number of the previous question and *a* is the answer that was clicked on in the previous question. Every response word linked specifically to the page named after it for the next question so that the browser's history acted as a trail of the responses given at each stage.

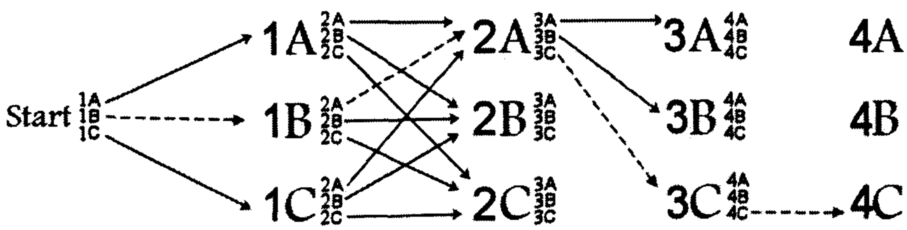


Figure 2.9 – Schematic of the response page design. Possible paths are represented with solid lines and the actual path by broken lines.

A simplified representation with only 4 questions and three options at each question can be seen in Figure 2.9. The large numbers and letters represent the page titles and the smaller letters and numbers beside them represent the links. Each link points to the corresponding page for the next question. All of the pages at each question have an identical layout; they contain the same links to the same pages. Questions one and three show all available paths at the question, question 2 shows all theoretical paths and question 4 shows only the taken path. In the example above, the participant has chosen B, A, and C. Since these are HTML pages, a web browser will log the path taken using the titles given to each while within the HTML code. The browser history for the response path in the figure above would read "Start, 1C, 2A, 3C…"; no history exists for 4 because this is only registered upon leaving the page.

2.3.3 Procedure

The first track on the playlist was a short file used to check the volume, a recording of a male voice saying "Qué tal el volúmen?" (How's the volume?). Each sound was numbered, one through thirty and each corresponding response page had the same number across the top. The iTunes playlist was set up so that each file would only play when double-clicked and would not go on to the next file automatically.

Participants listened to the initial track and adjusted volume levels. After this, the procedure was the same for each of the thirty questions. The participant had to listen to the stimulus word and decide with which of the response words it rhymed. Participants were told to listen to each stimulus word as many times as necessary and that there was no time limit to the task. When a decision had been reached, the word was to be clicked on, leading to the next question.

The rhyme task was tested on native speakers before administering it to any of the participants in the study. These natives scored nearly perfect, but when they did make mistakes, they indicated that this was a result of a reflexive response to the first word they saw with graphemes which in some cases represent the stimulus vowel. To minimize errors of this type, participants were asked to familiarize themselves with all of the response words for each coda consonant before answering and reminded to choose the response word which rhymed with the corresponding stimulus word regardless of spelling.

2.4 Methodology for Analysis

2.4.1 Level of significance and consistency

Since at each question there are ten possible answers, the probability of answering correctly by chance at each stage is .1. Even though there are only three questions per vowel, if the .1 probability of correct response is maintained, the probability of correctly answering two or more out of three answers correctly is only .027, below the level of statistical significance. The chosen methodology was thought to best maintain the 1/10 odds of a correct response being given by chance alone. Participants are unlikely to remember what words they have chosen in the past since the test left no trace of prior decisions for participants to see. Participants saw that there were 30 stimulus words but only saw ten response words at a time and would have no reason to assume that vowels could not be chosen more than once.

Since correct identification of a vowel in at least two out of three cases will only occur by chance in less than three percent of cases, it was considered to indicate the ability to categorize a vowel in a consistent way. Mistakes due to interference from the writing system or random error on the part of the participant are very unlikely to result in the random incorrect identification of one vowel as another in the same way in two out of three tries. Random incorrect identification refers to errors that are not explainable by either acoustic similarity or the interfering writing system. Results of the perceptual task will be represented in confusion matrices.

2.4.2 Confusion matrices

Confusion matrices are used in the field of artificial intelligence to gauge the efficacy of a classifier. They offer the benefit of displaying not only the number of correct and incorrect responses but also the nature of the classification errors. In a confusion matrix, the observed response is displayed on the x-axis and the expected response is displayed on the y-axis. Correct classifications (true positives) are found along the major diagonal, the squares in which the observed and expected responses are the same. All squares off of the major diagonal are errors of different kinds. Errors along the x-axis of vowel /α/ represent false negatives, instances where /α/ was played and the participant indicated /β/. Errors along the y-axis of /α/ are false positives, instances where /β/ was played and the participant indicated hearing /α/. True positives are all cases in which /α/ was not played which were correctly identified as not-/α/. This is the sum of the values of the cells found off of the row and column headed by /α/.

2.4.3 F1-F2 Plane

The F1-F2 plane is the most commonly used method to visually represent vowel inventories. In a traditional F1-F2 plane, the frequency of the first formant is represented along the y-axis and the frequency of the second formant is represented along the x-axis; the nexus is at the top right corner. This configuration is meant to resemble the position of the tongue within the mouth when articulating each vowel. F1-F2 planes which represent formant frequencies in Hertz focus on the area populated by the vowels of interest; they do not have inherent maximum or minimum values. However, due to the frequency range of the human voice, F1-F2 planes typically have x-axes that span from 700-3000 Hz and y-axes that span from 250-1000 Hz.

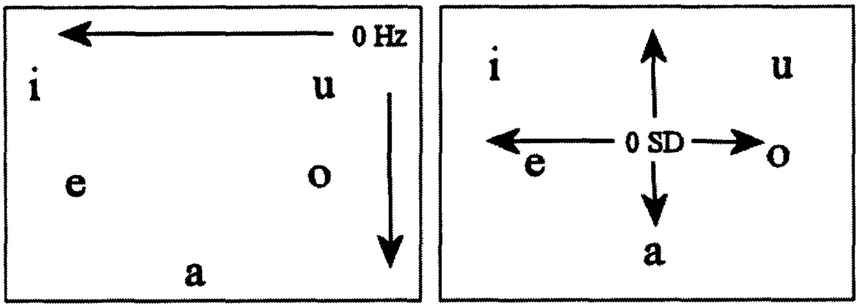


Figure 2.10 – A comparison of a standard F1-F2 plane with values in Hertz (left) and those resulting from SDC normalization with values in standard deviations (right).

F1-F2 planes that are a result of SDC normalization are slightly different form those representing Hertz values. Because values represent distance, in units of standard deviations, from the centroid, the nexus of all SDC F1-F2 planes will be in the exact center of the plane. The x-axis still represents the second formant and the y-axis still represents the first formant but these values now represent deviations from the middle of the observed frequency range. All F1-F2 planes will be positioned following the convention that the high-front vowels appear towards the top-left corner and low-back vowels appear towards the bottom-right corner.

2.5 Research questions

The research questions this thesis seeks to answer, along with an outline of how the methodology was designed to answer them, follows.

Q1: How do speakers of Spanish assimilate each of the vowels of GCE?

The assimilation pattern between two languages depends on the degrees and types of assimilation between the phonemes of the two languages. This relationship will be unidirectional and specific to any two languages. The sort of test described in Figure 1.7 in § 1.4 may lead to incorrect conclusions if it creates a false dichotomy. If it is the case that /ɪ/ assimilates to Spanish /e/ and not /i/, then adding the option of Spanish /e/ would drastically change the results of the reported experiments. A task in which all options are given will avoid this sort of problem.

If the perception and production are misaligned as a result of the English orthographic system it is expected that certain types of errors will occur. If the vowels /ɛ, ʌ, æ, ɑ/ are all assimilated to Spanish /a/ then the errors for these vowels will gravitate towards the closest vowel represented with an "a". If /ɪ/ is assimilated to Spanish /e/ it is expected that most participants will respond with a word containing a lone "e". An error of this type could be taken to reinforce the notion that the orthographic system interferes between perception and production. In this case participants choose /ɛ/ for the same reason they pronounce /ɛ/ as Spanish /e/ (even though it sounds like /a/); because of its orthographic representation.

This last point is worth elaborating. If participants select the word intended to represent /ɛ/ when presented with an /ɪ/ stimulus, they could very well be indicating that /ɪ/ is confused with /ɛ/ sometimes. However, the more /ɛ/ is assimilated into Spanish /a/

(for example), the less likely that this will be the case. For /ɪ/ to assimilate into the same category as /ɛ/ it would need to cross Spanish /e/ which is much closer spectrally to /ɪ/ than Spanish /a/; there is no reason to think this would happen.

If /ɛ/ and /æ/ are assimilated as good exemplars of Spanish /a/, then their distributions should overlap to a certain extent as seen in the overlapping distributions on the right side of Figure 2.11. The horizontal axis represents acoustic similarity so that more similar vowels have overlapping distributions and less similar vowels have distributions that are further apart.

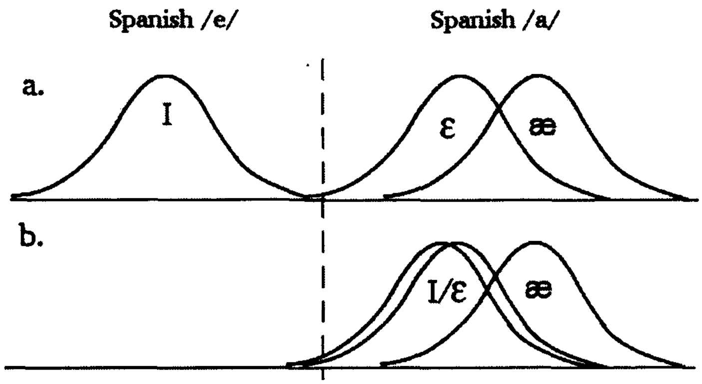


Figure 2.11 - Idealized representation of three GCE vowels along one dimension. Dotted line represents the category boundary between adjacent Spanish vowels.

If it is the case that /I/ assimilates to Spanish /e/, and /ɛ/ and /æ/ assimilate to Spanish /a/, then we would expect to see distributions as in (a), with little to no confusion between /æ/ and /I/. If /ɛ/ and/I/ were confused at a high rate then they must be acoustically similar, and, since /ɛ/ and /æ/ are also judged to be acoustically similar, we would expect to see some confusion between /æ/ and /I/ as in (b). In situations like this, where a first and third vowel or indirectly related by means of a connector vowel, if the first and third vowel are not difficult for participants to distinguish then if will be concluded that the connection via the second vowel is an artifice of the orthographic system.

Q2: Which vowel contrasts could be problematic? Which should be easy?

The Speech Learning Model predicts that the degree to which an English vowel is interpreted as an adequate exemplar of the L1 category it falls into should be inversely related to the ability of participants to establish a new category. It follows from this that the more participants are able to consistently identify an L2 vowel, the more it differs from an ideal example of the L1 vowel into which it is assimilated. After one knows which L1 category each L2 vowel falls into and what the degree of assimilation is, predictions as to which contrasts may be problematic can be made.

Q3: Does the opacity of the English writing system result in an indirect production-perception link?

If production is directly connected to perception it is expected that the production of L2 vowels will closely resemble their assimilation patterns. However, if the orthographic system mediates the relationship between perception and production then it is expected that this will be reflected not only in the sorts of perceptual errors but also in the misalignment of L1 assimilation categories and L2 production. For example, if /ɛ/ and /ɪ/ assimilate to Spanish /a/ and /e/ respectively, it would be expected that they would be produced in a similar fashion to those L1 categories. If the same English vowels are instead pronounced closer to Spanish /e/ and /i/ respectively, it can be concluded that their mispronunciation is based on a reliance on orthographic representation and not a direct result of perceptual errors.

Chapter Three

3. Results

This section will outline the results of both tasks. § 3.1 will present the results of the categorization task and § 3.2 will present the results of the production task. Complete individual results for both tasks can be found in Appendix B.

3.1 Perceptual results

Before moving on to more specific analysis, some general comments on the results can be made. Since there were 3 trials for each vowel and 11 participants, each vowel was heard a total of 33 times. Each row contains a total of 33 responses, one for each stage in the trial. Consequently, the maximum value for any single cell is 3 per participant or 33 in total. Because a false negative can only occur when the stimulus is present, the number of false negatives has an upper limit of 33 and, more generally, the number of false negatives will be [*n* – correct identifications], where *n* is the number of times each vowel was heard across all speakers. All responses across all participant can be seen in Table 3.1.

		Observed									
		i	ɪ	ɛ	æ	ʌ	ɑ	e	o	u	ʊ
Expected	i	**26**	7								
	ɪ	1	**8**	22		1		1			
	ɛ	1		**17**	14	1					
	æ				**32**	1					
	ʌ				13	**16**	2		1	1	
	ɑ				7	3	**21**			1	1
	e			2				**31**			
	o						2		**30**	1	
	u		1			1			1	**20**	10
	ʊ					6			2	12	**13**

Table 3.1 - Results of L2 group on the perception task.

The columns do not all contain an equal number of responses since these reflect the false positives; in theory, one vowel could have received every response from every participant. The expected number of total responses in each column was 33 and the more the total of a column deviates from 33, the more or less likely participants were to respond that they had heard that vowel. However, the sum of all responses across all vowels is still 330 so a higher total for one vowel will necessarily mean a lower total for another.

In general, responses were mostly distributed along the major diagonal with the average value of a cell along the major diagonal being 21 and the standard deviation being 8.2. Twenty-five of the ninety cells off the major diagonal received responses. Of these, 18 cells had a value of three or less, three representing only .9% of responses. The average value of these cells was 1.3. The other seven error cells, those representing 4 or more responses had an average value of 11.6. Counting only those cells which received at least 1% of the overall responses, 17 of the 100 cells received 92.4% of all responses.

To ensure that the task was not too difficult, four participants from the native speaker control group performed the categorization task. Total responses are given in Table 3.2.

		Observed									
		i	I	ɛ	æ	ʌ	ɑ	e	o	u	ʊ
Expected	i	12									
	I		11	1							
	ɛ			12							
	æ				12						
	ʌ			1		11					
	ɑ						12				
	e							12			
	o								12		
	u									11	1
	ʊ										12

Table 3.2 - Results of native-speaker control group on the perception task.

As expected, the native speakers showed no difficulty with the categorization task. The four participants committed three total mistakes; three participants committed one error each and one performed perfectly. No native-speaker committed any consistent errors. All participants reported having no problems with the task, in fact, these four participants committed less errors in total than even the best performing L2 participant.

3.1.1 Perception on the Individual level

For each participant, each cell which contained two or three responses was given a value of 1 and each cell which contained one or no responses was given a value of zero. The number in each cell represents the number of participants who made the identification. A row free of cell values except for the major diagonal represents a vowel which is never confused for another. Since this chart contains only consistent responses, the sum of every row may not be 11. For example, /ʊ/ was consistently categorized, correctly or incorrectly, by only six out of eleven participants. The other five participants did not identify the vowel in a consistent manner. Correct, consistent identification of a new vowel will be interpreted as being indicative of the Practically Sufficient Attainment of an L2 vowel category. Incorrect, consistent identification will be considered to be indicative of assimilation patterns. Consistent responses are seen in Table 3.3.

		Observed									
		i	I	ɛ	æ	ʌ	ɑ	e	o	u	ʊ
Expected	i	**8**	3								
	I		**1**	10							
	ɛ			**7**	4						
	æ				**11**						
	ʌ				4	**5**					
	ɑ				2		**8**				
	e							**11**			
	o								**11**		
	u									**8**	2
	ʊ									2	**4**

Table 3.3 – Consistent responses for the L2 group in the perception task.

It is remarkable how regular the performance of the participants becomes once only consistent replies are considered. The above table more clearly show the L2 group's trends when it comes to perception. The following analysis of results will use evidence from both the total and individual perceptual results. Assimilation patterns and the degree of assimilation will be discussed in terms of the L1 vowels.

It was thought that since GCE /e, o/ are phonetic diphthongs, Spanish speakers would interpret the vowels as examples of the Spanish diphthongs /ei/ and /ou/ respectively. The fact that /e, o/ were categorized accurately in a consistent manner by all participants reinforces this, as does the fact that there are no cases of any other vowel being confused for either of the two. It is considered that no further discussion of the assimilation patterns of these two vowels is necessary.

3.1.2 Assimilation Patterns
3.1.2.1 Assimilation into Spanish /a/

A confusion matrix with relevant results is seen in Table 3.4. Rows and columns representing cells which did not interact with the vowels of interest have been excised. Careful readers will note that /ɪ/ has been removed even though participants most often indicated /ɛ/ when presented with /ɪ/. It is considered that the possible assimilation of a second L2 vowel into the L2 vowel of interest has no bearing on the assimilation of the vowel of interest into the L1; each L2 vowel will be treated only in terms of its own errors. The reason for this is that when participants indicated /ɛ/ when presented with /ɪ/, they are doing so only in terms of their own lexicon. Another way of putting this is that they are selecting the vowel which *should* be, but may not be, /ɛ/. This may or may not be indicative of the assimilation pattern of /ɛ/.

		Observed			
		ɛ	æ	ʌ	ɑ
Expected	ɛ	**7**	4		
	æ		**11**		
	ʌ		4	**5**	
	ɑ		2		**8**

Table 3.4 - Perceptual results for the mid/lower vowels of English.

All three of /ɛ, ʌ, ɑ/ are confused only with /æ/ while perception for /æ/ is perfect. The first conclusion that can be drawn from this is that all four of the aforementioned vowels are assimilated to Spanish /a/. The fact that /æ/ is represented with the grapheme ‘a’ is very likely to have resulted in its perfect categorization and also for the fact that all confusion occurs in its direction. It seems reasonable to conclude that if /ʌ/ were consistently spelled with a single 'a' and /æ/ was spelled with a mismatched grapheme the results may very well have been different.

