Original Paper

Phonetica 2003;60:98–128
DOI: 10.1159/000071449

Received: October 9, 2001
Accepted: September 10, 2002

The Vowel Systems of Quichua-Spanish Bilinguals

Age of Acquisition Effects on the Mutual Influence of the First and Second Languages

Susan G. Guion

University of Oregon, Eugene, Oreg., USA

Abstract

This study investigates vowel productions of 20 Quichua-Spanish bilinguals, differing in age of Spanish acquisition, and 5 monolingual Spanish speakers. While the vowel systems of simultaneous, early, and some mid bilinguals all showed significant plasticity, there were important differences in the kind, as well as the extent, of this adaptability. Simultaneous bilinguals dffered from early bilinguals in that they were able to partition the vowel space in a more fine-grained way to accommodate the vowels of their two languages. Early and some mid bilinguals acquired Spanish vowels, whereas late bilinguals did not. It was also found that acquiring Spanish vowels could affect the production of native Quichua vowels. The Quichua vowels were produced higher by bilinguals who had acquired Spanish vowels than those who had not. It is proposed that this vowel reorganization serves to enhance the perceptual distinctiveness between the vowels of the combined first- and second-language system.

Introduction

What is the nature of the phonological system in bilinguals? Is it one, combined system or two separate systems? Does the age at which a bilingual learns a second language interact with the potential for overlap or separation of the two systems? Linguists have entertained these questions for some time. Swadesh [1941] proposed that the phonological inventories of bilinguals be regarded as a single system from the standpoint of phonemic theory and suggested that a bilingual has an enlarged system compared to a monolingual. Later, Weinreich [1974 (1953)] suggested that the phonemic systems of bilinguals[1] are kept separate in two coexisting systems. This proposal

[1] Note that Weinreich [1974, pp. 9–10] had a different proposal for semantic information. He proposed that bilinguals could have separate, compound, or subordinate representations for semantic information, while phonemic information would be kept separate.

KARGER

Fax +41 61 306 12 34
E-Mail karger@karger.ch
www.karger.com

Accessible online at:
www.karger.com/journals/pho

Dr. Susan G. Guion
Linguistics Department
1290 University of Oregon
Eugene, OR 97403–1290 (USA)
Tel. +1 541 346 3682, Fax +1 541 346 3917
E-Mail guion@oregon.uoregon.edu

was based on the observation that bilinguals are ordinarily aware of the language they are using and the phonological instantiation of language would be an automatic process. He proposed that an utterance is characterized by the feature of the language being spoken (e.g. its 'Englishness' or 'Russianness') over its entire length[2]. Thus, the sounds of the two languages would be in complementary distribution and a separation into two distinct systems would be preferable. However, Weinreich [1957] also noted that some context-sensitive allophones can be identified interlingually (i.e. form part of two language systems) and adopted the terminology of Haugen [1957] to call them 'diaphones'.

More recently, the Speech Learning Model [Flege, 1995] has proposed that the phonological systems of a bilingual's two languages reside in the same 'phonological space'. The model proposes that the second language sounds can either be equated with the native sounds or that new categories can be developed for the second language sounds. In either case, the first and second language sounds are considered to form part of one merged system.

In addition, theories of cross-linguistic speech perception, such as the Perceptual Assimilation Model [see e.g. Best et al., 1988, 2001; Best, 1993, 1995] have proposed that foreign language sounds are assimilated to native sounds in varying ways due to the perceived similarity of the foreign sounds to the native sounds. Such a theory might predict that, in the case of second language acquisition leading to bilingualism, first- and second-language sounds would be related to one another and exist in a common phonological system. As a bilingual became more proficient, however, the extent and number of assimilations might be predicted to decrease.

The question of combined or separate phonological, and more generally linguistic, systems has been the subject of neurological investigation as well. Studies of aphasics, and more recently, neuroimaging studies have painted a mixed picture. Grosjean [1982] reviews the aphasic and behavioral studies and concludes that bilinguals' languages are not stored in completely different locations and that second languages are, like first languages, left-hemisphere dominant. However, the exact details and the extent of the separation/overlap are not agreed upon in the literature.

The evidence from the neurophysiological studies, using such techniques as positron emission tomography (PET), functional magnetic resonance imaging (fMRI) and electroencephalography (EEG), indicates that some aspects of bilinguals' languages may be stored and processed in the same region, whereas others may not. In addition, the studies reveal the important effects of age of acquisition on language learning and organization in the brain.

Weber-Fox and Neville [1999] present evidence that early bilinguals use similar neural systems for processing their two languages. However, late-learner bilinguals used altered neural systems for syntactic processing but not for semantic processing. Kim et al. [1997] found that late (but not early) bilinguals activated different areas of the frontal cortex for first- and second-language processing during internal speech production. Perani et al. [1996] found greater and more widely distributed activation for first- than second-language auditory processing in late bilinguals. Interestingly, research into semantic and lexical tasks [Chee et al., 1999; Illes et al., 1999] have not

[2] The common use of code-switching in bilingual speech [see, e.g., Grosjean, 1982] was not yet fully appreciated at that time.

found cortical separation for language processing in native and second languages for either late or early bilinguals.

In a study focusing specifically on phonological processing, Winkler et al. [1999] found that late learners process the phonemes of second language in a way similar to native speakers. They found that fluent Hungarian learners of Finnish had EGG responses to Finnish vowel contrasts not found in Hungarian (specifically, mismatch negativity event-related potentials) that closely paralleled native Finnish listeners. Naïve Hungarian listeners, on the other hand, did not exhibit similar responses to the Finnish contrasts. Winkler et al. [1999] proposed that cortical memory representations for sounds in the late-acquired language are used in processing in a way similar to native memory representations.