Even though the orthographic system may be the cause of the direction of the errors, the fact that /æ/ is perfectly categorized and the fact that it has become so closely associated with the grapheme 'a' indicates that it is perceived as an excellent exemplar of Spanish /a/. /ʌ/ presents opposite evidence that leads to the same conclusion. /ʌ/ is most often denoted with 'u', a grapheme which is used to spell /u/ in Spanish; a very different vowel. Despite this, all consistent errors in categorizing this vowel point to the grapheme 'a'. In terms of total responses, when hearing /ʌ/, participants indicated hearing /æ/ 13 times, and /ʌ/ 16 times. Interestingly, /ʌ/ was confused for /ɑ/ two single times, which would further suggest that /ʌ/ is assimilated into Spanish /a/, especially considering that /ɑ/ was spelled with 'o', giving participants no reason to select it. However, since /ʌ/ was confused for /u/ and /o/ one single time each, this should be taken with a grain of salt. Because almost as many people committed this error as were able to consistently categorize it, /ʌ/ is concluded to be a good to very good exemplar of Spanish /a/.

Accurate categorization of /ɛ/ was slightly better than /ʌ/. /ɛ/ was confused for /æ/ as many times as /ʌ/; its higher correct classification is the result of more consistent responses. Its total responses were very similar to those of /ʌ/; when presented with /ɛ/, participants indicated hearing /æ/ 14 times and /ɛ/ 17 times. This slight increase in consistent, accurate responses is considered to indicate a slightly larger difference between /ɛ/ and /æ/ compared to that of /æ/ and /ʌ/. /ɛ/ is concluded to be a good exemplar of Spanish /a/.

/ɑ/ was categorized correctly most frequently of all the lower vowels. This, combined with the fact that /ɑ/ is produced relatively far back in GCE, and the fact that it is, in almost all cases, spelled with an 'o', might seem to indicate that /ɑ/ is assimilated to Spanish /o/. However, its confusion with /æ/, though fairly low, is considered to be indicative of /ɑ/'s assimilation into Spanish /a/. Further evidence of this is seen in the total results; when /ɑ/ was played, participants indicated hearing /ɑ/ 21 times, /æ/ 7 times and /ʌ/ 3 times. Only one person was not able to offer a consistent response though this person's results further reinforce the notion that /ɑ/ is assimilated into Spanish /a/. When presented with /ɑ/, one participant indicated hearing /æ/ in the first trial, /ɑ/ in the second trial and /ʌ/ in the third. These vowels were spelled with an 'a', 'o' and 'u' respectively; there is no common link between the three vowels or spellings beyond the fact that each is assimilated into Spanish /a/. Because of its higher rate of correct classification, /ɑ/ is concluded to be a poor exemplar of Spanish /a/.

3.1.2.2 Assimilation into Spanish /e/

Table 3.5 displays the relevant portions of the full confusion matrix. There is no evidence that the traditional /i/-/ɪ/ vowel contrast is problematic. Participants overwhelmingly identified /ɪ/ as /ɛ/. Not a single one chose /i/ when presented with /ɪ/. The probability that this would occur by chance in 10 out of 11 cases is vanishingly small. Also, /ɪ/ was spelled with 'i' in all cases while /ɛ/ was spelled with 'e' in all cases. If /ɪ/ did in fact assimilate to Spanish /i/, participants would not be expected to select not only the wrong vowel but also an incompatible grapheme. All of this taken together is compelling evidence that /ɪ/ assimilates to Spanish /e/.

		Observed			
		i	ɪ	ɛ	æ
Expected	i	**8**	3		
	ɪ		**1**	10	
	ɛ			**7**	4
	æ				**11**

Table 3.5 - Perceptual results for the mid/low, front vowels of English.

The possibility that participants were indicating that /ɪ/ in fact sounds like /ɛ/ is considered unlikely. Since /ɛ/ and/ɪ/ are confused at an overwhelming rate the results suggest then they must be extremely similar acoustically, and, since /ɛ/ and /æ/ are also judged to be acoustically similar, we would expect to see some confusion between /æ/ and /ɪ/. Since /ɛ/ is firmly in the space belonging to Spanish /a/, it is hard to imagine how /ɪ/ could be so similar to it and not enter into the same space. Since /ɪ/ was not confused with any of the low vowels, the conclusion that /ɪ/ is in fact being confused with /ɛ/ is rejected. It is concluded that /ɪ/ is an excellent exemplar of Spanish /e/.

In this particular case, three of the four participants who selected /ɛ/ when presented with /ɪ/ consistently identified /ɛ/ as /æ/ (or 'a'). It is unlikely that they would be associating the stimulus with a phoneme which is poorly defined by them.

3.1.2.3 Assimilation into Spanish /i/

A majority of participants categorized /i/ correctly. Where errors occurred, participants indicated /ɪ/ when hearing /i/. Of the three participants that selected /ɪ/ when presented with /i/, two could not identify /ɪ/ consistently. For these two, as well as for the 8 who identified /i/ correctly, it is concluded that /i/ assimilates to Spanish /i/ and not /e/ for the same reasons as outlined for both /ɛ/ and /ɪ/. The third of the participants who identified /i/ as /ɪ/ also categorized /ɪ/ correctly in all three trials; the only participant to do so.

		Observed		
		i	ɪ	ɛ
Expected	i	**8**	3	
	ɪ		**1**	10
	ɛ			**7**

Table 3.6 - Perceptual results for the mid/high, front vowels of English.

3.1.2.4 Assimilation into Spanish /u/

It is safe to say that /u/ assimilates to Spanish /u/. Two people confused /u/ for /ʊ/ and one person did not offer a consistent response. These categorization problems are thought to be a result of the shared yet inconsistent ways in which these two vowels are spelled; in the trials, /u/ was spelled 'oo', 'oo', 'u-e' and /ʊ/ was spelled 'oo', 'u' and 'ou'. Despite the inconsistent ways in which the words meant to represent /u/ were spelled, participants were able to select the words meant to denote /u/ a majority of the time. It is concluded that /u/ is a good to excellent exemplar of Spanish /u/.

		Observed	
		u	ʊ
Expected	u	**8**	2
	ʊ	2	**4**

Table 3.7 - Perceptual results for the high, back vowels of English.

Because five out of eleven participants were unable to categorize /ʊ/ consistently, correctly or incorrectly, it is harder to determine how /ʊ/ is assimilated. However, there are several reasons to believe that /ʊ/ assimilates to Spanish /u/. Firstly, when presented with /ʊ/, participants selected /ʊ/ 13 times and /u/ 12 times. In this case there is no orthographic motivation for the errors; in some cases response words for both vowels were spelled in the same way. This may very well be the cause for the relatively low number of consistent responses; the lack of orthographic consistency leaves the participants with no easy way to distinguish the response words of these two similar vowels. The word intended to denote /ʌ/ was also selected 6 times by participants when presented with /ʊ/. This is thought to be orthographically motivated since /ʌ/ was in all cases denoted by 'u'. The fact that /ʌ/ assimilates to Spanish /a/ and that no participants made this error consistently makes it seem unlikely that participants were really confusing /ʌ/ and /ʊ/. If this interpretation is correct then participants overwhelmingly intended to select /u/ when presented with /ʊ/. It is concluded that /ʊ/ is assimilated as a good exemplar of Spanish /u/.

3.1.3 Summary: Predicted discriminability of GCE contrasts

The results of the previous section are summarized in Table 3.7 below.

L1 vowel	**i**	**e**		**a**				**o**	**u**	
L2 vowel	**i**	**ɪ**	**e**	**æ**	**ʌ**	**ɛ**	**ɑ**	**o**	**u**	**ʊ**
GOF	1	1	DT	1	1	2	3	DT	1	2

Table 3.8 – Summary of perceptual results. Goodness of fit (GOF) of the L2 vowel into the L1 category above it is excellent (1), good (2), poor (3) or diphthong (DT).

From these results, one may infer the ease of discrimination between all GCE vowels for L1 Spanish learners using PAM. Each L2 vowel is placed within an ellipse anchored by an L1 vowel. Assimilated vowels with varying levels of similarity to the L1 category are placed in concentric rings surrounding the vowel so that more similar L2 vowels are separated by fewer rings from the L1 anchor. The result is a discriminability map as in Figure 3.1 where the contour lines designate levels of similarity so that vowels separated by more rings are less similar. The ability of participants to distinguish the L2 vowels will be based on the predictions made by PAM as seen in Table 1.3. Since all GCE vowels fall into the phonetic space belonging to one of the Spanish vowels, there will be three kinds of assimilation patterns: two-category assimilation, single-category assimilation and category-goodness difference.

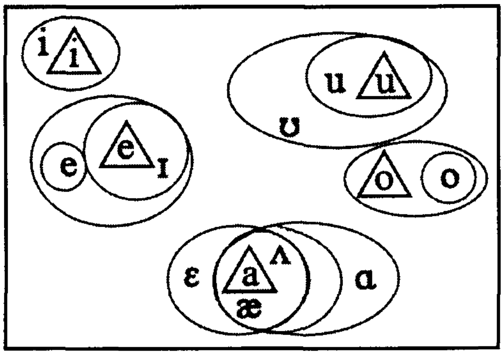


Figure 3.1 – A visual representation of the subjective perceptual vowel space. Spanish vowels are in triangles, circles indicate goodness of fit zones.

Two-category assimilation is the discrimination of two L2 vowels that are assimilated into two different L1 categories; L1 category boundaries are represented by the largest rings surrounding each L1 vowel. Discrimination of L2 vowels in these cases is predicted to be excellent. The current methodology does not allow for any conclusions to be made regarding the interior behaviour of the four vowels assimilated to Spanish /a/ and the two assimilated to Spanish /u/, however, some tentative conclusions may be reached.

/u/ and /ʊ/ should be moderate to very difficult for L1 Spanish L2 English speakers to discriminate. As for the lower vowels, /æ/ and /ʌ/ are likely very difficult for L2 speakers to discriminate. /ɛ/ should be slightly easier to discriminate from /æ/ and /ʌ/ and fairly easy to discriminate from /ɑ/. /ɑ/ is predicted to be only moderately difficult to discriminate from /æ/ and /ʌ/ and fairly easy to discriminate from /ɛ/.

3.2. Production Results

Results of the production task will be presented as follows. In § 3.2.1, the L2 English vowels will be discussed. They will be compared to those produced by the native-speaker group. Then the Spanish and English vowels produced by the L2 English group will be compared. In § 3.2.2, the English vowels produced by the L1 English group and the Spanish vowels produced by the L1 Spanish group will be compared.

3.2.1 L2 English vowels

The following section will outline the results of L2 English production. Results can be seen in Figure 3.2. Results are based on 66 tokens of most vowels; reading errors were omitted (reading errors will be discussed in more detail in section § 4.1). A mispronounced vowel was considered to be a reading error when it resulted in it being read as a member of a different, established vowel category.

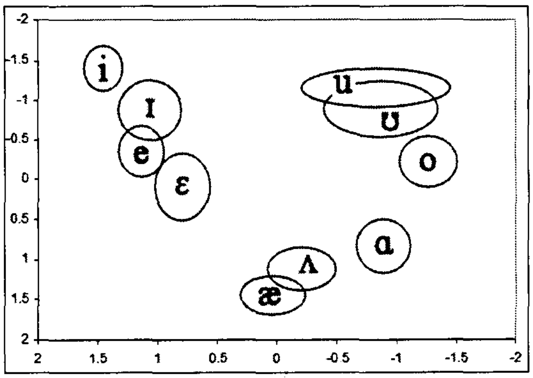


Figure 3.2 – English vowels produced by L2 English group. Ellipses enclose one standard deviation.

3.2.1.1 Cross-group and cross-language comparison of vowels

L2 production should be largely predictable from the assimilation patterns outlined above. Any deviation from assimilation patterns should be predictable in terms of orthographic interference.

An overlay of the L1 and L2 GCE vowels is seen in Figure 3.3. Where there was overlap for the same vowel between the two groups, the area has been shaded in black. The first thing that one notices is that the L2 group produces vowels mostly around the perimeter of the acoustic area. The point vowels /i, e, æ, o, u/ are produced almost perfectly by the L2 group. Granted, this does not take into account duration or nucleus movement, however, the proximity of each vowel as produced by each group suggests that they are produced 'well enough'.

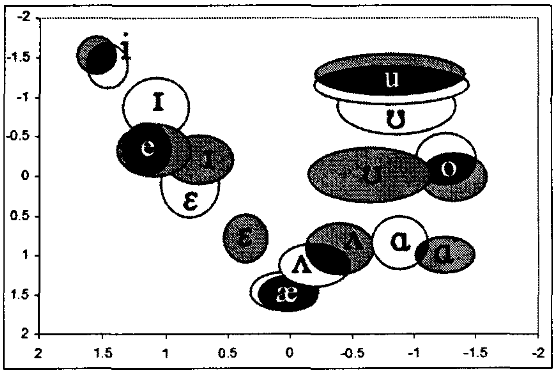


Figure 3.3 – GCE vowels produced by the L1 GCE group (grey) and L1 Spanish group (white). Same category overlap is in black. Ellipses enclose one standard deviation.

The vowels /ɛ, ɪ, ʌ, ɑ, ʊ/ are produced with moderate to considerable deviation from the L1 targets. In each case, the L2 group produces the vowel in between the L2 target and the interfering L1 vowel; the interference can be a result of assimilation patterns or orthographic representation. Each of /ʌ, ʊ/ is, on average, produced between the L1 category into which it is assimilated, Spanish /a, u/ respectively, and the GCE target. The interference for /ɛ/ and /ɪ/ is orthographically motivated, participants produce these vowels between the Spanish vowel which is spelled the same way as the interfering L1 vowel and the GCE target vowel. The starting point for /ɑ/ seems to be its orthographic representation, 'o'. This is not apparent from the group results but is more clearly seen in the production of individual participants as seen in 4.1.3.1.

There is more evidence of this when one compares the Spanish and English vowels produced by the L2 English group. An overlay of these two sets of vowels can be seen in Figure 3.4. No English vowel is produced identically to its corresponding Spanish vowel by the L2 English group. It seems as though the interfering vowel is the starting off point for the production of a new L2 vowel. From there, speakers begin to produce the English vowel that is different from the Spanish category, in the direction of the English target.

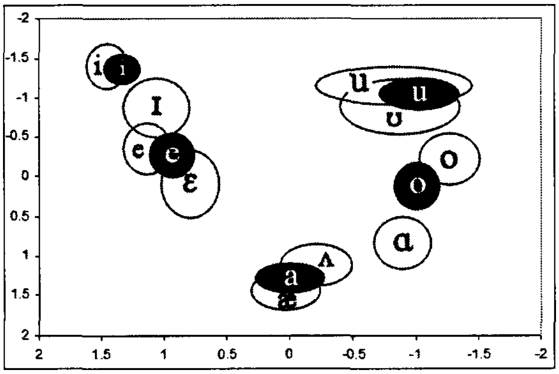


Figure 3.4 - GCE (white) and Spanish vowels (black) produced by the L1 Spanish group. Ellipses enclose one standard deviation.

In the case of /ɛ/, for example, mispronunciation cannot be a direct result of perceptual problems. The results of this study, as well as those of Flege et al (1995) show that /ɛ/ is assimilated into Spanish /a/ and yet is clearly pronounced as more /e/-like tan

/a/-like. The most plausible explanation for this is that mispronunciation of /ɛ/ is orthographically motivated.

The above results are based on the production of all eleven L2 English participants, however, group results do not necessarily reflect, and in fact may obscure, trends present in the production of individual participants. A more specific analysis of the production of individual participants can be found in the discussion in § 4.1.3.1.

3.2.2 Comparison of L1 Spanish & L1 English vowels

The vowels produced by the L1 English and L1 Spanish speakers in their respective languages are seen below. This includes all vowels produced by the 11 Spanish speakers and 9 native English speakers. 3 English speakers skipped one /i/ word once each; apart from this there were no misreadings. The English results are based on 54 tokens of each vowel (51 for /i/). The Spanish results are based on 66 tokens of each vowel.

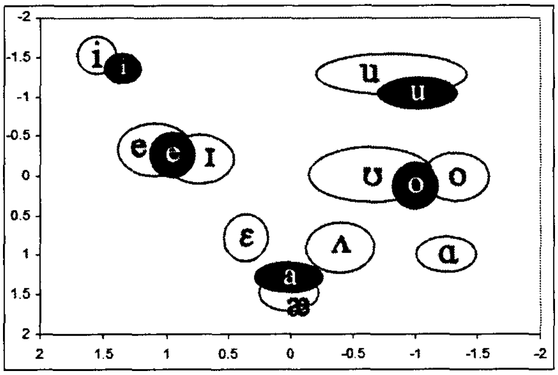


Figure 3.5 – L1 Spanish (black) and L1 English vowels (white). Ellipses enclose one standard deviation.

The normalization method used in this study worked very well at aligning the vowels not only of males and females but also across the two languages. Spanish clearly has three heights with low vowels appearing at 1.5, mid vowels appearing at 0 and high vowels appearing at -1.5. There is also a clear organization of back, mid and front vowels. The English system seems to have four levels of height with an additional mid-low row of vowels. The point vowels of the two languages align reasonably well, as do their mid vowels.

3.2.2.1 Support for perceptual analysis

The initial assimilation patterns reported in § 3.1.2 will be reassessed based on the production results presented in Figure 3.2. A complete description of these vowels involves considerably more information than what can be presented on an F1-F2 plane. However, since vowels in the two languages are primarily distinguished using F1-F2 information, it is considered that the assimilation pattern of the GCE vowels into Spanish categories should be related to proximity on the L1-L2 plane. If the preliminary assimilation patterns are supported by proximity on the F1-F2 plane, the initial conclusions were likely correct. If not, the results will be reassessed or modified.

The proximity of English /i, u/ and Spanish /i, u/ reinforces the notion that the former assimilates into the latter. It also appears that /ɪ/ assimilates into Spanish /e/, not only are they very close on the plane but there is even a fair amount of category overlap. GCE /ɛ, æ , ʌ/ are all very close to Spanish /a/. /ɛ/ and /ʌ/ appear equidistant from Spanish /a/; if /ʌ/ is considered to be a better exemplar of Spanish /a/ than /ɛ/, this would point to a preference for back vowels to be categorized as Spanish /a/. This preference for back vowels is supported by the assimilation of /ɑ/ into Spanish /a/. /ɑ/ is produced further back than Spanish /o/ and yet is assimilated into Spanish /a/; these results suggest that perceptual distance is not linear. For example, low vowels seem to assimilate to Spanish /a/, regardless of their frontness or backness, but the similar rate of correct identification of /ɛ/ and /ɑ/, even though /ɛ/ is much closer to Spanish /a/ than /ɑ/, suggests that low, front vowels are perceived as more dissimilar than low, back vowels of equal distance to Spanish /a/.

This notion is supported by the location of /ʊ/ on the F1-F2 plane. It was concluded earlier that /ʊ/ assimilates as a good exemplar of Spanish /u/. This is odd given the proximity of /ʊ/ to Spanish /o/. The situation with /ʊ/ could very well be the back-vowel equivalent of /ɪ/. Recall that /ɪ/ assimilates to Spanish /e/ and that its pronunciation as /i/ appears to be orthographically motivated (Morrison 2006). /ʊ/ could very well assimilate to Spanish /o/, there is even a fair amount of category overlap on the plane, and the apparent confusion with /u/ could be orthographically motivated. Recall that this categorization task relies on participants associating the stimulus sound with the vowel contained in the lexical entry of each of the response words. Participants could show confusion between /ʊ/ and /u/ not because the two vowels are assimilated into Spanish /u/ but simply because they have learned to pronounce words with both vowels as /u/. The question in this case is: What would motivate this mispronunciation? In the case of /ɪ/ it was fairly straightforward, participants pronounce /ɪ/ as /i/ because /ɪ/ is spelled with 'i' in a majority of cases. /ʊ/ is spelled with 'u' in 54% of cases and 'oo' in 31% of cases. If participants were stocking their lexicon based on orthographic representations, and /ʊ/ assimilated to Spanish /o/, it would be expected that they would at least be able to identify /ʊ/ correctly when it was spelled with 'oo'; this was not found to be the case. Another possibility is that participants have associated the 'oo' spelling with /u/ and so have learned to associate the two. This possibility is thought to be unlikely. If /ʊ/ assimilated to Spanish /o/, it would be the only GCE monophthong to do so. Participants would learn specific instances of words containing /ʊ/, regardless of spelling, as they have done for GCE /i/ and /u/.

If /ʊ/ does in fact assimilate to Spanish /u/ and not /o/, it might mean that although Spanish /o/ appears next to /ʊ/, Spanish /o/ has a low tolerance for F2 values above a certain point. The reason for this could be that the center of the acoustic space is considered to be a part of Spanish /u/. Borzone de Manrique (1976) found that when Spanish /u/ was realized as part of a diphthong, in either a /Vu/ or /uV/ context, its F1 and F2 frequencies tend to be considerably higher than Spanish /u/ in isolation; the result of this is that /u/ is realized as a central vowel when it is a part of a diphthong. Spanish speakers know to interpret vowels which fall into the central vowel space as reduced versions of Spanish /u/; this in turn may be what causes /ʊ/ to be assimilated into Spanish /u/.

Chapter Four

4. Discussion

The following sections will discuss the findings of this study and their implications. § 4.1 will discuss why orthographic interference might occur, and how it affects the acquisition of English by L1 Spanish Speakers. § 4.2 will discuss evidence that participants have access to language learning mechanisms into adulthood. Some reasons for the unpredictability of assimilation patterns will be discussed in § 4.3. In, § 4.4, the implications of disconnected perception and production abilities will be examined.

4.1 Perceptual vs. Orthographic interference

It has been hypothesized here that the apparent disconnection between perception and production can be accounted for by considering that the cause may be the English orthographic system. Young-Scholten (1995) suggests that premature exposure to an L2 orthography can be expected to impede phonological competence in an L2. If the L1 and L2 share an orthographic system, orthographic evidence can be seen as explicit evidence as to the phonemic content of a word (Young-Scholten 1995).

The ability to read in an L1 follows phonological competence in the language. If a learner is exposed to the L2 orthography before L2 categories have been established the L2 graphemes can only be associated with L1 phonemes. There is no guarantee that L2 learners will progress past this stage (Birch 2007):

> Many readers learn to read English without much direct instruction in decoding or recoding the letters. [...] However, not all [English as a second language] learners become expert readers; they don't seem to catch on to the relationship between letters and sounds, or they are unable to extend their knowledge to words that they haven't seen before. Some ESL [...] readers seem to get stuck in an early stage of reading development and they need direct intervention in order to move on. (8)

To see if the L2 orthography has caused interference, the author suggests that "one might examine the orthographic representation of the phonemes in the learner's L1 and L2 to ascertain whether, when the phoneme is realized differently in the L2 [...] the learner perhaps unexpectedly ignores the [primary linguistic data]" (113) and instead relies on its orthographic representation. The results of this study seem to be exactly this sort of evidence.

The end result is that production is a probable but not necessary reflection of perception. While the limits placed on the accurate perception and categorization of new vocalic phonemes by L2 learners appear to be purely linguistic ones, the production of these same phones is affected by extra-linguistic factors. If learners of an L2 had only the spoken language in their environment with which to acquire the target language, then the orthographic system of the language would be largely irrelevant.

The following sections will detail the different reading strategies employed by learners of both transparent and opaque orthographic systems and how the writing system is thought to interfere with acquisition when a reader of a transparent system attempts to learn a language with an opaque system. The following analysis extends specifically to languages which use the Latin alphabet

4.1.1 Reading strategies

Studies regarding the effects of a writing system on the ability to read have mostly dealt with children; however, they are relevant to the study of adult L2 acquisition. Children learning to read in their L1 apply different strategies depending on the kind of writing system they encounter (Birch 2007). These strategies are used to decode and interpret new words encountered while reading. One would expect that these strategies would persist into adulthood since they would be optimized to deal with the style of representation in the L1. If this is the case, then the strategies employed by children of a transparent system (like Spanish) and an opaque system (like English) are highly relevant. If the reading strategies of the L1 and the L2 are not compatible then one would expect certain types of errors to occur. These errors will interfere with the acquisition of new vocabulary the learner encounters in written form.

Wimmer & Goswami (1994) tested the reading abilities of 7, 8 and 9 year old German and English children. The two groups were asked to read a numeral aloud ('4'), the corresponding orthographic representation of the numeral ('four') and a nonce word which contained the same graphemes as the numeral ('nour'). The two groups performed similarly on the first two tasks, however, "[a] substantial number of English children at each age group had enormous difficulty in deriving acceptable pronunciations for [the nonce] words, while for German children - even for the youngest ones - nonsense word reading posed little difficulty" (99). This is despite the fact that the authors accepted any possible phonemic realization of the sequence of graphemes in the nonce words. For example, for the nonce word 'nour', pronunciations that rhymed with 'our', 'tour' and 'four' were all accepted (96). German children committed phonological errors which resulted in non-words, for example reading the word 'drink' as 'brink'. The English children committed lexical errors which resulted in actual, yet incorrect, English words, for example reading 'sen' as 'seen' and 'thrine' as 'thing'. The types of errors suggest that when encountering new words, readers of transparent orthographies will assemble pronunciations while readers of opaque orthographies will interpret larger units and even whole words at a time. These finding were replicated by Landerl (2000) using the same languages.

Defior et al (2002) conducted a similar study on groups of L1 Spanish and Portuguese children. The orthographies of both languages are fairly transparent with Spanish being slightly more predictable than Portuguese. As predicted by the findings of the aforementioned studies, neither group made a significant number of lexical errors when reading the nonce words. However, the Portuguese children did make significantly more phonological errors than the Spanish children, leading to the conclusion that even a slight increase in the opacity of an orthographic system can affect the ability to properly interpret new words.

Goswami et al (2003) found that children learning to read in English employ different strategies to decode different sized orthographic units and that there is a negative cost associated with the switch from one to the other. For example, the word /map/ may be spelled 'map' or 'mappe'. In the first word, the intended vowel can be recognized based on the single grapheme 'a' while the vowel in the second word can only be identified by using the entire sequence '-appe'. In a transparent orthography, the graphemes that follow and precede a letter are largely irrelevant for the decoding of that letter. This entails that reading an opaque orthography requires not only recognition of the loose association of grapheme to phoneme but also the use of different reading strategies based on the situation in which the reader finds herself.

4.1.2 The Reading errors.

As mentioned earlier in § 3.2.1, a mispronunciation was considered an error only when the error was anomalous. The aforementioned studies distinguish two types of errors, lexical errors and phonemic errors. Lexical errors are the result of the incorrect interpretation of a unit of one or several graphemes and phonemic errors are the result of too-strict adherence to the L1 phoneme-grapheme associations. Since, in this study, phonemic errors are consistently the result of direct adherence to the orthographic system of the L1, they will be referred to as orthographic errors.

Fifteen tokens were not included in calculations because they were considered reading errors. Two tokens of /i/ were not read by participants and another two tokens of /u/ were excluded because of recording errors. There were three other cases in which a participant committed what seemed to be reading errors. This participant produced what appeared to be instances of /ɪ/ when prompted to read /ɛ/. This same participant produced Spanish /e/ and /ɛ/ in basically the same way. This participant seems to have made a direct association between the perceptual category into which /ɪ/ is assimilated and the L1 orthographic representation for that category. Due to a general lack of definition in the front-mid vowels produced by this participant, these vowels were included in the totals of that participant. All reading errors are presented in Table 4.1.

Lexical Errors		
Word	Intended Reading	Observed Reading
boot	/ but /	[boʊt]
cod	/ cɑd /	[coʊd]
dead	/ dɛd /	[did]
peck	/ pɛk /	[pik]

Orthographic Errors		
Word	Intended Reading	Observed reading
deed	/ did /	[ded]
shoot (2)	/ ʃut /	[ʃot]
dud (4)	/ dʌd /	[dud]
bud	/ bʌd /	[bud]
did (2)	/ dId /	[did]
meet	/ mit /	[met]

Table 4.1 – Reading errors committed by L2 group. Numbers in brackets indicate the number of times an error was committed.

The lexical errors are clear cut cases of misinterpretation of a group of graphemes; in each case, the resulting word is a real word of English. In some of these cases, participants reported having misread a word immediately after reading it.

The orthographic errors are fairly straightforward: In all cases participants read the word essentially as if it were spelled in Spanish. The mispronunciations of 'deed' and 'meet' resulted in a vowel that sounded very much like /ɪ/. However, these participants did not consistently produce an /ɪ/; their mispronunciations in those two cases sounded like a very short /e/. In both cases, their mistakes are listed as having resulted in [e] because of the spectral similarity between Spanish /e/ and GCE /ɪ/. It is important to note that these participants have twenty years of experience speaking English; it is impossible that they are not familiar with the word 'did'. Despite this, two participants misread one instance of /ɪ/ as /i/, presumably because of its orthographic representation 'i'. It seems that the inclination towards an L1 reading strategy may be very strong even for years after the L2 has been acquired.

The word 'dud' presents a perfect example of how reading strategies may interfere with acquisition. As noted in Table 1.4, the grapheme 'u' is four times as likely to denote /ʌ/ as opposed to /u/ in English, whereas in Spanish 'u' denotes /u/ in all cases. If participants used the trends of English orthography to decode new words, as would be expected from people who learn to read an opaque writing system, it seems logical to think that, if they did not know the word, they would likely have guessed that this word was pronounced /dʌd/. The fact that participants relied on the single-unit decoding strategy more suited to transparent orthographies suggests that reading strategies may persist even despite prolonged exposure to different orthographic systems. The same participants who read 'dud' as /dud/ produced a very /a/-like vowel in the cases which they did produce /ʌ/. This suggests that words which require a mismatched grapheme-phoneme pronunciation may be learned on a case by case basis and that participants may fail to capitalize on generalizations regarding the L2 orthography even well into the acquisition of the language.

Given their lengthy residence in Canada and the simplicity of the words, it was taken for granted that participants would be familiar with the words used in the production task. The high rate of mispronunciation of the word 'dud' suggests that at least some participants did not know this word. Information regarding participants' familiarity with each word would have been useful to compare with the reading errors (and perhaps even with pronunciation in general). This oversight is an unfortunate but not critical flaw in the experimental design.

4.1.3 Orthographic interference

The fact that two different L2 vowels are pronounced in the same way does not necessarily mean that they are perceived in the same way or even that they are ever confused at all, however, this is not to say that the relationship between the two is entirely unconstrained. The above sections showed that readers of different kinds of orthographies employ different strategies when trying to learn new words encountered in writing and that these can have an effect on L2 reading. The following orthographic interference hypothesis will outline the ways in which incorrect reading strategies could result in a disconnection between production and perception of an L2.

When one reads a transparent orthography, graphemes and phonemes become intimately connected; if one has spent more than twenty years forming an association between the two, it seems reasonable to think that this association would be fairly strong.

If learners are using incorrect reading strategies to learn vocabulary or to verify forms they already know, the accuracy of phonemic representations cannot be verified at least until practically sufficient attainment of the phoneme exists.

Initially, participants who learn a second language will produce new words encountered in text using their orthographic representation; they cannot know the 'proper' way to pronounce them. If the orthographic representation of two very similar vowels in the two languages is represented with the same grapheme, there will be no errors as the L1 vowel is a 'good enough' fit for the L2 vowel; this is the case of GCE /ae/ and Spanish /a/. There will also not be a problem for L2 sounds which are assimilated into an L1 category into which no other L2 sound is assimilated; this is the case for English /i/.

If the orthographic representation of an L1 vowel and an L2 vowel which are considered to be 'different' is the same, one of two things may happen. If the L2 vowel is 'similar' enough to the L1 vowel spelled in the same way, that L1 vowel will be the starting off point for pronunciation of that L2 vowel; this is the case for GCE /ɪ/. When forced to make a categorization, participants overwhelmingly indicated that /ɪ/ assimilates into Spanish /e/. However, Flege et al (1995) demonstrated that when giving similarity judgments, Spanish speakers hear something at least partly /i/-like about English /ɪ/. Because of this, and because of the overwhelming regularity with which /i/ is spelled with 'i', it is thought that participants accept /i/ as an adequate initial pronunciation for GCE /ɪ/.

If the spelling of an L2 vowel would lead to a pronunciation which would be too 'different' from the L1 vowel which is spelled in the same way, then the L1 vowel into which the L2 vowel is perceptually assimilated will be the starting off point. This is the case with English /ʌ/. Participants may initially pronounce unknown words meant to denote /ʌ/ with a /u/ but they will quickly learn that this difference is unacceptably large.

Participants may very well be sensitive to general trends in the orthographic system, however, as evidenced by the reading errors.

The above depends on the consistency with which a grapheme-phoneme relation can be established. If orthographically motivated mispronunciations are special cases they will not have much influence on pronunciation of that phoneme in general. On the other hand, if the relationship is predominant, it may come to be the default one in the lexicon. It seems reasonable to consider that the more people acquire words with the interpretation 'i' = /i/, the more likely they are to continue to do so in the future. The inverse should also hold, the more diffuse a relationship between a phoneme and its corresponding graphemes, the more difficult it will be to establish a pattern, correct or otherwise. This may not be a problem for vowels which are assimilated as lone, excellent exemplars of an L1 category, as seems to be the case with GCE /i/, but it could create serious problems with the pronunciation of an L2 vowel which is assimilated into an L1 category with one or more other L2 sounds.

As to how 'different' or 'similar' two vowels need to be in other for the result to be one or the other, this is likely only knowable as a result of experimentation and specific not only to any two languages but likely even to two dialects.

4.1.3.1 Orthographic Interference: Evidence from individual participants

This section will detail evidence of the orthographic interference hypothesis as seen in the individual performance of the participants of this study. The following convention will be used to represent all vowel inventories in the diagrams to follow. Spanish vowels will be circled and vowels which were pronounced with overlapping locations on average will be placed side by side and within an ellipse. The phoneme symbols are placed on the mean F1 and F2 values for each vowel.

In the initial stage, before L2 categories are set, all English graphemes will be read as instances of L1 categories. As noted by Birch (2007) a learner who does not receive specific instruction may never progress past this stage. This is not to say that instruction is necessary but simply that reading is not a natural phenomenon and that without specific instruction, adequate reading strategies in the L2 may not develop. The vowels of a participant (S1) who typified this stage are seen in Figure 4.1.

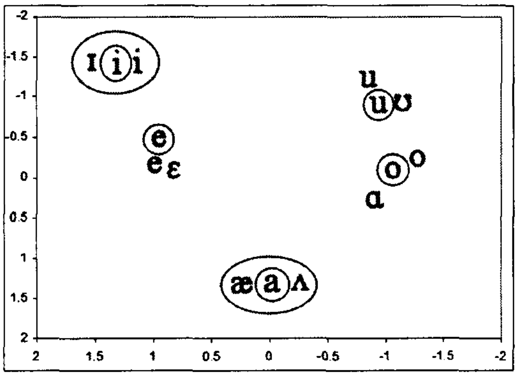


Figure 4.1 – Spanish and English vowel inventory of one participant (S1). See text.