The results from the neurophysiological studies point to the important effect of age of acquisition in the potential separation or combination of linguistic systems within a bilingual. It seems that bilinguals may be able to learn some aspects of language in a way comparable to a first language only at a very young age, whereas other aspects may be learned in a way comparable to a first language throughout the lifespan.

Investigations focusing on behavioral evidence from perception and production in bilinguals indicate that they have combined, or at least interrelated, systems. Results show that bilinguals' languages are able to mutually influence each other. It seems likely that the two systems coexist in the same phonological space, at least for some bilinguals. Many studies have documented the interaction of the first- and second-language systems.

hm.

Since the earliest days of study into second-language acquisition, the influence of the first language on the second has been well documented [see e.g. Lado, 1957; Stockwell and Bowen, 1965; Wardaugh, 1970; and Flege, 1995 for a more recent account]. Perhaps less well documented is the effect of the second language on the native language. However, a growing body of empirical evidence (detailed below) indicates that the acquisition of new phonetic categories can affect the perception and production of existing phonetic categories. These results argue for the proposal that a bilingual's phonetic system is a combination of the two languages' segmental inventories.

As the effect of a second language on the first language phonetic system does not seem to be common knowledge, and may indeed be surprising upon first encounter, a review of the literature supporting this claim would seem to be appropriate. Early work in this area found evidence for *perceptual* effects on the first language. Anisfeld et al., [1969] and Anisfeld and Gordon [1971] found that studying a foreign language affected acceptability judgments for native-language segmental sequences. The authors concluded that even a small amount of second-language experience could alter the processing of the first language. Later work investigating the effect of the second language on the perceptual system of the first focused on the effects of consonant acquisition. Caramazza et al. [1973] and Williams [1977] investigated bilinguals' identification of stops along a synthesized voice onset time (VOT) continuum and found that the perceptual crossover points were intermediate between those found for monolinguals of the two languages. Hazan and Boulakia [1993] investigated voicing judgments of French and English monolinguals as well as French-English bilinguals. They found that shifts in the first formant affected the voicing judgments in the same direction for the two types of monolinguals, but to a greater extent for the English monolinguals.

The bilinguals showed an effect intermediate to the monolingual groups, with the English-dominant bilinguals showing a greater effect than the French-dominant bilinguals.

There is also a large body of evidence that learning a second language can affect the *production* of the first language. Two main types of production effects are found. In the first, the native segment is produced in a manner more similar to a second-language segment. Williams [1979] found that child native Spanish learners of English produced Spanish voiced stops with less voicing lead and voiceless stops with more voicing lag than did Spanish monolingual adults and that, furthermore, the younger children differed to a greater extent. Flege and Hillenbrand [1984] and Flege [1987] found that highly experienced late learners of English produced their native French stops with VOT values intermediate between their first- and second-languages. Mack [1990] found similar results with a bilingual child. The French (native language) voiceless stop had VOT values much longer than those produced by monolingual speakers. In a case study of a Brazilian Portuguese speaker who learned English late in life, Sancier and Fowler [1997] found that the stop production varied in VOT for both English and Portuguese depending on recent linguistic exposure. The VOTs of stops were shorter for both languages after several months in Brazil than after several months in the US. Finally, Peng [1993] investigated the production of fricatives by Taiwanese Amoy learners of Mandarin and found that the Amoy [h] of proficient Mandarin speakers showed influence from Mandarin [x].

In the second type of production effect, the native segment is produced in a manner to dissimilate it from a second-language segment. Flege and Eefting [1987a, b] studied early and late learners of English whose first language was Spanish or Dutch (languages with short-lag VOT). They found that both early and late bilinguals who were highly proficient in English produced VOTs for their native stops that were shorter than monolingual speakers of Spanish and Dutch (or less proficient bilinguals). The authors interpreted the findings to indicate that the acquisition of a long-lag VOT (English /t/) could cause a shortening of the native stop's VOT, possibly to ensure sufficient discrimination between the two through a process of polarization.

Effects of the first type (first-language segment is produced more like second-language segment) have also been found for vowel production. Flege [1987] found that experienced French learners of English produced their French /u/ with a higher F_2 (i.e., more like English) than monolingual French speakers. In addition, Schouten [1977], in a study on Dutch-English bilinguals, found that acquisition of a vowel from the second-language that was regarded as distinct from but close to a native vowel affected the 'stability' of the production and classification of the native vowel.

However, not all investigations testing for second-language effects on the first-language have found an effect. For example, Bohn and Flege [1992] found that 7 years of English experience did not affect the production of native German vowels. The predicted second type of effect (first-language segment produced less like a second-language segment) was not found. German [ɛ] was not raised to differentiate it from the English [æ]. From these results, it might be hypothesized that vowels shared by two languages are more susceptible to change and that a process of polarization is less common for vowels. Note, however, that in the German case, the [ɛ] vowel does not have a lot of room to move given the crowded nature of the German and English vowel space. Alternatively, due to differences in duration, the German [ɛ] may not have needed to shift upwards to be kept perceptually distinct from English [æ]. Bohn and Flege [1992] reported that native English [æ] was more than three times longer than native German [ɛ]. In any case, an investigation into languages with smaller vowel inventories could prove more probative of the polarization question.

One explanation for polarization in vowel systems would be the goal of sufficient contrast for all vowels in the combined first/second language system through an adaptive dispersion process [see, e.g. the Speech Learning Model of Flege, 1995]. In principle, we should expect bilingual phonological systems to conform to the same typological universals and be subject to the same functional constraints as monolingual systems.