S1 produces each of the ten vowels of GCE in close proximity to one of the five Spanish vowels. In the perceptual task, this participant identified /ɛ/ as 'a', and /ɪ/ as 'e' and yet /ɛ/ is produced almost identically to Spanish /e/ and /ɪ/ is produced in an identical fashion to /i/. S1 also produced /ɑ/ in a very similar way to Spanish /o/; /ɑ/ is spelled with 'o' in almost all cases in English. If this participant's production of these vowels were based on the way in which those vowels were perceived this would not be the case. In each case, the pronunciation of the GCE vowels is explainable using the orthographic interference hypothesis. This participant also consistently indicated 'i' when presented with /i/ suggesting an all-around predisposition towards a direct, phonemic decoding of words.

In English /u/ and /ʊ/ are spelled with a varying combination of the same set of graphemes. Participants demonstrated difficulty in identifying /ʊ/ in the perceptual task; this was attributed to the inconsistent ways in which it is spelled. Participants also produced little or no difference in their realizations of /u/ and /ʊ/ and it seems that this may also be attributable to the inconsistent orthographic representations of /ʊ/. If L1 Spanish speakers in the process of learning English initially assimilate both /u/ and /ʊ/ to Spanish /u/ then words containing both English phonemes will tend to be pronounced with /u/. For participants to learn which word contains which of the two phonemes they must first achieve Practically Sufficient attainment of the two phonemes since there is no orthographic consistency to rely on. Until this is achieved, participants will pronounce both phonemes as one. S1 above, as well as S2 and S3, seen in Figure 4.2 below, make little or no contrast between the two vowels.

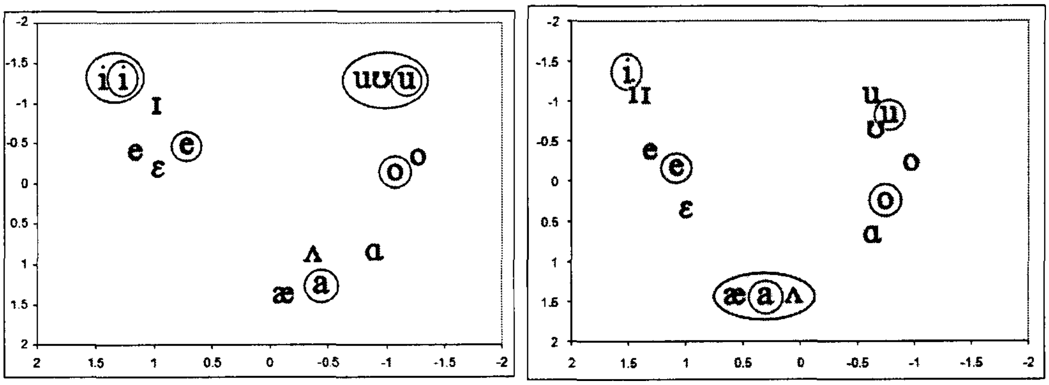


Figure 4.2 - Spanish and English vowel inventory of S2 (left) and S3 (right). See text.

There does not seem to be a set ordering of the acquisition of contrasts. S2 produces GCE /ɛ/ and /e/ at almost the same height but produces all the vowels that assimilate into

/a/ distinctly, from each other and from /a/. This speaker has also separated /ɑ/ from Spanish /o/. Inversely, S3 shows a considerable height difference between GCE /ɛ/ and /e/ but does not distinguish /æ/ and /ʌ/ and pronounces /ɑ/ considerably out of position towards Spanish /o/.

This account of orthographic interference can be extended to hypothetical cases which are entirely plausible. Since /ɛ/ seems to be assimilated as a good exemplar of Spanish /a/, if /ɛ/ were generally spelt, with 'a', L1 Spanish speakers would likely pronounce /ɛ/ like Spanish /a/. If, for whatever reason, GCE /ɪ/ were spelled with 'u', Spanish learners might conclude that the representation is too 'different' and pronounce it like Spanish /e/, the category into which it is assimilated. If this were the case, an L1 Spanish L2 English accent might have been very different from what is heard today and all that would have changed is the arbitrarily assigned grapheme that is used to designate each English vowel.

This explanation of events was formulated to explain the asymmetry of perceptual assimilation patterns and production patters. This relationship is specific to Spanish and Canadian English; in some ways the relationship between the vocalic systems and orthographic systems of the two languages seems to be designed to make acquisition of English as an L2 by L1 Spanish speakers particularly tricky. However, it is possible that this sort of phenomenon occurs frequently across languages and in unpredictable ways between languages with different vocalic and writing systems.

4.2 Access to language learning mechanisms in adulthood

The Speech Learning Model (Flege 1995) hypothesizes that humans have access to the same language learning mechanisms throughout their lives; the results of this study support that claim. Although no L2 participant produced native-like vowels, in most cases participants produced distinct vowels for L1 and L2 categories. The production results of one participant, S4, are seen on the left in Figure 4.3 below.

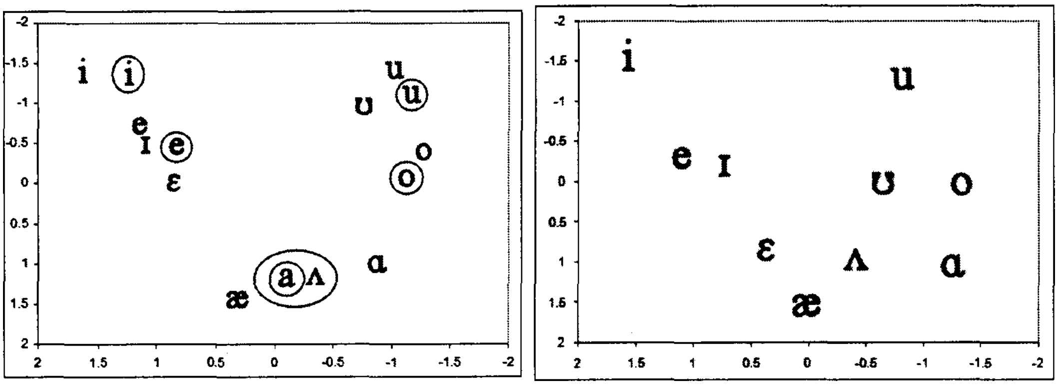


Figure 4.3 - Spanish and English vowel inventory of S4 (left) and the average vowel produced by the L1 English group (right). See text.

The English vowels produced by S4, while not exactly like those of native speakers, are organized in the same basic structure. Looking specifically at the low vowels produced by S4, it is surprising that the structure of the three vowels so closely resembles those produced by native speakers. S4 has fused /ʌ/ and Spanish /a/, this suggests that /ʌ/ may very well be as good an exemplar of /a/ as /æ/. S4 produces his /ʌ/-/a/ merged vowel where native speakers would pronounce their /æ/ but this speaker still produces /æ/ a little further front; in doing so preserving the structure of the low vowels. The minute phonetic differences consistently produced for these vowels, the fact that these speakers consistently produce L2 vowels that are different from their L1 vowels and the fact that these differences are always specifically in the direction of the target are strong evidence that learners have access to this phonetic detail and specialized language learning mechanisms well into adulthood. If participants had only access to crude, distinctive-feature style information regarding the L2 vowel it is hard to imagine what would motivate the gradual movement of each L2 vowel towards its target.

Results of the perceptual task are not indicative of absolute perceptual abilities. The task removed all contextual cues and evidence and forced participants to make a classification. The results of this task are believed to fairly represent assimilation patterns but not the extent to which each phoneme is assimilated within a category. For example, S4 consistently identified /ɪ/ as 'e' and yet produces it in a native-like position.

The results of the perceptual task also suggest that access to language learning mechanisms is available to learners into adulthood. If learners did not have access to these mechanisms, results of the perceptual task should be more or less stable since participants would only be able to answer in terms of their shared L1 phonology. This was not the case; two individual participants' results on the perception task are seen in Table 4.2 below.

		Expected									
		i	ʌ	ɛ	ɑ	e	ɪ	u	o	æ	ʊ
Observed	i	1					2				
	ʌ		3								
	ɛ	1								2	
	ɑ				1			1			1
	e			1		2					
	ɪ	1		2							
	u		1					2			
	o				1				2		
	æ									3	
	ʊ		1					1	1		

		Expected									
		i	ʌ	ɛ	ɑ	e	ɪ	u	o	æ	ʊ
Observed	i	3									
	ʌ		2							1	
	ɛ			2						1	
	ɑ		1		2						
	e					3					
	ɪ			2			1				
	u							2			1
	o								3		
	æ									3	
	ʊ							1			2

Table 4.2 – Perception task results for S5 (left) and S6 (right).

S5 commits several errors, but also shows high levels of inconsistency in responses. S6, on the other hand, has almost native-like performance. These two learners began with the same L1 and have been living in Canada for roughly the same period of time. It must be assumed that these two participants had the same potential to learn English as an L2 and that the difference in their end-state is attributable to non-biological factors.

4.3 Unpredictability of assimilation patterns

Previous studies have used traditional, feature-based classification as their starting point for the comparisons of vowels across languages. The results of this study demonstrate that these classifications are only accidentally related to the assimilation patterns of real learners. If features were true atomic elements which fully described phonemes, in the way that a water particle is fully described by its hydrogen and oxygen atoms, then it is difficult to understand how phonemes composed of the same features could differ in significant ways.

It also appears that the symbols used to denote phonemes across languages are rather arbitrarily assigned. Flege (2005) states that the problem with using phonemic symbols to make cross language comparisons "is that transcription practices and symbolization may vary across languages, and vowels transcribed using the same IPA symbol (e.g., the /u/s of Korean and English; Yang, 1996) may differ systematically" (441). The assimilation patterns of the L2 group, and even the production of the native English group, in many cases does not align well with what would be expected for each phoneme based on the phonemic symbol attached to it.

Cutler (1979) says that a linguistic analysis can be 'psychologically real' in two senses. A linguistic process is psychologically real in the strong sense if it reflects actual stages in an actual process in the performance of language. An analysis is real in the weak sense if it only captures a piece of knowledge that speakers have of a language.

For example, a 'rule' of plural formation in English which attaches the abstract, underlying representations of two morphemes, the singular noun stem and the plural marker /s/, is often posited. The surface representation of the plural morpheme undergoes changes, also motivated by 'rules' in the grammar of the speaker, depending on the final segment(s) of the noun to which it attaches. This 'rule' is likely psychologically real in the weak sense; English speakers surely do articulate plurals by producing modified versions of the singulars of regular nouns in systematic ways. However, this 'rule' is only psychologically real in the strong sense if all of its many assumptions reflect language as it exists in the mind[4]. This split can be expanded to scientific theory in general; a short historical digression will make this point.

In Ptolemaic astronomy, the Earth is at the center of the universe and the sun, moon and all planets rotate around it. To account for the varying speeds and motion of the heavenly bodies in relation to the Earth (a result of the actual heliocentric nature of the universe), scientists introduced the idea of epicycles, the idea that each body moved in a small circular motion as it rotated around the Earth. In the seventeenth century, Phlogiston theory posited that an unobservable element called phlogiston was released during combustion and that this could account for the loss of mass experienced by a material after combustion. To account for the increased mass of some elements after burning, it was hypothesized that phlogiston could have a negative or positive weight. Both of these theories had a certain degree of explanatory, and even predictive, power.

We know today that these theories are incorrect, that they are fundamentally flawed. These theories do, however, contain a certain amount of truth; they could be thought of as

[4] Some of these assumptions include that plurals must be derived from singular forms, that morphemes have underlying abstract representations, that words are stored as morphemes and that underlying representations undergo rule-motivated change *prior* to articulation.

representing a 'weak' physical reality in that their descriptions capture something true about the phenomenon in question. However neither theory describes physical reality in the strong sense as neither accurately captures the process, condition and nature of the phenomenon they seek to describe.

The switch from a Ptolemaic to a Copernican solar system immediately eliminates the need for epicycles. This does not make epicycles any more 'wrong' or 'right' than they were within their particular framework, but rather, the switch to a model with a stronger link to physical reality obviates recourse to those sorts of ad hoc mechanisms. As one approaches a 'truer' understanding of the solar system, one requires less and less of these mechanisms until the behaviour of the components of the system can be understood without 'rules' or 'special cases' and solely in reference to the system itself.

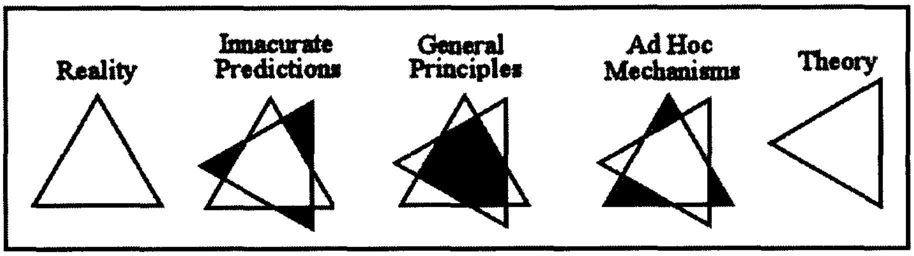


Figure 4.4 – A visual representation of the effects of a misalignment of theory and reality. Shaded areas indicate how the theory explains aspects of reality.

Phonological and linguistic theories that do not seek to model behaviour that is psychologically real in the strong sense may very well have explanatory and even predictive power. But for every asymmetry between them and the reality they seek to describe there be will an inaccurate prediction made and a corresponding element that seemingly does not fit the theory. Theories which are real in the weak sense must use arbitrary, ad hoc mechanisms to explain an observed phenomenon that does not fit the framework. Every mechanism of this kind is necessarily a reaction to an inaccurate prediction made by the theory. On the other hand, theories that reflect psychological reality in the strong sense will need considerably fewer such mechanisms since the behaviour of the elements of a system in most cases follow from an accurate understanding of the system itself.

This is evident in our understanding of the physical universe. Where before specific phenomena, for example rain, lightning or fire, were explained within discreet frameworks, modern explanations of these events simply follow from the general properties that define the physical universe as a whole.

The assimilation patterns of a speaker of language X trying to acquire language Y may be unpredictable for two reasons. One source of this unpredictability is that the phoneme inventory of a language and the way in which each phoneme is defined may vary in arbitrary (though systematic) ways across languages. This source of unpredictability is a natural by-product of linguistic diversity and cannot be avoided.

The second way in which assimilation patterns may be unpredictable is because the system or framework used to describe the phonological elements, and perhaps even the phonology itself, represents only a weak psychological reality, and, as a result of this, may differ from the true system in significant and unforeseeable ways. It appears that feature based accounts, and cross-language based comparisons of vocalic systems based on phonemic symbols, may result in this second kind of unpredictability. This form of unpredictability *can* be accounted for with a better understanding of how phonemes are conceptualized and how they interact within the mind of a speaker.

Linguistics is a relatively nascent science and a reliance on explanations which are only psychologically real in the weak sense has certainly been beneficial to our understanding of how language works. However, relying solely on these explanations can only lead to an understanding of language which might perhaps be parallel to, but which does not necessarily have any bearing on, the system as it is.

Theories that are psychologically real in the weak sense are not entirely without value, but they serve only as metaphors for actual psychological reality. It is obvious that a figurative representation is only accurate until it is not; the relationship of similar behaviours and properties between the actual and figurative representations is not predictable or bi-directional. For example, to say that 'a glove is a hat for the hand' does not allow one to safely project other properties from one category onto the other. Frameworks that are a figurative representation of actual psychological processes will only be correct until they are not and, consequently, generalizations about the behaviour of the figurative representation will not necessarily carry over onto language as it is.

As for how to determine the psychological plausibility of a linguistic generalization, it is a difficult though not impossible task. Derwing & Nearey (1986) state that since "the truth to be discovered is not physical in character but rather psychological, [...] it follows that a large assortment of psychological tests is required in order to discover it" (187). The authors also point out that even the transcriptions used by most phonologists to analyze data represent a distortion of the actual speech signal; it is impossible to really analyze language as it is, without the interfering biases of the transcriber, in this way[5]. The most important step towards formulating a phonological theory that approaches psychological reality in the strong sense is to reject the view "that linguistic competence can be established on the basis of purely formal, non-empirical, criteria which are devoid

[5] Phonemic transcription also assumes the psychological reality of the phoneme; the existence and nature of representation of minimal speech sounds cannot be stated with any certainty at this point.

of any external psychological support, as in the work of Chomsky. Such competence can only be declared so 'by definition'" (Derwing & Nearey 1986, 189).

4.4 Implications of the perception-production disconnect

The phonological competence of a person can be split into two distinct areas, each one corresponding to one's role as either speaker or listener. On the one hand, speech perception requires that the incoming acoustic signal be mapped onto symbolic elements in the mind of the speaker. As a speaker the inverse process takes place, symbolic elements must be performed so that the resulting acoustic output can be decoded in the intended way by the listener. Nearey (1997) and Kleunder & Lotto (1999) outline some of the ways different theories organize the perceptual, gestural and symbolic components of phonological competence.

Accounts of speech perception can be divided into those that place primacy on the gestural aspect of speech production and those that place it on the auditory aspect of speech perception. For a gesturalist, the sound that is interpreted by a speaker as an instance of /a/ is merely a carrier for the articulatory configuration necessary to produce /a/; the listener works backwards and retrieves gesture associated with each speech sound. Auditorists suggest the opposite; that the symbolic representation of a speech sound is the sound itself and articulatory gestures are merely a means to an end.

The findings of this study suggest that it may be possible for speakers to pronounce phonemes in a way that is different from the way they perceive the same phonemes. If either the auditory or gestural information of a phoneme were the main component of the mental representation, and the other aspect simply followed from this, then it is difficult to see how it would be possible for this to occur. Since only one of the two would be directly linked to the symbolic representation, the other must be identical, or very similar to it.

Nearey (1997) proposes an alternative organization of the auditory, gestural and symbolic components:

> Only two conditions are necessary for speech to operate as an effective communication system. First, a symbol sequence must be encoded into gestures. Second, the acoustic output of those gestures must provide the listener with auditory cues sufficient to decode the intended symbol sequence. [...] On this account, gestures and auditory properties are linked only indirectly, through separate links to shared symbols. (3243)

Nearey's model is compatible with the findings of this study that perception and production may misalign because of paralinguistic factors. If the auditory and gestural components of a phoneme are linked only indirectly, then at least the potential for this disconnection exists. To illustrate this point, the perception and production of GCE /ɪ/ will be discussed; a visual representation of this mental representation compared to that of /i/ is seen in Figure 4.5 below.

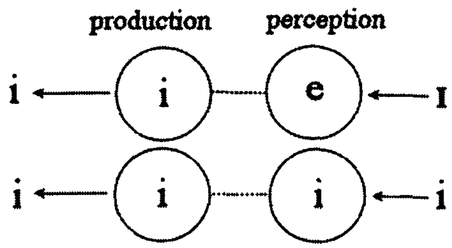


Figure 4.5 – Visual representation of the auditory and procedural knowledge of an L1 Spanish L2 GCE speaker. See text.

The mental representation of a phoneme for perception is an associated group of acoustic cues; the mental representation of the same phoneme for production is the procedural knowledge associated with its production. The two components may result in the same sound but they are still distinct pieces of knowledge regarding the phoneme. It is this distinctness that allows for something like orthographic interference to occur.

Is it reasonable to think that two ends of a converse action are stored independently of one another? It seems that the relationship between the ability to produce and perceive a vowel accurately is in some ways similar to the relationship between the ability to catch and throw a ball. Certainly the two are related in some ways and they both employ much of the same knowledge regarding the properties of bodies in motion and the same sort of compensatory mechanical actions. However, it also seems fairly clear that these two actions are distinct and that performance of one will not necessarily affect the other.

In a first language and, one imagines, in most situations, the representation of the procedural and auditory components of a phoneme will be of the same sound. In this situation, as seen for /i/ in Figure 4.5, a primarily auditory or a primarily gestural mental representation may be defensible because both the auditory cues and the gestural procedure describe the same physical sound. In the representation of /I/, the way in which the vowel is interpreted describes a sound that is different from the sound that results from the carrying out of the procedural knowledge associated with the vowel. In these cases, it is crucial that the auditory and gestural specifications of a phoneme be separate.

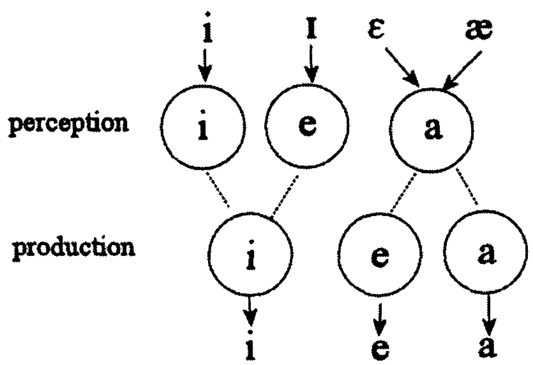


Figure 4.6 – Procedural and auditory competence of S1.

The disconnection can lead to a series of asymmetrical mergers and splits of the auditory and gestural components of vowels, as seen in Figure 4.6 (the representation shown corresponds to the performance of S1, shown in Figure 4.1). In the above figure it can be seen that there is a clear disassociation between the auditory and procedural descriptions of L2 vowels.

As to why English speakers are able to understand vowels that are mispronounced in this way, it seems that L1 English speakers could also make the /i/-/ɪ/ association based on orthographic similarity. Also, since this mispronunciation is systematic and stable across L1 Spanish L2 English speakers, L1 English speakers may have learned to 'decode' Spanish-accented speech in the same way that familiarity with other dialects of English allows for their interpretation.

If this interpretation of events are correct and speech perception and production are "distinct but cooperative systems" (Nearey 1997, 3241), then it seems that accounts of one or the other should only make reference to information that is available to the the system. This issue will be dealt with in the following section.

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Appendix A: Task materials

Response Words

/d/	/t/	/k/
could	coat	joke
dad	cut	luck
did	fat	luke
made	feet	sock
mood	late	neck
mud	dot	sick
need	put	make
red	root	sack
road	set	week
rod	sit	book

Production Words Lists

English Word List				Spanish Word List	
1	bet	31	food	1	boca
2	boat	32	foot	2	cita
3	book	33	get	3	lupa
4	boot	34	hate	4	feta
5	bud	35	kick	5	foto
6	cat	36	kid	6	gota
7	coat	37	load	7	luto
8	cod	38	lot	8	lucho
9	code	39	luke	9	paco
10	coke	40	make	10	pasa
11	cook	41	mate	11	pato
12	could	42	meet	12	peca
13	cut	43	mood	13	peso
14	dad	44	nut	14	pino
15	dead	45	pad	15	piso
16	deck	46	paid	16	pita
17	deed	47	peck	17	pito
18	did	48	peek	18	pizza
19	dock	49	pod	19	puno
20	dot	50	poke	20	quema
21	duck	51	put	21	saca
22	dud	52	rack	22	seco
23	duke	53	sack	23	sopa
24	fade	54	seek	24	supe
25	fake	55	shoot	25	taco
26	fat	56	should	26	tema
27	fed	57	sick	27	toco
28	feed	58	sit	28	toma
29	feet	59	sock	29	tuco
30	fit	60	suck	30	vaca

Stimulus words

	Read:	Similar Words:	Vowel
1	had		æ
2	hawed	cod, pod	ɑ
3	head		ɛ
4	hid		ɪ
5	hud	mud, dud	ʌ
6	hood		ʊ
7	who'd	dude, booed	u
8	heed		i
9	hode	load, mode	o
10	hade	made, laid	e
11	hat		æ
12	hot		ɑ
13	het	met, pet	ɛ
14	hit		ɪ
15	hut		ʌ
16	hut	put, foot	ʊ
17	hoot		u
18	heat		i
19	hote	coat	o
20	hate		e
21	hack		æ
22	hawk		ɑ
23	heck		ɛ
24	hick		ɪ
25	huck	luck, puck	ʌ
26	hook		ʊ
27	hooke	luke	u
28	heek	seek, peek	i
29	hoke	soak, poke	o
30	hake	make, lake	e

Appendix B: Results

L2 English L1 Spanish Production

1														
English										Spanish				
	Hertz		Normalized			Hertz		Normalized			Hertz		Normalized	
	F1	F2	F1	F2		F1	F2	F1	F2		F1	F2	F1	F2
i	258	2741	-1.86	1.54	ɑ	702	1005	0.83	-1.21	i	290	2603	-1.15	1.27
	263	2875	-1.82	1.67		752	1097	1.08	-0.98		243	2662	-1.44	1.32
	313	2770	-1.47	1.57		753	1179	1.09	-0.79		234	2702	-1.50	1.36
	255	2789	-1.88	1.58		709	1088	0.87	-1.00		236	2597	-1.48	1.27
	326	2688	-1.38	1.48		697	1044	0.81	-1.11		247	2650	-1.41	1.31
						732	1132	0.98	-0.90		250	2600	-1.40	1.27
ɪ	472	2148	-0.44	0.86	o	579	1048	0.18	-1.10	e	494	2132	-0.04	0.81
	493	2103	-0.31	0.80		524	1052	-0.13	-1.09		432	2254	-0.36	0.94
	482	2128	-0.38	0.83		461	1020	-0.51	-1.17		415	2320	-0.45	1.00
	512	2218	-0.20	0.95		532	969	-0.08	-1.30		458	2439	-0.23	1.12
	527	2001	-0.11	0.66		519	903	-0.16	-1.47		486	2126	-0.08	0.80
	479	2171	-0.40	0.89		535	916	-0.07	-1.44		448	2387	-0.28	1.07
ɛ	528	2161	-0.11	0.88	ʌ	776	1373	1.20	-0.39	a	846	1383	1.50	-0.21
	652	1917	0.58	0.54		759	1570	1.12	-0.02		812	1438	1.36	-0.12
	669	1740	0.66	0.27		806	1467	1.34	-0.20		800	1510	1.32	0.00
	633	1799	0.48	0.36		836	1465	1.48	-0.21		821	1466	1.40	-0.07
	709	1828	0.87	0.41		794	1425	1.28	-0.28		823	1563	1.41	0.08
						690	1356	0.77	-0.42		788	1433	1.27	-0.12
e	436	2525	-0.66	1.31	ʊ	476	1059	-0.41	-1.07	o	559	940	0.27	-1.05
	492	2072	-0.32	0.76		485	1147	-0.36	-0.87		554	912	0.25	-1.11
	470	2173	-0.45	0.89		411	944	-0.82	-1.36		512	913	0.05	-1.11
	465	2505	-0.48	1.29		523	1018	-0.14	-1.17		610	1048	0.51	-0.82
	517	2484	-0.17	1.27		463	1244	-0.49	-0.65		569	1019	0.32	-0.88
	406	2517	-0.85	1.30		476	1323	-0.41	-0.49		586	899	0.40	-1.14
æ	836	1820	1.48	0.40	u	327	952	-1.37	-1.34	u	347	864	-0.82	-1.22
	834	1597	1.47	0.03		360	1050	-1.15	-1.10		334	983	-0.90	-0.96
	849	1554	1.54	-0.05		393	832	-0.93	-1.67		318	945	-0.99	-1.04
	848	1555	1.53	-0.04		348	873	-1.23	-1.55		299	861	-1.10	-1.23
	888	1625	1.71	0.08		361	1209	-1.14	-0.73		313	806	-1.02	-1.36
	927	1667	1.88	0.15										

2														
English										Spanish				
	Hertz		Normalized			Hertz		Normalized			Hertz		Normalized	
	F1	F2	F1	F2		F1	F2	F1	F2		F1	F2	F1	F2
i	241	2373	-1.64	1.65	ɑ	662	1044	1.39	-0.80	i	254	2363	-1.36	1.37
	328	2279	-0.93	1.53		573	950	0.83	-1.06		273	2299	-1.22	1.30
	275	2363	-1.36	1.64		585	1022	0.91	-0.86		241	2113	-1.45	1.09
	271	2373	-1.39	1.65		592	1013	0.95	-0.88		247	2308	-1.41	1.31
	246	2377	-1.60	1.66		592	1092	0.95	-0.67		237	2271	-1.48	1.27
						611	992	1.07	-0.94		267	2162	-1.26	1.15
ɪ	393	2020	-0.42	1.16	o	476	853	0.18	-1.34	e	392	1879	-0.43	0.81
	391	1897	-0.44	0.97		429	856	-0.16	-1.33		356	1853	-0.66	0.77
	320	2047	-0.99	1.20		428	1101	-0.17	-0.65		379	1929	-0.51	0.87
	312	2141	-1.05	1.34		368	942	-0.61	-1.08		365	2034	-0.60	1.00
	371	1984	-0.59	1.10		343	797	-0.81	-1.51		415	1846	-0.29	0.76
	375	1969	-0.56	1.08		365	753	-0.64	-1.66		388	2031	-0.45	1.00

2														
	Hertz		Normalized			Hertz		Normalized			Hertz		Normalized	
	F1	F2	F1	F2		F1	F2	F1	F2		F1	F2	F1	F2
ɛ	445	1808	-0.04	0.82	ʌ	644	1236	1.28	-0.32	a	671	1244	1.15	-0.19
	478	1748	0.19	0.72		650	1441	1.32	0.13		676	1305	1.17	-0.08
	442	1765	-0.06	0.75		597	1305	0.99	-0.16		738	1285	1.48	-0.11
	461	1898	0.07	0.97		620	1285	1.13	-0.21		657	1302	1.08	-0.08
	439	1873	-0.09	0.93		647	1312	1.30	-0.14		653	1349	1.06	0.00
	434	1856	-0.12	0.90		589	1305	0.93	-0.16		669	1262	1.14	-0.16
e	409	1956	-0.30	1.06	ʊ	360	1080	-0.68	-0.70	o	529	937	0.39	-0.83
	384	1876	-0.49	0.93		325	1153	-0.95	-0.52		440	719	-0.13	-1.37
	406	1843	-0.33	0.88		299	882	-1.16	-1.25		413	787	-0.30	-1.19
	332	2149	-0.89	1.35		340	935	-0.83	-1.10		435	865	-0.16	-1.00
	409	2014	-0.30	1.15		333	1177	-0.89	-0.46		462	805	0.00	-1.14
	338	2106	-0.85	1.29		303	1129	-1.13	-0.58		396	757	-0.40	-1.27
æ	653	1560	1.33	0.37	u	269	1064	-1.41	-0.75	u	323	898	-0.88	-0.92
	705	1481	1.64	0.22		271	1073	-1.39	-0.72		259	832	-1.32	-1.08
	678	1447	1.48	0.15		285	767	-1.27	-1.61		277	838	-1.19	-1.06
	677	1594	1.48	0.44		281	812	-1.31	-1.47		291	723	-1.10	-1.36
	701	1548	1.62	0.35		266	1107	-1.43	-0.63		265	809	-1.28	-1.13
	637	1543	1.24	0.34		287	687				267	730	-1.26	-1.34

3														
English										Spanish				
	Hertz		Normalized			Hertz		Normalized			Hertz		Normalized	
	F1	F2	F1	F2		F1	F2	F1	F2		F1	F2	F1	F2
i	380	2837	-1.47	1.63	ɑ	746	1057	0.42	-1.48	i	356	2515	-1.24	1.26
	417	2796	-1.26	1.59		786	1131	0.60	-1.28		384	2706	-1.08	1.44
	330	2761	-1.78	1.55		791	1203	0.62	-1.09		303	2657	-1.57	1.40
	363	2715	-1.58	1.49		709	1182	0.25	-1.14		371	2665	-1.16	1.41
	392	2630	-1.40	1.39		757	1168	0.47	-1.18		319	2636	-1.47	1.38
	371	2696	-1.53	1.47		805	1174	0.68	-1.17		330	2525	-1.40	1.27
ɪ	450	2058	-1.07	0.61	o	574	1003	-0.40	-1.63	e	595	2122	0.04	0.81
	438	2309	-1.14	0.98		562	1033	-0.46	-1.55		570	2153	-0.08	0.85
	419	2381	-1.24	1.08		528	1146	-0.64	-1.24		520	2263	-0.33	0.98
	457	2090	-1.03	0.66		609	1093	-0.22	-1.38		598	2357	0.06	1.09
	423	2091	-1.22	0.66		586	1123	-0.34	-1.30		559	2128	-0.13	0.82
						523	1035	-0.67	-1.54		539	2380	-0.24	1.11
ɛ	666	1957	0.05	0.45	ʌ	852	1364	0.88	-0.70	a	911	1544	1.42	-0.02
	807	1846	0.69	0.26		873	1564	0.97	-0.27		950	1582	1.57	0.04
	678	1956	0.11	0.45		864	1498	0.93	-0.41		895	1553	1.36	-0.01
	642	2252	-0.06	0.90		867	1419	0.94	-0.58		906	1645	1.40	0.14
	737	1998	0.38	0.51		862	1469	0.92	-0.47		872	1606	1.27	0.08
	687	2003	0.15	0.52		841	1594	0.83	-0.21		936	1478	1.51	-0.13
e	546	2705	-0.55	1.48	ʊ	495	1243	-0.82	-0.99	o	622	1000	0.17	-1.10
	509	2415	-0.74	1.12		443	1345	-1.11	-0.75		587	1016	0.00	-1.06
	508	2459	-0.75	1.18		446	1205	-1.09	-1.09		588	1082	0.01	-0.91
	499	2576	-0.80	1.33		468	1238	-0.97	-1.00		579	1044	-0.03	-1.00
	568	2549	-0.43	1.29		448	1534	-1.08	-0.33		562	1071	-0.12	-0.94
	446	2572	-1.09	1.32		426	1891	-1.20	0.34		565	1007	-0.10	-1.09
æ	1087	1826	1.78	0.22	u	421	2002	-1.23	0.52	u	402	1073	-0.98	-0.93
	883	1977	1.01	0.48		435	1600	-1.15	-0.20		389	1207	-1.05	-0.65
	1057	1699	1.67	-0.01		441	1255	-1.12	-0.96		386	1286	-1.07	-0.49
	860	1616	0.91	-0.17		416	1246	-1.26	-0.98		391	861	-1.04	-1.44
	919	1639	1.15	-0.12		432	1361	-1.17	-0.71		351	892	-1.27	-1.37
	1051	1834	1.65	0.24		389	1264	-1.42	-0.94		393	918	-1.03	-1.30