Typological studies of vowel systems have found that the vowels in a language can be predicted to a large extent by the number of vowels in the system. For example, Crothers [1978] found that three-vowel systems usually have vowels of qualities similar to [i a u], five-vowel systems added [ɛ ɔ], and seven-vowel systems added [e o]. Crothers noted several other universals from his typological work: the number of height distinctions is typically equal to or greater than the number of front-back distinctions; the number of central vowels is less than the number of front or back vowels; the number of height distinctions for front vowels is equal to or greater than the number of height distinctions for back vowels. In other words, vowels tend to be dispersed more or less equally in the vowel space, preferring more peripheral to central locations.

A widely agreed-upon explanation for the typological findings is that the constraints of our articulatory and perceptual systems serve to shape vowel systems in a similar way across languages. For example, the theory of Adaptive Dispersion, proposed by Liljencrants and Lindblom [1972], Lindblom [1986, 1998] and Lindblom and Engstrand [1989], states that vowel systems have the configurations they do due to factors of perception and production. On the perceptual side, vowel inventories evolve to provide distinctive perceptual information. On the production side, vowel inventories evolve within the constraints of a biomechanical system that tends toward economy of gesture. An earlier version of the theory emphasized maximal perceptual contrast, whereas the later version proposed the notion of 'sufficient contrast'. The latter proposal provides a more balanced weighting of perceptual and production factors. According to the notion of sufficient contrast, systemic inventories will provide just enough perceptual contrast, and expend just enough energy in production, for reliable differentiation between segments. Thus, Adaptive Dispersion Theory predicts that vowels will be dispersed in the perceptual space to the extent needed to provide sufficient discrimination among the vowels.

Along a similar line, Schwartz et al. [1997a, b] have proposed the Dispersion-Focalization Theory, which attempts to predict vowel systems based on two perceptual components. The first is a maximization of global dispersion, following earlier versions of the Adaptive Dispersion Theory. This has the effect of making vowels more discriminable and easier to perceive by maximally dispersing them in perceptual space. The second is a maximization of local focalization, which is based on intravowel spectral salience related to the proximity of formants. Focalization of a vowel makes it more quantal in nature [Stevens, 1989] and thus more stable acoustically and easier to perceive. Their model successfully predicts most of the universal tendencies found in the UPSID (UCLA Phonological Segmental Inventory Database) [Maddieson, 1984].

In a recent study, de Boer [2000] explored the process by which vowel systems come to have the inventories they do. He proposed that the structure of vowel systems is determined by self-organization under the constraints of the perceptual and production systems [see also Lindblom et al., 1984]. De Boer presented the results of a computer simulation in which a population of agents (having the constraints of the human perception and production mechanisms) developed vowel systems based upon a process of self-organization through attempts at communication. These systems displayed the dispersion patterns typically seen in natural languages.

The above-mentioned studies used (computer) modeling to test their theory of vowel system formation and compared the results to the structure of vowel systems as reported in typological databases [e.g. UPSID as analyzed by Schwartz et al., 1997a, or Crothers, 1978]. These databases are compiled from secondary sources and based largely on impressionistic data. The secondary sources are then typically regularized so that vowels that are in similar areas of the vowel space are grouped together. For example, Schwartz et al. [1997a] conflate [i] with [ɪ] and [u] with [ɯ ɯ̹ ʊ] and Crothers [1978] conflates [i] with [ɪ e] and [u] with [ɯ ʊ o] in three-vowel systems. Thus, work on universal tendencies in vowel systems has been based on regularized, structural categories and not fine-grained phonetic information. Testing theories by attempting to model the universal tendencies of regularized data is problematic, as it does not allow the exploration of the full predictive power of the theories. Rigorous empirical testing is not possible with impressionistic, regularized data.

For example, Schwartz et al. [1997b] report the focalization term (roughly the inherent perceptual saliency of the vowels) for some of the most common vowels. The focalization term for the back vowels [u ʊ o] is the same (i.e. 318), indicating that they are approximately equivalent in perceptual saliency. On the other hand, [i] has a considerably higher focalization term (1225) than [ɪ] (788) or [e] (676), indicating that [i] is perceptually more salient [Schwartz et al., 1997b, table 1]. Thus, it would seem that under some circumstances, the effect of the focalization component would be to predict a system with higher front than back vowels. The regularized dataset which lists /i a u/ as the preferred three-vowel system does not allow for such an investigation. However, an examination of the nonregularized data in Crothers [1978, appendix III] for three-vowel systems indicates that where an asymmetry in height of the front and back vowels is found (5 out of the 22 cases listed), the back vowel is lower in four out of the five cases.

Allowing for the potential shortcomings in testing their models with regularized data, the theories of the Adaptive Dispersion family go a long way toward predicting the shape of vowel inventories based on perceptual and production constraints. A major question that arises is how and when the process of Adaptive Dispersion shapes vowel systems. Since the vowel systems of languages are by no means static, we cannot place the effect at some time in the distant past. Instead, languages seem to dynamically maintain sufficient distance between their vowels to allow for sufficient discrimination as the system changes (i.e. as vowels are lost, gained or changed). The constraints of the production and perceptual systems seem to have a persistent effect.

The research reported here examines the effect of learning second-language vowels on first language vowel *production*. The languages investigated here had relatively small vowel inventories. Four groups, varying in age of acquisition, participated to allow investigation into the effect of age of acquisition on the ability to acquire new

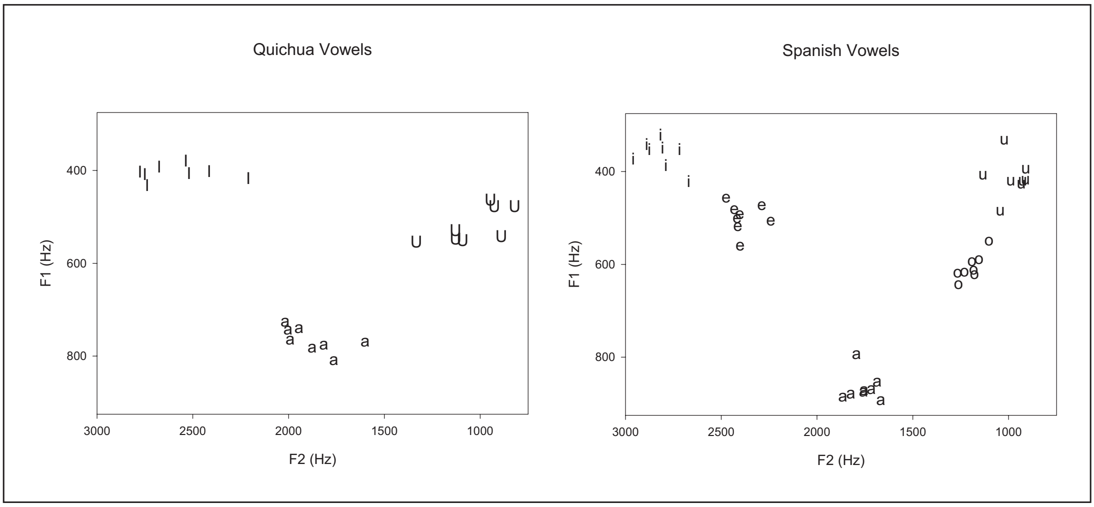

Fig. 1. F_1 and F_2 values (Hz) for a near-monolingual Quichua speaker and a monolingual Spanish speaker, both female. The data have been normalized to allow a direct comparison between the speakers. See Method section for description of the normalization procedure and information about the production of the words from which the vowel tokens were collected.

second-language vowels. It is hypothesized that earlier learners will be more likely to establish vowel categories for the second-language than later learners given the known powerful effect of age of acquisition on the success of learning a second-language [see, e.g., papers in Birdsong, 1999].

Based on the behavioral and neurophysiological studies discussed above, it seems likely that phonological systems are merged in both early and late bilinguals. If so, the merged vowel systems should be subject to the same functional pressures of perception and production as single-vowel systems. These pressures are manifested in the typological regularities of vowel systems [Lindblom, 1986]. Specifically, it is predicted that effects of Adaptive Dispersion will be found in bilinguals who acquire new vowels and incorporate them into a single system. It is hypothesized that the acquisition of new second-language vowel categories will trigger a reorganization of the vowel system to enhance perceptual distinctiveness between the vowels of the combined first- and second-language system.

Quichua-Spanish bilinguals who differed in age of Spanish acquisition participated in the study. Spanish has five vowels, usually transcribed as /i e a o u/. The highland Ecuadorian Quichua spoken by the participants has only three vowels, usually transcribed as /i a u/ [see e.g., Cole, 1982]. For clarity's sake, the Quichua vowels will be transcribed as /ɪ a ʊ/ in the current study. Note that the Quichua spoken in Ecuador has no uvulars, which are known to affect vowel quality in other Quechuan languages (e.g. Peruvian Quechua). Note also that there is no major vowel allophony in the Quichua studied here. All data presented were collected in the small city of Otavalo, Ecuador. Otavalo is located in the highland Andes, roughly 60 miles north of the capital city, Quito. The Otavalo area is characterized by widespread bilingualism, espe-

Table 1. Quichua words

First vowel	Second vowel		
	low	back	front
/ɪ/	'hɪta 'rɪʃa 'sɪsa[a]	'sɪkʊ 'sɪpʊ 'sɪsʊ	'pɪkɪ 'sɪkɪ
/a/	'papa 'pata 'taka	'hakʊ 'rakʊ 'rasʊ	'katɪ 'takɪ
/ʊ/	'kʊsa 'pʊka 'tʊta	'kʊtʊ 'sʊkʊ 'tʊpʊ	'fʊtɪ 'sʊpɪ

[a] Translations of the words can be found in the Appendix.

Table 2. Spanish words

First vowel	Second vowel		
	low	back	front
/i/	'kita 'pika 'pisa[a]	'kito 'piko 'biro	'kite 'pike
/e/	'beta 'seka 'peka	'beto 'seko 'seso	'bete 'seke
/a/	'bata 'saka 'bara	'bato 'sako 'baso	'bate 'sake
/o/	'bota 'toka 'kosa	'boto 'toko 'koro	'bote 'toke
/u/	'kuka 'tusa 'kura	'kuko 'supo 'buso	'buke 'supe

[a] Translations of the words can be found in the Appendix.

cially among the indigenous Otavaleños who typically learn Quichua as their first language and Spanish either simultaneously in the home or when they go to school or begin work.

Figure 1 presents typical first- and second-formant values (Hz) for Quichua and Spanish vowels. The data have been normalized (see Method section) to allow direct comparison between the Quichua and Spanish vowels. Note that, as predicted by Adaptive Dispersion Theory, the larger Spanish vowel inventory is more dispersed than smaller Quichua inventory. A similar finding is reported by Jongman et al. [1989] who found that English and German vowel systems had more dispersed peripheral vowels than the smaller Greek vowel system.