4																	
English												Spanish					
	Hertz			Normalized			Hertz			Normalized			Hertz			Normalized	
	F1	F2		F1	F2		F1	F2		F1	F2		F1	F2		F1	F2
i	307	2944		-1.55	1.58	ɑ	802	1269		1.03	-0.89	i	365	2658		-1.17	1.15
	319	2991		-1.47	1.63		817	1235		1.10	-0.97		339	2833		-1.33	1.30
	357	2979		-1.24	1.61		795	1241		1.00	-0.95		347	2875		-1.28	1.33
	298	2865		-1.61	1.50		777	1282		0.92	-0.86		350	2969		-1.26	1.41
	267	2807		-1.81	1.44		709	1244		0.62	-0.95		303	2877		-1.56	1.33
	331	2896		-1.40	1.53		916	1471		1.50	-0.46		367	2785		-1.15	1.26
ɪ	524	2594		-0.29	1.21	o	640	1091		0.30	-1.31	e	620	2264		0.24	0.77
	534	2121		-0.24	0.62		638	1131		0.29	-1.21		611	2448		0.20	0.95
	459	2509		-0.64	1.12		472	1147		-0.57	-1.17		604	2398		0.16	0.90
	473	2419		-0.57	1.01		665	1155		0.42	-1.16		634	2565		0.31	1.06
	492	2321		-0.46	0.89		608	1104		0.14	-1.28		600	2393		0.14	0.90
	505	2237		-0.39	0.78		668	1117		0.43	-1.25		632	2445		0.30	0.95
ɛ	728	2286		0.71	0.84	ʌ	799	1410		1.02	-0.59	a	851	1571		1.30	-0.11
	788	2169		0.97	0.69		965	1553		1.69	-0.31		860	1572		1.34	-0.11
	709	2169		0.62	0.69		809	1503		1.06	-0.40		914	1547		1.56	-0.15
	628	2149		0.24	0.66		877	1526		1.34	-0.36		897	1619		1.49	-0.04
	693	2094		0.55	0.58		899	1483		1.43	-0.44		872	1592		1.39	-0.08
	794	2180		1.00	0.70		791	1575		0.98	-0.26		860	1563		1.34	-0.12
e	642	2465		0.31	1.07	ʊ	553	1168		-0.14	-1.12	o	614	1066		0.21	-1.00
	605	2359		0.12	0.94		481	1237		-0.52	-0.96		635	1047		0.32	-1.04
	581	2223		0.00	0.76		458	1163		-0.65	-1.14		623	1004		0.26	-1.13
	455	2720		-0.67	1.35		533	1008		-0.24	-1.53		659	1074		0.43	-0.99
	641	2564		0.30	1.18		511	1281		-0.36	-0.86		663	1058		0.45	-1.02
	572	2516		-0.04	1.13		337	1285		-1.36	-0.85		725	1003		0.74	-1.14
æ	875	1851		1.34	0.21	u	347	1289		-1.30	-0.85	u	388	959		-1.03	-1.23
	880	1691		1.36	-0.05		447	1329		-0.71	-0.76		396	1089		-0.98	-0.96
	918	1598		1.51	-0.22		379	1029		-1.11	-1.47		377	1108		-1.09	-0.92
	942	1564		1.60	-0.28		431	1123		-0.80	-1.23		420	882		-0.84	-1.41
	904	1669		1.45	-0.09		372	1423		-1.15	-0.56		401	1077		-0.95	-0.98
	996	1804		1.81	0.14		357	971		-1.24	-1.63		337	919		-1.34	-1.32

5																	
English												Spanish					
	Hertz			Normalized			Hertz			Normalized			Hertz			Normalized	
	F1	F2		F1	F2		F1	F2		F1	F2		F1	F2		F1	F2
i	314	2702		-1.89	1.52	ɑ	868	1242		1.23	-0.89	i	310	2679		-1.41	1.31
	371	2828		-1.50	1.66		771	1066		0.78	-1.34		325	2779		-1.33	1.39
	387	2639		-1.39	1.45		868	1231		1.23	-0.92		296	2650		-1.49	1.29
	320	2733		-1.85	1.55		835	1128		1.08	-1.17		307	2752		-1.43	1.37
	332	2762		-1.76	1.59		779	1137		0.82	-1.15		313	2669		-1.40	1.30
	349	2675		-1.65	1.49		853	1158		1.17	-1.10		315	2627		-1.38	1.27
ɪ	446	2194		-1.01	0.87	o	630	979		0.06	-1.58	e	458	2344		-0.62	1.01
	537	2310		-0.46	1.03		601	1110		-0.10	-1.22		463	2342		-0.59	1.00
	558	2227		-0.34	0.92		648	1268		0.15	-0.83		501	2493		-0.40	1.15
	544	2198		-0.42	0.88		582	1074		-0.21	-1.32		539	2444		-0.22	1.10
	532	2224		-0.49	0.92		505	1132		-0.65	-1.16		559	2102		-0.13	0.76
	479	2111		-0.81	0.75		558	951		-0.34	-1.66		472	2391		-0.55	1.05

5																	
	Hertz			Normalized			Hertz			Normalized			Hertz			Normalized	
	F1	F2		F1	F2		F1	F2		F1	F2		F1	F2		F1	F2
ɛ	583	2078		-0.20	0.70	ʌ	828	1302		1.05	-0.75	a	823	1508		0.99	-0.01
	675	2042		0.30	0.65		766	1510		0.75	-0.30		898	1532		1.27	0.03
	732	2173		0.59	0.84		771	1274		0.78	-0.81		905	1530		1.29	0.03
	635	1992		0.08	0.57		842	1649		1.12	-0.02		976	1661		1.54	0.21
	650	1933		0.16	0.48		817	1602		1.00	-0.11		876	1576		1.19	0.09
	700	2002		0.42	0.59								819	1531		0.97	0.03
e	600	2415		-0.11	1.17	ʊ	572	1211		-0.26	-0.96	o	603	909		0.08	-1.10
	518	2297		-0.58	1.02		551	1153		-0.38	-1.11		517	893		-0.32	-1.13
	534	2418		-0.48	1.18		544	1103		-0.42	-1.24		496	890		-0.43	-1.14
	508	2408		-0.64	1.16		518	1370		-0.58	-0.59		682	973		0.42	-0.96
	531	2471		-0.50	1.24		411	1271		-1.24	-0.82		599	1040		0.06	-0.82
	477	2465		-0.82	1.24		542	1587		-0.44	-0.14		710	996		0.54	-0.91
æ	992	1856		1.77	0.35	u	409	1207		-1.25	-0.97	u	380	877		-1.02	-1.17
	917	1814		1.45	0.28		467	1459		-0.88	-0.40		288	957		-1.54	-0.99
	915	1458		1.44	-0.40		382	1266		-1.43	-0.83		444	1063		-0.69	-0.78
	1020	1744		1.89	0.15		494	1053		-0.72	-1.37		414	899		-0.84	-1.12
	942	1739		1.56	0.14		495	1384		-0.71	-0.56		366	988		-1.10	-0.93
	892	1679		1.34	0.03		385	1246		-1.41	-0.88		358	781		-1.14	-1.39

6																	
English												Spanish					
	Hertz			Normalized			Hertz			Normalized			Hertz			Normalized	
	F1	F2		F1	F2		F1	F2		F1	F2		F1	F2		F1	F2
i	256	2029		-1.62	1.29	ɑ	530	1074		0.64	-0.65	i	270	2070		-1.47	1.30
	278	2173		-1.42	1.50		449	892		0.03	-1.17		269	2114		-1.48	1.36
	281	2001		-1.39	1.24		493	950		0.37	-1.00		259	2098		-1.56	1.34
	290	2003		-1.31	1.25		483	1050		0.29	-0.72		268	2127		-1.49	1.38
	266	1979		-1.53	1.21		471	979		0.20	-0.92		270	2093		-1.47	1.33
	272	2095		-1.48	1.39		490	1008		0.34	-0.84		275	2060		-1.43	1.28
ɪ	275	2171		-1.45	1.50	o	432	880		-0.11	-1.21	e	396	1811		-0.54	0.90
	284	2062		-1.37	1.34		399	886		-0.38	-1.19		443	1844		-0.22	0.95
	260	2088		-1.59	1.38		428	940		-0.14	-1.03		431	1834		-0.30	0.94
	289	2023		-1.32	1.28		398	846		-0.38	-1.31		375	1985		-0.69	1.17
	306	1938		-1.17	1.14		402	815		-0.35	-1.41		385	1860		-0.62	0.98
							446	876		0.00	-1.22		394	1754		-0.55	0.81
ɛ	460	1753		0.11	0.83	ʌ	605	1331		1.18	-0.02	a	685	1342		1.27	0.03
	449	1686		0.03	0.71		660	1324		1.55	-0.04		739	1267		1.56	-0.13
	425	1796		-0.16	0.90		636	1323		1.39	-0.04		697	1285		1.33	-0.09
	429	1849		-0.13	1.00		607	1341		1.19	0.00		617	1503		0.88	0.35
	413	1735		-0.26	0.80								668	1304		1.17	-0.05
													638	1127		1.00	-0.46
e	418	1898		-0.22	1.08	ʊ	320	909		-1.05	-1.12	o	482	858		0.04	-1.18
	421	1758		-0.20	0.84		331	860		-0.95	-1.27		468	869		-0.05	-1.14
	469	1713		0.18	0.76		352	961		-0.77	-0.97		428	865		-0.32	-1.16
	405	1883		-0.33	1.05		329	787		-0.97	-1.50		449	905		-0.18	-1.04
	417	1873		-0.23	1.04		346	838		-0.82	-1.34		471	906		-0.03	-1.04
	406	1861		-0.32	1.02		313	1175		-1.11	-0.39		469	931		-0.04	-0.97
æ	671	1421		1.62	0.18	u	302	1027		-1.20	-0.78	u	346	887		-0.90	-1.09
	613	1350		1.23	0.02		311	984		-1.12	-0.90		359	1032		-0.80	-0.70
	620	1247		1.28	-0.22		296	1053		-1.26	-0.71		340	1031		-0.94	-0.70
	629	1353		1.34	0.03		318	896		-1.06	-1.16		351	791		-0.86	-1.38
	667	1367		1.60	0.06								275	938		-1.43	-0.95
	626	1418		1.32	0.17								337	860		-0.96	-1.17

7																	
English												Spanish					
	Hertz			Normalized			Hertz			Normalized			Hertz			Normalized	
	F1	F2		F1	F2		F1	F2		F1	F2		F1	F2		F1	F2
i	401	2457		-1.29	1.25	ɑ	843	1198		0.94	-0.98	i	297	2669		-1.55	1.56
	489	2818		-0.78	1.68		892	1155		1.15	-1.09		332	2684		-1.35	1.57
	422	2476		-1.16	1.28		865	1289		1.04	-0.76		378	2624		-1.10	1.51
	410	2590		-1.24	1.42		862	1123		1.02	-1.17		324	2587		-1.40	1.47
	428	2483		-1.13	1.29		880	1295		1.10	-0.75		301	2563		-1.53	1.45
	418	2532		-1.19	1.35		896	1268		1.16	-0.81		391	2610		-1.03	1.50
ɪ	416	2546		-1.20	1.36	o	570	940		-0.34	-1.68	e	590	2201		-0.04	1.02
	471	2518		-0.88	1.33		638	1075		0.00	-1.30		604	2181		0.02	0.99
	432	2508		-1.11	1.32		686	1201		0.24	-0.97		554	2067		-0.21	0.84
	446	2531		-1.03	1.35		714	1153		0.37	-1.09		524	2479		-0.35	1.35
	463	2299		-0.93	1.05		695	1201		0.28	-0.97		604	2198		0.02	1.02
	420	2491		-1.18	1.30		632	1016		-0.03	-1.46		607	2293		0.04	1.14
ɛ	798	2145		0.75	0.83	ʌ	949	1142		1.38	-1.12	a	900	1616		1.22	0.15
	634	2034		-0.02	0.66		943	1689		1.35	0.07		934	1547		1.34	0.03
	689	2072		0.25	0.72		955	1531		1.40	-0.23		995	1547		1.55	0.03
	772	2079		0.63	0.73		927	1552		1.29	-0.19		940	1609		1.36	0.14
	653	2117		0.08	0.79		908	1518		1.21	-0.26		911	1579		1.26	0.09
	792	1991		0.72	0.59								918	1491		1.29	-0.07
e	708	2335		0.34	1.09	ʊ	432	1271		-1.11	-0.80	o	702	1030		0.45	-1.06
	629	2285		-0.04	1.03		389	954		-1.36	-1.64		702	980		0.45	-1.18
	590	2310		-0.24	1.06		472	1267		-0.88	-0.81		708	1147		0.47	-0.78
	613	2437		-0.12	1.23		459	1116		-0.95	-1.19		709	1254		0.48	-0.54
	697	2462		0.29	1.26		399	1322		-1.30	-0.68		687	1169		0.38	-0.73
	613	2309		-0.12	1.06		423	1822		-1.16	0.31		704	1169		0.46	-0.73
æ	947	1691		1.37	0.08	u	450	1643		-1.00	-0.01	u	424	1123		-0.85	-0.83
	938	1586		1.33	-0.12		416	1609		-1.20	-0.08		413	1313		-0.91	-0.42
	922	1389		1.27	-0.53		382	1138		-1.40	-1.13		402	1361		-0.97	-0.32
	911	1383		1.22	-0.55		419	1088		-1.18	-1.26		312	835		-1.47	-1.57
	956	1536		1.40	-0.22		423	1981		-1.16	0.58		359	1162		-1.20	-0.75
	890	1486		1.14	-0.32		412	1311		-1.22	-0.71		408	1076		-0.94	-0.95

8																	
English												Spanish					
	Hertz			Normalized			Hertz			Normalized			Hertz			Normalized	
	F1	F2		F1	F2		F1	F2		F1	F2		F1	F2		F1	F2
i	283	2161		-1.68	1.59	ɑ	679	1053		1.01	-0.97	i	304	1878		-1.46	1.09
	271	2194		-1.78	1.65		617	1014		0.65	-1.09		305	2000		-1.45	1.30
	341	1976		-1.23	1.27		584	1161		0.44	-0.64		312	1917		-1.38	1.16
	356	1960		-1.11	1.24		647	1103		0.83	-0.81		301	1894		-1.49	1.12
	359	1965		-1.09	1.25		629	1084		0.72	-0.87		303	2103		-1.47	1.47
	338	2050		-1.25	1.40		660	1109		0.90	-0.79		310	2163		-1.40	1.56
ɪ	370	1658		-1.01	0.63	o	494	851		-0.14	-1.65	e	448	1685		-0.09	0.72
	384	1687		-0.91	0.69		447	932		-0.46	-1.36		405	1819		-0.48	0.98
	407	1734		-0.74	0.79		473	1101		-0.28	-0.82		425	1754		-0.30	0.86
	428	1792		-0.59	0.91		428	909		-0.59	-1.44		427	1921		-0.28	1.16
	375	1779		-0.97	0.88		436	892		-0.53	-1.50		435	1727		-0.21	0.80
							434	878		-0.55	-1.55		432	1822		-0.24	0.98

8																	
	Hertz			Normalized			Hertz			Normalized			Hertz			Normalized	
	F1	F2		F1	F2		F1	F2		F1	F2		F1	F2		F1	F2
	512	1693		-0.02	0.70		692	1248		1.09	-0.39		640	1441		1.49	0.20
	487	1862		-0.18	1.05		718	1476		1.24	0.21		632	1177		1.43	-0.45
	461	1784		-0.36	0.89		654	1340		0.87	-0.14		623	1246		1.36	-0.27
ɛ	469	1769		-0.31	0.86	ʌ	666	1359		0.94	-0.09	a	637	1378		1.47	0.05
	466	1683		-0.33	0.68		621	1351		0.67	-0.11		626	1447		1.38	0.22
	493	1785		-0.14	0.90								583	1296		1.04	-0.14
	404	1996		-0.76	1.30		340	943		-1.24	-1.33		522	968		0.54	-1.05
	420	1915		-0.65	1.15		360	998		-1.08	-1.14		457	951		-0.01	-1.11
	487	1618		-0.18	0.54		382	1035		-0.92	-1.02		458	990		-0.01	-0.99
e	454	1862		-0.41	1.05	ʊ	338	1008		-1.25	-1.11	o	462	938		0.03	-1.15
	527	1886		0.08	1.10		385	1169		-0.90	-0.61		467	991		0.07	-0.98
	422	1954		-0.63	1.23		344	1429		-1.20	0.09		464	930		0.05	-1.17
	759	1356		1.46	-0.10		351	1294		-1.15	-0.26		359	1016		-0.92	-0.91
	777	1456		1.56	0.16		341	897		-1.23	-1.49		360	957		-0.91	-1.09
	761	1243		1.47	-0.40		361	890		-1.08	-1.51		385	964		-0.67	-1.07
æ	746	1343		1.39	-0.13	u	373	1220		-0.99	-0.47	u	372	812		-0.79	-1.56
	818	1527		1.78	0.33		272	864		-1.77	-1.60		337	1031		-1.13	-0.86
	799	1512		1.68	0.29		368	1876		-1.02	1.08		330	977		-1.20	-1.03