However, not all investigations into dispersion of relatively larger and smaller vowel systems have found clear support for greater dispersion of the larger system. Mendez [1982] did not find greater dispersion for the English vowel system relative to the smaller Spanish vowel system. Bradlow [1995] found evidence for greater dispersion of English vs. Spanish vowels in some environments but not in others. In addition, she reported that the English vowels tended to have a higher second formant and suggested [following Honikman, 1964, and Disner, 1983] that languages can have different 'bases of articulation'. These results caution against predicting vowel inventories based on consistent locations in acoustic space for similar phonemic vowel categories across languages. Bradlow's results also highlight the need for investigating vowel systems using subphonemic, fine-grained phonetic information.

Table 3. Participants

Group	Age[a]	AOL[b]	M/F[c]
Monolingual Spanish	43 (38–48)	0.0	3/2
Simultaneous bilingual	29.4 (24–34)	0.0	2/3
Early bilingual	31.2 (22–36)	5.8 (5–7)	3/2
Mid bilingual	33.6 (18–46)	11.4 (9–13)	3/2
Late bilingual	38.9 (27–49)	19.4 (15–25)	3/2

[a] Mean age at time of testing with range in parentheses.
[b] Mean age of learning Spanish with range in parentheses in cases where the cell contains variance.
[c] Number of male (M) and female (F) speakers.

Method

Materials

One female native speaker of Quichua was recorded reading the words listed in table 1 and one female native speaker of Spanish was recorded reading the words listed in table 2. The carrier phrases ____ *nipai* 'say ____' for Quichua and ____ *es la proxima palabra* '____ is the next word' for Spanish were used by the speakers when producing the words. The talkers read the list twice. The second set of productions was used for the stimulus materials unless there was a problem with the second production. In that case (only two instances), the first production was used.

The Quichua and Spanish words were selected to provide examples of the Quichua and Spanish vowels in accented penultimate syllables followed by a variety of consonants and vowels in the following syllable. Note that the places of the preceding and following consonants are representative of all the places used by Quichua and Spanish (i.e., bilabial, dental/alveolar, post-alveolar/palatal, and velar) and that there are no uvulars in Ecuadorian Quichua. The vowels in the following syllable also represent all the possible types for each language. The words were thus designed to provide a representative set of segmental contexts in which the vowel can be found.

The Spanish speaker was a monolingual native of the city of Otavalo and the Quichua speaker was an early Quichua-Spanish bilingual (Quichua as first language) who lived in an indigenous community close to Otavalo[3]. The words were recorded on a DAT recorder using a high-quality head-mounted microphone. The words were then digitized on a personal computer at 22.05 kHz with 16-bit resolution. Each word was edited into its own file and normalized to 50% peak intensity. The words were later presented using one production of the frame ____ *nipai* for Quichua and ____ *es la proxima palabra* for Spanish combined with a target word. The constant frames were used to minimize the inter-trial variation in the presentation of the stimuli.

The Quichua speaker was also recorded producing a few words in the frame *ñuka nini* ____ 'I say ___'. Likewise, the Spanish speaker was recorded producing a few words in the frame *yo digo así* ____ 'I say thus ___'. These frames were later used to model the production task to the participants.

Participants

Twenty Quichua-Spanish bilinguals and 5 Spanish monolinguals participated in this study. All reported normal hearing and were born and had lived most of their lives in the area around Otavalo. Of the 20 Quichua-Spanish bilinguals, 5 were simultaneous bilinguals, and the remaining 15 began learning Spanish from the age of 5–25. These participants can be divided into 3 nonoverlapping groups of early, mid, and late bilinguals. See table 3 for details. True Quichua monolinguals are almost impossible to find in the Otavalo area, and are therefore not included in the study. It is assumed that the late

[3] The Quichua model had vowels typical of an early bilingual. The Quichua [ɪ]'s were rather high. The Quichua [ʊ]'s were produced in a high manner most of the time as well.

bilinguals exemplify monolingual norms that would have been found in previous generations. All of the bilingual participants' parents were late-learners of Spanish or Quichua (near-)monolinguals. It is a relatively new phenomenon to learn Spanish at home or at an early age, due largely to the greater access to education that has happened in the last generation.

Procedure

A native Quichua-speaking experimenter gave all instructions and asked all questions for the bilingual participants in Quichua. A native English speaker with near-native Spanish interacted with the monolingual Spanish participants. Participants were first asked biographical questions orally and the experimenter noted their answers.

The participants were then asked to listen to and repeat words in Quichua and Spanish (monolinguals heard the Spanish words only). All subjects heard the same word tokens (collection of these tokens is described in the Materials section) presented over high-quality loudspeakers in a quiet room. Presentation of the stimuli was regulated with software on a personal computer. The Quichua and Spanish words were presented in two separate randomized blocks that were counterbalanced across the participants within each group. In other words, for each group of 5, 2 or 3 of the participants heard the Quichua words then the Spanish words. The rest heard the reverse order.

The Quichua words (listed in table 1) were presented in the frame ___ *nipai* and the participants then repeated them in the frame *ñuka nini* ____. The participants heard this task modeled with recorded examples and produced a few practice trials before the elicitation began. Likewise, the Spanish words (listed in table 2) were presented in the frame ____ *es la proxima palabra* and repeated in the frame *yo digo así* ____ after modeling and practice trials.

The presentation of the auditory material after the stimulus and the production material before the repetition was designed to minimize the possibility of mimicry. The demands placed on the processing system by the intervening perception and production tasks made it likely that the target word be lexically coded before repetition, thus activating a speaker's long-term memory representation of the word. The use of real words as well as the intervening stimulus material made it unlikely that the model presentation would influence the production of the target words.

The repetitions were recorded on a DAT recorder with a high quality head-mounted microphone and later digitized at 22.05 kHz with 16-bit resolution on a personal computer. A total of 1,480 words were analyzed (24 Quichua words × 20 talkers + 40 Spanish words × 25 talkers). The first three formants of each vowel were measured at the temporal midpoint using PCquirer software. Both LPC (26 coefficients) and FFT (512 pts) spectra were calculated and plotted together in a single window. The peaks from the formant-picking algorithm based on the LPC analysis were recorded except in the very few instances in which the LPC peaks did not align with the FFT spectral peaks on visual inspection. In these cases, the spectra were recalculated 5 ms later or earlier in the waveform. In all cases, the second set of spectra showed alignment of the LPC and FFT peaks.

As the research questions investigated here deal with perceptual distances, the hertz measurements were converted to the auditory Bark scale using the formula in (1) [Traunmüller, 1990]. For the within talker analysis reported in the next section, the Bark data will be used.

$$z = [26.81/(1 + 1960/f)] - 0.53 \qquad (1)$$

where f = value in hertz.

As between-talker analyses were also planned, the range of average F_3 for the vowel /a/ in Quichua and Spanish was investigated to give an estimate of the variance between talkers due to vocal tract size. It is commonly noted that F_3 serves as a good index of vocal tract length, the primary source of the difference between male and female formant values [Fujisaki and Kawashima, 1968; Nearey, 1989]. Mean values were found to range from 13.7 to 16.1 Bark for the 25 talkers recorded. Given the range of variation, it was decided to normalize the Bark data based on the F_3 values. The formants (in Bark) for each talker were multiplied by a k factor calculated with the formula given in (2) [see also Yang, 1996, for a similar procedure performed on cross-linguistic vowel data].

$$14.927/\text{mean } F_3\, S_i = k_i \qquad (2)$$

where 14.927 = the average F_3 of /a/ for one male speaker to whom all others are normalized and mean $F_3\, S_i$ = the mean F_3 of /a/ for subject i.

The k factors ranged from 0.93 to 1.09. The normalized Bark data will be used for all between-talker analyses.

Results

The results of the acoustic investigation are presented in four sections. In the first section, the hypothesis that age of acquisition affects the ability to learn vowels in a second language is tested. Vowel productions of individual Quichua-Spanish bilingual subjects are investigated to determine whether or not the bilinguals produce Spanish vowels distinctly from Quichua vowels.

In the next two sections, the hypothesis that learning second-language vowels can affect first language vowels is tested. The Quichua vowel productions of bilinguals who had distinct Spanish and Quichua vowels are compared to the Quichua vowels of bilinguals who did not differentiate Spanish and Quichua vowels. The second section investigates the high vowels and the third section investigates the low vowels.

In the fourth section, the accuracy of Spanish vowel production is investigated. The bilinguals' Spanish vowels will be compared to Spanish monolinguals' to determine the extent to which the bilingual groups produce Spanish vowels in a native-like way. In this section, the Quichua and Spanish vowel systems will also be compared by examining the Spanish vowels of monolingual speakers and the Quichua vowels of late learners who show no signs of Spanish vowel acquisition.

Within-Subjects Analysis: Quichua and Spanish Vowels

The statistical tests reported here were designed to answer the following three questions: (1) for a given speaker, are the Spanish and Quichua vowels different overall? (2) If so, do they differ in F_1 and/or F_2? and (3) If significant differences are found in (2), from which Spanish vowels do the Quichua vowels differ?

For each Quichua-Spanish bilingual, separate investigations for the front, back and low vowels were conducted. The front vowels Quichua /ɪ/, Spanish /i/ and Spanish /e/ were compared. Then, the back vowels Quichua /ʊ/, Spanish /u/ and Spanish /o/ were compared. Finally, the low vowels Quichua /a/ and Spanish /a/ were compared. The procedure was as follows. First, an overall multivariate analysis of variance (MANOVA) on F_1 and F_2 values was conducted. Where the results were significant, univariate analyses on F_1 and F_2 were conducted. Significant results from these analyses were followed up with pairwise comparisons testing the difference between Quichua and Spanish vowels.

The results for the front vowels are presented first. The overall MANOVA on F_1 and F_2 with the 3-level factor of front vowel (Quichua /ɪ/, Spanish /i/ and Spanish /e/) returned a significant finding for 11 out of the 20 bilinguals [$F(4, 26)$ ranged from 9.99 to 53.40, $p < 0.001$]. Table 4 presents the results from the univariate analyses on F_1 and F_2 and the paired comparisons of Quichua and Spanish vowels for the speakers for whom the MANOVA returned a significant finding.