9																	
English												Spanish					
	Hertz			Normalized			Hertz			Normalized			Hertz			Normalized	
	F1	F2		F1	F2		F1	F2		F1	F2		F1	F2		F1	F2
	267	2096		-1.77	1.57		736	1109		1.06	-0.75		298	2056		-1.26	1.35
	361	1849		-1.11	1.10		752	1097		1.14	-0.79		294	2087		-1.29	1.39
	351	1931		-1.18	1.26		802	1145		1.38	-0.64		277	2108		-1.40	1.42
i	347	1845		-1.20	1.09	ɑ	787	1193		1.31	-0.50	i	273	2118		-1.43	1.43
	359	1967		-1.12	1.33		783	1282		1.29	-0.24		271	2045		-1.44	1.33
													274	2106		-1.42	1.42
	283	1998		-1.65	1.39		478	890		-0.36	-1.48		510	1749		0.02	0.87
	407	1821		-0.80	1.05		433	918		-0.64	-1.38		447	1762		-0.34	0.90
	322	2011		-1.38	1.42		495	997		-0.26	-1.11		442	1820		-0.37	0.99
ɪ	388	1870		-0.93	1.14	o	496	928		-0.25	-1.35	e	408	1888		-0.57	1.10
	368	1836		-1.06	1.08		627	910		0.50	-1.41		502	1731		-0.02	0.84
	378	1767		-0.99	0.93		565	928		0.15	-1.35		476	1830		-0.17	1.01
	470	1755		-0.41	0.91		623	1345		0.48	-0.07		748	1455		1.22	0.34
	421	1906		-0.71	1.22		767	1416		1.22	0.12		797	1411		1.44	0.26
	395	1915		-0.88	1.23		699	1316		0.88	-0.15		788	1405		1.40	0.24
ɛ	345	1980		-1.22	1.36	ʌ	783	1408		1.29	0.10	a	751	1542		1.23	0.51
	482	1685		-0.33	0.76		765	1298		1.21	-0.20		756	1447		1.26	0.33
	550	1772		0.07	0.94		685	1327		0.80	-0.12		795	1280		1.43	-0.02
	476	1977		-0.37	1.35		336	899		-1.28	-1.45		562	856		0.30	-1.08
	599	1695		0.34	0.78		404	999		-0.82	-1.11		603	927		0.52	-0.88
	395	1915		-0.88	1.23		384	1020		-0.96	-1.04		551	953		0.24	-0.81
e	453	1844		-0.51	1.09	ʊ	427	912		-0.68	-1.40	o	542	936		0.20	-0.86
	535	1868		-0.02	1.14		371	1237		-1.04	-0.37		513	954		0.04	-0.81
	418	1902		-0.73	1.21		419	1456		-0.73	0.22		534	932		0.15	-0.87
	820	1502		1.47	0.33		319	1281		-1.40	-0.24		353	814		-0.91	-1.21
	664	1471		0.69	0.26		439	1049		-0.60	-0.94		327	920		-1.07	-0.90
	730	1217		1.03	-0.43		410	958		-0.79	-1.24		344	1064		-0.96	-0.52
æ	769	1237		1.23	-0.37	u	391	1195		-0.91	-0.49	u	334	740		-1.03	-1.43
	885	1355		1.77	-0.04		335	866		-1.29	-1.57		308	846		-1.20	-1.11
	765	1272		1.21	-0.27								304	780		-1.22	-1.31

10																	
English												Spanish					
	Hertz			Normalized			Hertz			Normalized			Hertz			Normalized	
	F1	F2		F1	F2		F1	F2		F1	F2		F1	F2		F1	F2
i	409	2676		-1.24	1.51	ɑ	767	1086		0.60	-0.95	i	345	2619		-1.09	1.06
	405	2541		-1.27	1.37		816	1114		0.81	-0.88		313	3151		-1.25	1.49
	428	2306		-1.13	1.10		829	1121		0.87	-0.87		280	3021		-1.43	1.39
	347	2628		-1.62	1.46		820	1106		0.83	-0.90		299	3100		-1.32	1.45
	394	2564		-1.33	1.40		822	1140		0.84	-0.82		305	2802		-1.29	1.22
	397	2511		-1.31	1.34		834	1107		0.89	-0.90		296	2879		-1.34	1.28
ɪ	362	2307		-1.52	1.11	o	605	980		-0.17	-1.21	e	490	2201		-0.39	0.65
	465	2300		-0.92	1.10		582	998		-0.29	-1.16		472	2324		-0.47	0.78
	448	2392		-1.01	1.21		530	941		-0.56	-1.31		461	2267		-0.53	0.72
	449	2295		-1.01	1.09		561	971		-0.40	-1.23		428	2471		-0.68	0.93
	499	2069		-0.73	0.80		582	910		-0.29	-1.39		477	2170		-0.45	0.62
	484	2077		-0.81	0.81		603	952		-0.18	-1.28		488	2243		-0.40	0.70
ɛ	618	2286		-0.11	1.08	ʌ	902	1275		1.17	-0.53	a	962	1333		1.38	-0.53
	669	2162		0.14	0.93		806	1430		0.77	-0.22		935	1406		1.30	-0.41
	640	2244		0.00	1.03		856	1395		0.98	-0.29		887	1402		1.14	-0.41
	548	2133		-0.47	0.89		846	1391		0.94	-0.29		933	1440		1.29	-0.35
	541	2097		-0.50	0.84		783	1297		0.67	-0.48		820	1500		0.91	-0.26
	595	2176		-0.22	0.94		798	1343		0.73	-0.39		975	1390		1.43	-0.43
e	566	2455		-0.37	1.28	ʊ	383	873		-1.40	-1.49	o	479	1026		-0.44	-1.11
	556	2364		-0.42	1.17		396	1116		-1.32	-0.88		498	939		-0.36	-1.30
	536	2336		-0.53	1.14		333	923		-1.71	-1.35		578	1017		-0.01	-1.13
	484	2316		-0.81	1.12		471	1035		-0.88	-1.07		566	1058		-0.06	-1.05
	645	2370		0.03	1.18		423	1033		-1.16	-1.07		521	1038		-0.26	-1.09
	582	2233		-0.29	1.02		410	1543		-1.24	-0.01		593	1045		0.05	-1.07
æ	1041	1649		1.71	0.17	u	384	1157		-1.39	-0.78	u	347	1077		-1.08	-1.01
	907	1436		1.19	-0.21		405	863		-1.27	-1.51		318	1129		-1.22	-0.91
	944	1428		1.34	-0.22		407	1053		-1.25	-1.03		315	1198		-1.24	-0.77
	886	1333		1.10	-0.41		437	1178		-1.08	-0.74		299	858		-1.32	-1.49
	1008	1469		1.58	-0.15		438	933		-1.07	-1.33		323	983		-1.20	-1.21
	959	1517		1.39	-0.06		362	1447		-1.52	-0.19		334	980		-1.14	-1.21

11																	
English												Spanish					
	Hertz			Normalized			Hertz			Normalized			Hertz			Normalized	
	F1	F2		F1	F2		F1	F2		F1	F2		F1	F2		F1	F2
i	379	2763		-1.18	1.45	ɑ	770	1143		0.87	-0.65	i	335	2662		-1.24	1.47
	454	2767		-0.74	1.46		633	1042		0.22	-0.85		339	2759		-1.21	1.55
	372	2500		-1.23	1.22		808	1222		1.03	-0.49		290	2660		-1.52	1.46
	296	2577		-1.71	1.29		636	1133		0.23	-0.67		281	2736		-1.58	1.53
	375	2440		-1.21	1.16		713	1171		0.60	-0.59		295	2766		-1.49	1.55
	479	2913		-0.60	1.58		799	1234		1.00	-0.47		329	2682		-1.27	1.48
ɪ	402	2814		-1.05	1.49	o	585	1056		-0.03	-0.82	e	534	2014		-0.09	0.83
	366	2843		-1.26	1.52		590	1000		0.00	-0.94		600	2210		0.25	1.04
	441	2458		-0.82	1.17		533	1025		-0.30	-0.89		461	2199		-0.49	1.03
	307	3051		-1.64	1.68		464	905		-0.68	-1.15		455	2518		-0.52	1.34
	418	2723		-0.95	1.42		584	1077		-0.03	-0.78		598	2155		0.24	0.98
	376	2535		-1.20	1.25		505	903		-0.45	-1.16		463	2439		-0.48	1.27

11														
	Hertz		Normalized			Hertz		Normalized			Hertz		Normalized	
	F1	F2	F1	F2		F1	F2	F1	F2		F1	F2	F1	F2
ɛ	692	2121	0.51	0.82	ʌ	966	1630	1.69	0.18	a	838	1704	1.34	0.44
	698	2409	0.53	1.13		942	1774	1.59	0.39		883	1574	1.53	0.26
	671	2192	0.40	0.90		775	1724	0.89	0.32		896	1605	1.58	0.30
	539	2295	-0.27	1.01		896	1706	1.41	0.29		840	1781	1.35	0.54
	654	2396	0.32	1.11		924	1617	1.52	0.16		883	1798	1.53	0.57
	688	2312	0.49	1.03		899	1705	1.42	0.29		791	1442	1.14	0.06
e	545	2543	-0.24	1.26	ʊ	447	1132	-0.78	-0.67	o	561	896	0.05	-0.96
	594	2325	0.02	1.04		454	1123	-0.74	-0.69		568	894	0.09	-0.96
	529	2371	-0.32	1.09		375	816	-1.21	-1.37		560	978	0.04	-0.78
	449	2903	-0.77	1.57		496	946	-0.50	-1.06		647	1148	0.48	-0.44
	526	2753	-0.34	1.44		519	1093	-0.38	-0.75		591	1066	0.20	-0.60
	465	2728	-0.68	1.42		465	1744	-0.68	0.35		654	1039	0.51	-0.66
æ	931	1647	1.55	0.21	u	368	791	-1.25	-1.43	u	449	847	-0.56	-1.07
	860	1731	1.26	0.33		318	693	-1.57	-1.68		386	1223	-0.92	-0.31
	856	1574	1.24	0.10		396	1284	-1.08	-0.38		414	1280	-0.76	-0.21
	943	1704	1.60	0.29		357	927	-1.32	-1.10		353	651	-1.13	-1.55
	922	1577	1.51	0.10		480	1717	-0.59	0.31		367	1186	-1.04	-0.37
	972	1837	1.71	0.47		480	1748	-0.59	0.35		402	895	-0.83	-0.96

L1 English Production

1														
	Hertz		Normalized			Hertz		Normalized			Hertz		Normalized	
	F1	F2	F1	F2		F1	F2	F1	F2		F1	F2	F1	F2
i	258	2741	-1.86	1.54	æ	836	1820	1.48	0.40	ʌ	776	1373	1.20	-0.39
	263	2875	-1.82	1.67		834	1597	1.47	0.03		759	1570	1.12	-0.02
	313	2770	-1.47	1.57		849	1554	1.54	-0.05		806	1467	1.34	-0.20
	255	2789	-1.88	1.58		848	1555	1.53	-0.04		836	1465	1.48	-0.21
	326	2688	-1.38	1.48		888	1625	1.71	0.08		794	1425	1.28	-0.28
						927	1667	1.88	0.15		690	1356	0.77	-0.42
ɪ	472	2148	-0.44	0.86	ɑ	702	1005	0.83	-1.21	ʊ	476	1059	-0.41	-1.07
	493	2103	-0.31	0.80		752	1097	1.08	-0.98		485	1147	-0.36	-0.87
	482	2128	-0.38	0.83		753	1179	1.09	-0.79		411	944	-0.82	-1.36
	512	2218	-0.20	0.95		709	1088	0.87	-1.00		523	1018	-0.14	-1.17
	527	2001	-0.11	0.66		697	1044	0.81	-1.11		463	1244	-0.49	-0.65
	479	2171	-0.40	0.89		732	1132	0.98	-0.90		476	1323	-0.41	-0.49
ɛ	528	2161	-0.11	0.88	o	579	1048	0.18	-1.10	u	327	952	-1.37	-1.34
	652	1917	0.58	0.54		524	1052	-0.13	-1.09		360	1050	-1.15	-1.10
	669	1740	0.66	0.27		461	1020	-0.51	-1.17		393	832	-0.93	-1.67
	633	1799	0.48	0.36		532	969	-0.08	-1.30		348	873	-1.23	-1.55
	709	1828	0.87	0.41		519	903	-0.16	-1.47		361	1209	-1.14	-0.73
						535	916	-0.07	-1.44					
e	436	2525	-0.66	1.31										
	492	2072	-0.32	0.76										
	470	2173	-0.45	0.89										
	465	2505	-0.48	1.29										
	517	2484	-0.17	1.27										
	406	2517	-0.85	1.30										

2														
	Hertz		Normalized			Hertz		Normalized			Hertz		Normalized	
	F1	F2	F1	F2		F1	F2	F1	F2		F1	F2	F1	F2
i	239	2233	-1.65	1.70	æ	736	1602	1.79	0.38	ʌ	645	1244	1.26	-0.60
	248	2094	-1.58	1.45		552	1565	0.67	0.29		590	1503	0.92	0.13
	252	2188	-1.54	1.62		661	1483	1.35	0.08		580	1211	0.85	-0.70
	269	2202	-1.40	1.65		724	1523	1.72	0.18		563	1444	0.75	-0.03
						646	1525	1.26	0.19		612	1277	1.06	-0.50
	223	2296	-1.79	1.81		635	1543	1.20	0.23		566	1365	0.76	-0.24
ɪ	407	1839	-0.33	0.93	ɑ	651	1192	1.29	-0.76	ʊ	486	1282	0.23	-0.49
	450	1732	-0.02	0.69		611	1074	1.05	-1.15		429	1426	-0.17	-0.08
	442	1956	-0.07	1.17		635	1133	1.20	-0.95		378	1090	-0.54	-1.09
	421	1923	-0.23	1.11		651	1137	1.29	-0.94		488	1049	0.25	-1.23
	441	1777	-0.08	0.79		677	1198	1.45	-0.74		453	1113	0.00	-1.02
	440	1787	-0.09	0.81		663	1130	1.37	-0.96		441	1427	-0.08	-0.07
ɛ	580	1587	0.85	0.34	o	574	1025	0.82	-1.32	u	260	1293	-1.48	-0.45
	617	1625	1.09	0.44		555	1082	0.69	-1.12		251	1386	-1.55	-0.19
	592	1628	0.93	0.44		494	1150	0.29	-0.89		289	890	-1.24	-1.81
	549	1646	0.65	0.49		508	988	0.38	-1.45		289	983	-1.24	-1.46
	587	1681	0.90	0.57		455	933	0.02	-1.65		286	1033	-1.26	-1.29
	587	1652	0.90	0.50		449	952	-0.02	-1.58		254	903	-1.53	-1.76
e	352	1813	-0.74	0.87										
	480	1798	0.19	0.84										
	420	1826	-0.23	0.90										
	419	2003	-0.24	1.27										
	371	1857	-0.60	0.97										
	425	2053	-0.20	1.37										

3														
	Hertz		Normalized			Hertz		Normalized			Hertz		Normalized	
	F1	F2	F1	F2		F1	F2	F1	F2		F1	F2	F1	F2
i	287	2058	-1.58	1.32	æ	835	1638	1.69	0.30	ʌ	586	1212	0.38	-1.00
	285	2126	-1.60	1.46		797	1645	1.50	0.32		680	1313	0.90	-0.66
	309	2167	-1.42	1.55		832	1419	1.67	-0.32		761	1300	1.32	-0.70
	283	2112	-1.61	1.43		825	1571	1.64	0.12		719	1370	1.11	-0.48
	309	2031	-1.42	1.26		782	1571	1.43	0.12		690	1322	0.95	-0.63
	273	2134	-1.69	1.48		807	1596	1.55	0.19		648	1401	0.73	-0.38
ɪ	463	1743	-0.37	0.58	ɑ	781	1114	1.42	-1.35	ʊ	557	1156	0.21	-1.20
	534	1795	0.07	0.71		672	1123	0.86	-1.32		493	1374	-0.18	-0.46
	549	1842	0.16	0.83		736	1183	1.19	-1.10		459	1079	-0.40	-1.48
	460	1878	-0.39	0.91		723	1151	1.13	-1.21		569	1061	0.28	-1.55
	517	1727	-0.03	0.54		730	1232	1.16	-0.93		541	1260	0.11	-0.83
	545	1729	0.14	0.54		730	1155	1.16	-1.20		428	1278	-0.60	-0.77
ɛ	679	1745	0.89	0.58	o	520	1071	-0.02	-1.51	u	334	1109	-1.24	-1.37
	715	1620	1.09	0.26		528	1119	0.03	-1.33		322	1165	-1.33	-1.16
	697	1627	0.99	0.27		570	1108	0.28	-1.37		331	1212	-1.26	-1.00
	636	1737	0.66	0.56		496	1126	-0.16	-1.30		327	1196	-1.29	-1.05
	703	1706	1.02	0.48		473	1107	-0.31	-1.37		326	1194	-1.30	-1.06
	642	1783	0.69	0.68		535	1101	0.08	-1.40		322	1091	-1.33	-1.43
e	458	1932	-0.40	1.04										
	555	1823	0.19	0.78										
	471	1662	-0.32	0.37										
	432	2001	-0.57	1.19										
	470	1810	-0.33	0.75										
	516	1802	-0.04	0.73										

4																	
	Hertz			Normalized			Hertz			Normalized			Hertz			Normalized	
	F1	F2		F1	F2		F1	F2		F1	F2		F1	F2		F1	F2
i	246	2405		-1.90	1.56	æ	810	1733		1.65	0.36	ʌ	556	1233		0.25	-0.86
	299	2381		-1.49	1.52		685	1723		1.00	0.34		662	1384		0.87	-0.45
	276	2377		-1.67	1.52		861	1641		1.90	0.16		613	1274		0.59	-0.74
	266	2279		-1.75	1.36		761	1640		1.40	0.16		643	1363		0.76	-0.51
	253	2302		-1.85	1.40		719	1700		1.18	0.29		640	1284		0.74	-0.72
	265	2321		-1.76	1.43		828	1618		1.74	0.11		556	1394		0.25	-0.43
ɪ	381	1976		-0.90	0.84	ɑ	651	1038		0.81	-1.44	ʊ	571	1156		0.34	-1.08
	420	1918		-0.63	0.73		629	1002		0.68	-1.56		449	1246		-0.43	-0.82
	453	2079		-0.41	1.03		653	1126		0.82	-1.17		460	1080		-0.36	-1.31
	397	1980		-0.79	0.85		637	1042		0.73	-1.43		488	1020		-0.18	-1.50
	481	1763		-0.22	0.42		662	1062		0.87	-1.37		475	1101		-0.26	-1.25
	452	1824		-0.41	0.55		646	1062		0.78	-1.37		415	1450		-0.66	-0.28
ɛ	618	1732		0.62	0.36	o	504	1018		-0.08	-1.51	u	263	1327		-1.77	-0.60
	658	1799		0.84	0.50		501	1100		-0.09	-1.25		288	1690		-1.58	0.27
	539	1910		0.14	0.72		484	1052		-0.20	-1.40		302	1227		-1.47	-0.88
	546	1820		0.19	0.54		502	1108		-0.09	-1.23		276	1204		-1.67	-0.94
	648	1619		0.79	0.11		481	1099		-0.22	-1.25		303	1237		-1.46	-0.85
	574	1669		0.36	0.22		497	1011		-0.12	-1.53		299	1408		-1.49	-0.39
e	404	2171		-0.74	1.19												
	419	1951		-0.63	0.80												
	540	1808		0.15	0.52												
	413	2254		-0.67	1.32												
	546	2010		0.19	0.90												
	415	2140		-0.66	1.13												