As can be seen from table 4, the bilingual participants fall into three groups: (1) those who differentiate their Quichua /ɪ/ from both Spanish /i/ and /e/ in either the F_1 or F_2 domain, (2) those who differentiate their Quichua /ɪ/ from Spanish /e/, but not Spanish /i/, and (3) those who do not differentiate their Quichua vowel from either of the Spanish vowels. For ease of reference, the groups will be referred to as

Table 4. Differences between Quichua and Spanish front vowels

Bilingual group	Participant's initials[a]	F-value F_1[b]	Pairwise comparison[c]	F-value F_2[b]	Pairwise comparison[c]
Simultaneous	JC (0)	45.3	S/i/ < Q/ɪ/ < S/e/	15.6	S/e/ < Q/ɪ/
	RA (0)	135.3	Q/ɪ/ < S/e/	65.5	S/e/ < Q/ɪ/ < S/i/
	HC (0)	81.7	S/i/ < Q/ɪ/ < S/e/	60.1	S/e/ < Q/ɪ/ < S/i/
	CC (0)	249.2	Q/ɪ/ < S/e/	167.1	S/e/ < Q/ɪ/ < S/i/
	VC (0)	23.6	Q/ɪ/ < S/e/	34.8	S/e/ < Q/ɪ/
Early	AY (5)	177.7	Q/ɪ/ < S/e/	18.5	S/e/ < Q/ɪ/
	MC (5)	140.4	Q/ɪ/ < S/e/	n.s.	
	JV (5)	n.s.	n.s.	n.s.	
	ZM (6)	41.4	Q/ɪ/ < S/e/	18.5	S/e/ < Q/ɪ/
	LM (7)	91.3	Q/ɪ/ < S/e/	56.8	S/e/ < Q/ɪ/
Mid	HQ (9)	94.6	Q/ɪ/ < S/e/	46.3	S/e/ < Q/ɪ/
	JMA (11)	n.s.		n.s.	
	MA (12)	16.1	Q/ɪ/ < S/e/	n.s.	
	RM (12)	n.s.		n.s.	
	GM (13)	n.s.		n.s.	
Late	NQ (15)	n.s.		n.s.	
	MM (15)	n.s.		n.s.	
	ECM (17)	n.s.		n.s.	
	MEA (25)	n.s.		n.s.	
	MRQ (25)	n.s.		n.s.	

[a] Age of Spanish acquisition in parentheses.
[b] $F(2, 14)$, $p < 0.001$.
[c] Bonferroni $p < 0.01$ (based on 2–4 comparisons for each speaker).

the 3-vowel group (1), the 2-vowel group (2), and the 1-vowel group (3). The 3-vowel group is made up of 4 of the 5 simultaneous bilinguals; the 2-vowel group is composed of mostly early and mid bilinguals, and the 1-vowel group mostly of mid and late bilinguals. It appears that the simultaneous bilinguals maintain separate production for Quichua and Spanish front vowels. In contrast, the early and some mid bilinguals do not produce significantly different Quichua /ɪ/ and Spanish /i/. However, they do have a distinct Spanish /e/ production that other mid and late bilinguals lack. Figure 2 presents the mean F_1 and F_2 with standard deviations for representative talkers of the three groups. A likely interpretation of the data is that the 3-vowel group has three phonetic categories for front vowels, the 2-vowel group has two categories, and the 1-vowel group has only one category that serves both Quichua and Spanish.

A similar analysis was conducted on the back vowels: Quichua /ʊ/, Spanish /u/, and Spanish /o/. A MANOVA investigating the F_1 and F_2 values (in Bark) for the three vowels was run on each of the bilingual participants. Significant findings were returned for 13 of the 20 bilinguals [$F(4, 26)$ ranged from 6.36 to 64.16, $p < 0.001$). Univariate analyses investigating F_1 and F_2 separately were conducted for those participants with an overall significant MANOVA result. Table 5 presents the results of the univariate analyses as well as the pairwise comparisons. Note that no talkers differentiated the