5																	
	Hertz			Normalized			Hertz			Normalized			Hertz			Normalized	
	F1	F2		F1	F2		F1	F2		F1	F2		F1	F2		F1	F2
i	269	2084		-1.64	1.49	æ	686	1508		1.56	-0.03	ʌ	679	1420		1.51	-0.31
	292	2212		-1.43	1.77		681	1512		1.52	-0.02		637	1443		1.23	-0.23
	262	2019		-1.70	1.34		679	1424		1.51	-0.29		551	1303		0.64	-0.70
	350	2152		-0.93	1.64		668	1471		1.44	-0.14		618	1432		1.11	-0.27
	268	2082		-1.65	1.49		650	1439		1.32	-0.25		546	1300		0.60	-0.71
	267	2156		-1.66	1.65		709	1513		1.70	-0.01		535	1349		0.52	-0.54
ɪ	483	1700		0.14	0.53	ɑ	653	1183		1.34	-1.13	ʊ	511	1462		0.35	-0.17
	453	1643		-0.09	0.37		643	1188		1.27	-1.11		533	1522		0.51	0.01
	476	1773		0.08	0.73		653	1128		1.34	-1.34		482	1240		0.13	-0.92
	443	1726		-0.17	0.60		612	1148		1.07	-1.26		457	1113		-0.06	-1.40
	480	1620		0.11	0.31		629	1189		1.18	-1.11		507	1313		0.32	-0.66
	449	1600		-0.12	0.25		611	1208		1.06	-1.04		488	1471		0.17	-0.14
ɛ	639	1583		1.25	0.20	o	497	1095		0.24	-1.47	u	287	1271		-1.48	-0.81
	629	1593		1.18	0.23		533	1165		0.51	-1.20		305	1326		-1.32	-0.62
	553	1586		0.65	0.21		451	1047		-0.11	-1.66		328	1085		-1.12	-1.51
	533	1595		0.51	0.23		481	1040		0.12	-1.69		298	1151		-1.38	-1.25
	521	1571		0.42	0.16		461	1116		-0.03	-1.39		347	1158		-0.95	-1.23
	536	1622		0.53	0.31		539	1107		0.55	-1.42		273	1021		-1.60	-1.77
e	482	1942		0.13	1.16												
	467	1800		0.01	0.80												
	437	1848		-0.22	0.92												
	414	2000		-0.40	1.30												
	449	1836		-0.12	0.89												
	414	1906		-0.40	1.07												

6																	
	Hertz			Normalized			Hertz			Normalized			Hertz			Normalized	
	F1	F2		F1	F2		F1	F2		F1	F2		F1	F2		F1	F2
i	277	2303		-1.66	1.76	æ	897	1571		1.66	0.30	ʌ	752	1274		1.02	-0.48
	302	2259		-1.49	1.69		824	1565		1.35	0.29		779	1380		1.14	-0.18
	289	2065		-1.58	1.34		877	1482		1.58	0.08		744	1270		0.98	-0.49
	296	2140		-1.53	1.48		886	1429		1.61	-0.05		800	1416		1.24	-0.09
	280	2158		-1.64	1.51		842	1493		1.43	0.11		747	1227		1.00	-0.61
							840	1455		1.42	0.02		692	1317		0.73	-0.35
ɪ	430	1964		-0.68	1.15	ɑ	670	1014		0.63	-1.28	ʊ	532	1335		-0.09	-0.30
	455	1820		-0.53	0.86		721	1066		0.87	-1.11		479	1409		-0.39	-0.10
	454	1986		-0.54	1.20		694	1087		0.74	-1.04		554	1197		0.03	-0.70
	449	1972		-0.57	1.17		732	1036		0.93	-1.21		510	1089		-0.22	-1.04
	510	1802		-0.22	0.82		747	1082		1.00	-1.06		564	1286		0.08	-0.44
	480	1800		-0.39	0.82		668	1032		0.62	-1.22		460	1487		-0.50	0.10
ɛ	759	1656		1.05	0.50	o	519	1019		-0.17	-1.27	u	303	1311		-1.49	-0.37
	769	1623		1.10	0.43		527	1037		-0.12	-1.21		315	1422		-1.41	-0.07
	621	1679		0.38	0.56		527	1017		-0.12	-1.27		295	959		-1.54	-1.47
	614	1751		0.34	0.71		459	953		-0.51	-1.50		292	1048		-1.56	-1.17
	711	1695		0.83	0.59		467	929		-0.46	-1.58		306	1296		-1.47	-0.41
	718	1808		0.86	0.84		463	880		-0.49	-1.76		290	1053		-1.57	-1.15
e	453	2101		-0.54	1.41												
	434	1979		-0.66	1.18												
	462	1898		-0.49	1.02												
	429	2071		-0.69	1.36												
	452	2007		-0.55	1.24												
	454	2022		-0.54	1.26												

7																	
	Hertz			Normalized			Hertz			Normalized			Hertz			Normalized	
	F1	F2		F1	F2		F1	F2		F1	F2		F1	F2		F1	F2
i	341	2971		-1.34	1.62	æ	1102	1716		1.83	-0.35	ʌ	917	1761		1.22	-0.26
	273	3076		-1.73	1.74		981	1804		1.44	-0.17		878	1834		1.08	-0.11
	397	2941		-1.03	1.58		1054	1629		1.68	-0.54		912	1434		1.20	-1.00
	288	3004		-1.64	1.66		1147	1736		1.97	-0.31		904	1768		1.17	-0.24
	318	2882		-1.47	1.51		1013	1735		1.55	-0.31		892	1664		1.13	-0.46
	232	2896		-1.97	1.53		1022	1729		1.58	-0.33		860	1828		1.01	-0.12
ɪ	560	2202		-0.23	0.55	ɑ	781	1176		0.71	-1.69	ʊ	664	1608		0.23	-0.59
	578	2122		-0.15	0.42		867	1183		1.04	-1.67		540	1631		-0.32	-0.54
	600	2152		-0.05	0.47		914	1212		1.21	-1.58		666	1471		0.24	-0.91
	548	2030		-0.28	0.26		847	1225		0.96	-1.55		662	1272		0.22	-1.42
	588	2216		-0.10	0.57		802	1241		0.79	-1.50		712	1497		0.43	-0.84
	595	2164		-0.07	0.49		852	1207		0.98	-1.60		644	1843		0.15	-0.09
ɛ	851	2070		0.98	0.33	o	694	1286		0.36	-1.38	u	402	1947		-1.01	0.11
	839	1947		0.93	0.11		576	1158		-0.16	-1.74		409	2080		-0.97	0.35
	769	2014		0.66	0.23		639	1502		0.13	-0.83		415	1549		-0.94	-0.72
	761	2044		0.63	0.28		615	1219		0.02	-1.56		341	1492		-1.34	-0.86
	797	2034		0.77	0.26		627	1285		0.07	-1.38		331	1913		-1.39	0.04
	977	2062		1.43	0.31		670	1222		0.26	-1.55		466	1749		-0.68	-0.28
e	545	2727		-0.30	1.32												
	577	2220		-0.15	0.58												
	516	2226		-0.44	0.59												
	496	2687		-0.53	1.27												
	655	2634		0.19	1.19												
	503	2431		-0.50	0.91												

8																	
	Hertz			Normalized			Hertz			Normalized			Hertz			Normalized	
	F1	F2		F1	F2		F1	F2		F1	F2		F1	F2		F1	F2
i	324	2888		-1.44	1.77	æ	1193	1882		1.77	0.26	ʌ	830	1543		0.68	-0.45
	315	2925		-1.48	1.81		1064	1735		1.41	-0.03		988	1783		1.19	0.06
	331	2873		-1.40	1.75		1007	1638		1.25	-0.24		897	1587		0.90	-0.35
	334	2942		-1.39	1.83		1068	1651		1.43	-0.21		908	1673		0.94	-0.16
	322	2861		-1.45	1.74		1084	1660		1.47	-0.19		867	1590		0.80	-0.34
	260	2963		-1.77	1.86		1059	1734		1.40	-0.04		734	1736		0.34	-0.03
ɪ	463	2448		-0.77	1.19	ɑ	941	1299		1.04	-1.05	ʊ	644	1402		-0.01	-0.79
	590	2106		-0.22	0.66		953	1270		1.08	-1.13		515	1603		-0.54	-0.32
	561	1964		-0.34	0.41		894	1280		0.89	-1.10		590	1616		-0.22	-0.29
	469	2493		-0.74	1.26		951	1259		1.07	-1.16		609	1235		-0.15	-1.22
	579	2113		-0.27	0.67		950	1374		1.07	-0.86		627	1469		-0.07	-0.62
	557	2083		-0.36	0.62		960	1325		1.10	-0.98		589	1643		-0.23	-0.23
ɛ	964	1864		1.11	0.22	o	605	1253		-0.16	-1.17	u	368	1820		-1.22	0.14
	961	1858		1.10	0.21		545	1236		-0.41	-1.22		373	2001		-1.19	0.47
	893	1878		0.89	0.25		566	1503		-0.32	-0.54		347	1594		-1.32	-0.34
	757	2032		0.42	0.53		587	1216		-0.23	-1.27		331	1411		-1.40	-0.76
	889	1873		0.87	0.24		476	1188		-0.71	-1.35		344	1448		-1.34	-0.67
	873	1844		0.82	0.18		516	1019		-0.53	-1.86		334	1493		-1.39	-0.57
e	526	2712		-0.49	1.55												
	561	2343		-0.34	1.04												
	490	2345		-0.65	1.04												
	402	2824		-1.05	1.69												
	522	2678		-0.51	1.51												
	481	2680		-0.69	1.51												

9																	
	Hertz			Normalized			Hertz			Normalized			Hertz			Normalized	
	F1	F2		F1	F2		F1	F2		F1	F2		F1	F2		F1	F2
i	317	2712		-1.43	1.60	æ	973	1838		1.66	0.21	ʌ	814	1463		1.05	-0.59
	380	2702		-1.06	1.58		947	1862		1.57	0.26		775	1771		0.88	0.08
	375	2681		-1.09	1.56		938	1802		1.53	0.14		838	1555		1.14	-0.38
	277	2547		-1.68	1.38		975	1610		1.67	-0.26		878	1753		1.30	0.05
	322	2668		-1.40	1.54		978	1873		1.68	0.28		848	1664		1.18	-0.14
	392	2683		-0.99	1.56		975	1838		1.67	0.21		770	1766		0.86	0.07
ɪ	508	2185		-0.36	0.83	ɑ	796	1090		0.97	-1.60	ʊ	663	1693		0.39	-0.08
	602	2403		0.11	1.17		817	1192		1.06	-1.30		549	1718		-0.15	-0.03
	649	2419		0.33	1.20		850	1165		1.19	-1.38		670	1462		0.42	-0.60
	495	2463		-0.43	1.26		795	1167		0.97	-1.37		705	1419		0.58	-0.70
	557	1962		-0.11	0.45		788	1195		0.94	-1.29		730	1451		0.69	-0.62
	515	1926		-0.33	0.38		837	1128		1.14	-1.48		537	1814		-0.21	0.17
ɛ	814	2078		1.05	0.65	o	649	1380		0.33	-0.80	u	318	1406		-1.43	-0.73
	931	1921		1.51	0.37		599	1333		0.09	-0.92		371	1610		-1.11	-0.26
	821	1778		1.08	0.10		601	1243		0.10	-1.16		393	1704		-0.99	-0.06
	797	1948		0.98	0.42		619	1251		0.19	-1.14		442	1505		-0.71	-0.50
	832	2005		1.12	0.53		572	1108		-0.04	-1.54		439	1573		-0.73	-0.34
	771	1982		0.87	0.48		567	1120		-0.06	-1.51		338	1246		-1.31	-1.15
e	528	2481		-0.26	1.28												
	464	2565		-0.59	1.40												
	539	2396		-0.20	1.16												
	490	2639		-0.46	1.50												
	589	2478		0.04	1.28												
	511	2620		-0.35	1.48												

L2 English L1 Spanish Perception

1 — Expected

Observed	i	ʌ	ɛ	ɑ	e	ɪ	u	o	æ	ʊ
i	3									
ʌ		2							1	
ɛ			2						1	
ɑ		1		2						
e					3					
ɪ			2			1				
u							2			1
o								3		
æ									3	
ʊ							1			2

2 — Expected

Observed	i	ʌ	ɛ	ɑ	e	ɪ	u	o	æ	ʊ
i	3									
ʌ		3								
ɛ			2						1	
ɑ				3						
e					3					
ɪ			2			1				
u							2			1
o								3		
æ									3	
ʊ		1					2			

3 — Expected

Observed	i	ʌ	ɛ	ɑ	e	ɪ	u	o	æ	ʊ
i	3									
ʌ		1					1		1	
ɛ			2						1	
ɑ				2					1	
e			1		2					
ɪ			2			1				
u							3			
o								3		
æ									3	
ʊ							2			1

4 — Expected

Observed	i	ʌ	ɛ	ɑ	e	ɪ	u	o	æ	ʊ
i						3				
ʌ		2							1	
ɛ			1						2	
ɑ		1		2						
e					3					
ɪ						3				
u						1	2			
o								3		
æ		1							2	
ʊ		1					1			1

5 — Expected

Observed	i	ʌ	ɛ	ɑ	e	ɪ	u	o	æ	ʊ
i	3									
ʌ		1							2	
ɛ		1							2	
ɑ				2					1	
e					3					
ɪ		1	2							
u							1	1		1
o								3		
æ									3	
ʊ							1			2

6 — Expected

Observed	i	ʌ	ɛ	ɑ	e	ɪ	u	o	æ	ʊ
i	1					2				
ʌ		3								
ɛ	1								2	
ɑ				1			1			1
e			1		2					
ɪ	1		2							
u		1					2			
o				1				2		
æ									3	
ʊ		1					1	1		

		7									
		Expected									
		i	ʌ	ɛ	ɑ	e	ɪ	u	o	æ	ʊ
Observed	i	3									
	ʌ								1	2	
	ɛ			2						1	
	ɑ				3						
	e					3					
	ɪ			2		1					
	u							2			1
	o				1				2		
	æ									3	
	ʊ							1	1		1

		8									
		Expected									
		i	ʌ	ɛ	ɑ	e	ɪ	u	o	æ	ʊ
Observed	i	3									
	ʌ				1					2	
	ɛ			2						1	
	ɑ				3						
	e					3					
	ɪ			2			1				
	u							1			2
	o								3		
	æ									3	
	ʊ		1					1			1

		9									
		Expected									
		i	ʌ	ɛ	ɑ	e	ɪ	u	o	æ	ʊ
Observed	i	1					2				
	ʌ		1		1					1	
	ɛ			3							
	ɑ				1					2	
	e					3					
	ɪ			2			1				
	u							2			1
	o							1	2		
	æ									3	
	ʊ							1			2

		10									
		Expected									
		i	ʌ	ɛ	ɑ	e	ɪ	u	o	æ	ʊ
Observed	i	3									
	ʌ		2							1	
	ɛ			1						2	
	ɑ		1		1					1	
	e					3					
	ɪ			3							
	u							2			1
	o								3		
	æ									3	
	ʊ		1					1			1

		11									
		Expected									
		i	ʌ	ɛ	ɑ	e	ɪ	u	o	æ	ʊ
Observed	i	3									
	ʌ		1							2	
	ɛ			2						1	
	ɑ				1					2	
	e					3					
	ɪ			3							
	u							1			2
	o								3		
	æ									3	
	ʊ		1								2

L1 English Perception

		1									
		Expected									
		i	ʌ	ɛ	ɑ	e	ɪ	u	o	æ	ʊ
Observed	i	3									
	ʌ		3								
	ɛ			3							
	ɑ				3						
	e					3					
	ɪ						3				
	u							2			1
	o								3		
	æ									3	
	ʊ										3

		2									
		Expected									
		i	ʌ	ɛ	ɑ	e	ɪ	u	o	æ	ʊ
Observed	i	3									
	ʌ		3								
	ɛ			3							
	ɑ				3						
	e					3					
	ɪ						3				
	u							3			
	o								3		
	æ									3	
	ʊ										3

		3									
		Expected									
		i	ʌ	ɛ	ɑ	e	ɪ	u	o	æ	ʊ
Observed	i	3									
	ʌ		3								
	ɛ			3							
	ɑ				3						
	e					3					
	ɪ			1			2				
	u							3			
	o								3		
	æ									3	
	ʊ										3

		4									
		Expected									
		i	ʌ	ɛ	ɑ	e	ɪ	u	o	æ	ʊ
Observed	i	3									
	ʌ		2	1							
	ɛ			3							
	ɑ				3						
	e					3					
	ɪ						3				
	u							3			
	o								3		
	æ									3	
	ʊ										3