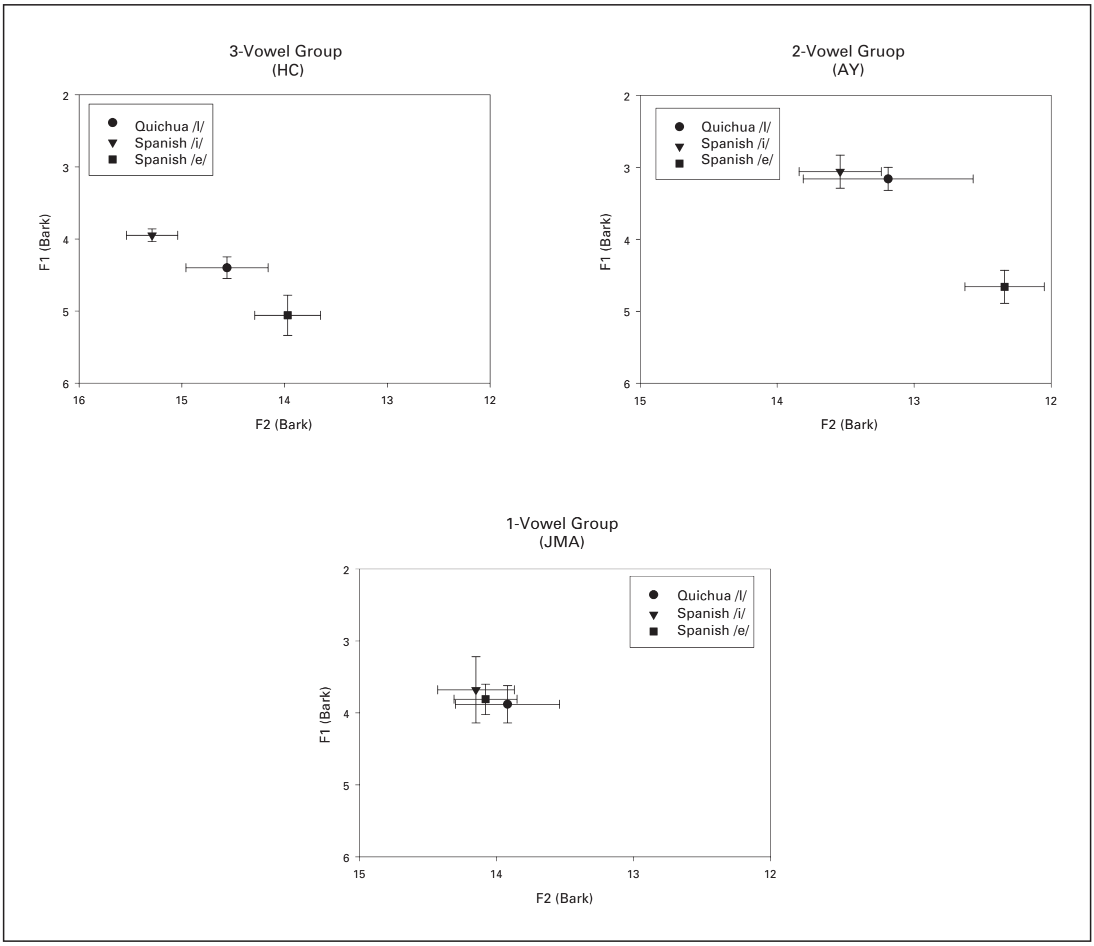

Fig. 2. F_1 and F_2 mean values (Bark) and standard deviations of front vowels for individual representative speakers from the three groups: the 3-vowel group differentiates Quichua /ɪ/ from both Spanish /i/ and /e/, the 2-vowel group differentiates Quichua /ɪ/ from Spanish /e/ but not Spanish /i/, and the 1-vowel group does not differentiate Quichua /ɪ/ from either Spanish vowel.

three vowels in the F_2 domain, indicating that the significant results of the MANOVA were due to differences in F_1 alone.

Three clear groups emerge from an examination of table 5: (1) those who differentiate Quichua /ʊ/ from Spanish /u/ but not Spanish /o/ (the separate Spanish /u/ group), (2) those who differentiate Quichua /ʊ/ from Spanish /o/ but not Spanish /u/ (the separate Spanish /o/ group), and (3) those who do not differentiate Quichua /ʊ/ from either of the Spanish vowels (the 1-vowel group). In addition, there are 2 talkers who do not fit in any group. Participant VC, a simultaneous bilingual, differentiates both Spanish vowels from the Quichua /ʊ/. Participant MM, a late bilingual, produces a difference between Quichua /ʊ/ and Spanish /u/ that is in the opposite direction of

Table 5. Differences between Quichua and Spanish back vowels

Bilingual group	Participant's initials[a]	F-value F_1[b]	Pairwise comparison[c]	F-value F_2[b]	Pairwise comparison[c]
Simultaneous	JC (0)	20.2	S/u/ < Q/ʊ/	n.s.	
	RA (0)	121.8	Q/ʊ/ < S/o/	n.s.	
	HC (0)	155.4	Q/ʊ/ < S/o/	n.s.	
	CC (0)	247.3	Q/ʊ/ < S/o/	n.s.	
	VC (0)	15.8	S/u/ < Q/ʊ/ < S/o/	n.s.	
Early	AY (5)	271.4	Q/ʊ/ < S/o/	n.s.	
	MC (5)	62.2	Q/ʊ/ < S/o/	n.s.	
	JV (5)	16.3	S/u/ < Q/ʊ/	n.s.	
	ZM (6)	n.s.		n.s.	
	LM (7)	34.4	Q/ʊ/ < S/o/	n.s.	
Mid	HQ (9)	109.2	S/u/ < Q/ʊ/	n.s.	
	JMA (11)	n.s.		n.s.	
	MA (12)	20.1	Q/ʊ/ < S/o/	n.s.	
	RM (12)	19.4	S/u/ < Q/ʊ/	n.s.	
	GM (13)	n.s.		n.s.	
Late	NQ (15)	n.s.		n.s.	
	MM (15)	16.1	Q/ʊ/ < S/u/	n.s.	
	ECM (17)	n.s.		n.s.	
	MEA (25)	n.s.		n.s.	
	MRQ (25)	n.s.		n.s.	

[a] Age of Spanish acquisition in parentheses.
[b] $F(2, 14)$, $p < 0.001$.
[c] $p < 0.01$.

the Separate Spanish /u/ Group (Quichua /ʊ/ F_1 is lower than Spanish /u/). Figure 3 presents the F_1 and F_2 mean values and standard deviations for representative members of the three groups. Thus, it appears that the separate Spanish /u/ group has a single phonetic category for both Spanish /o/ and Quichua /ʊ/ and a separate category for Spanish /u/, the separate Spanish /o/ group has a single phonetic category for both Spanish /u/ and Quichua /ʊ/ and a separate category for Spanish /o/, and the 1-vowel group has only one phonetic category for all Spanish and Quichua back vowels.

In the case of the low vowels, only 2 speakers were found to differentiate Quichua /a/ production from Spanish /a/ production. A single speaker in the simultaneous bilingual group (HC) and a single speaker in the early bilingual group (AY) had a significant result on the MANOVA [$F(2, 6) = 25.55$ and 14.44, respectively, $p < 0.001$]. The univariate analyses revealed that both speakers differentiated the two vowels in terms of F_1 only [$F(1, 7) = 56.36$ and 26.73, respectively, $p < 0.001$]. Specifically, they produced the Spanish /a/ with a higher F_1 than the Quichua /a/. In other words, the Quichua /a/ was produced higher than the Spanish /a/. As only 2 of the 20 participants had significant differences for the production of these 2 vowels, it is not possible to create groups to examine /a/ production based on individual participants' /a/ productions (as was done for the front and back vowels). We will, however, investigate /a/ production between speakers by forming groups based on the front and back vowel

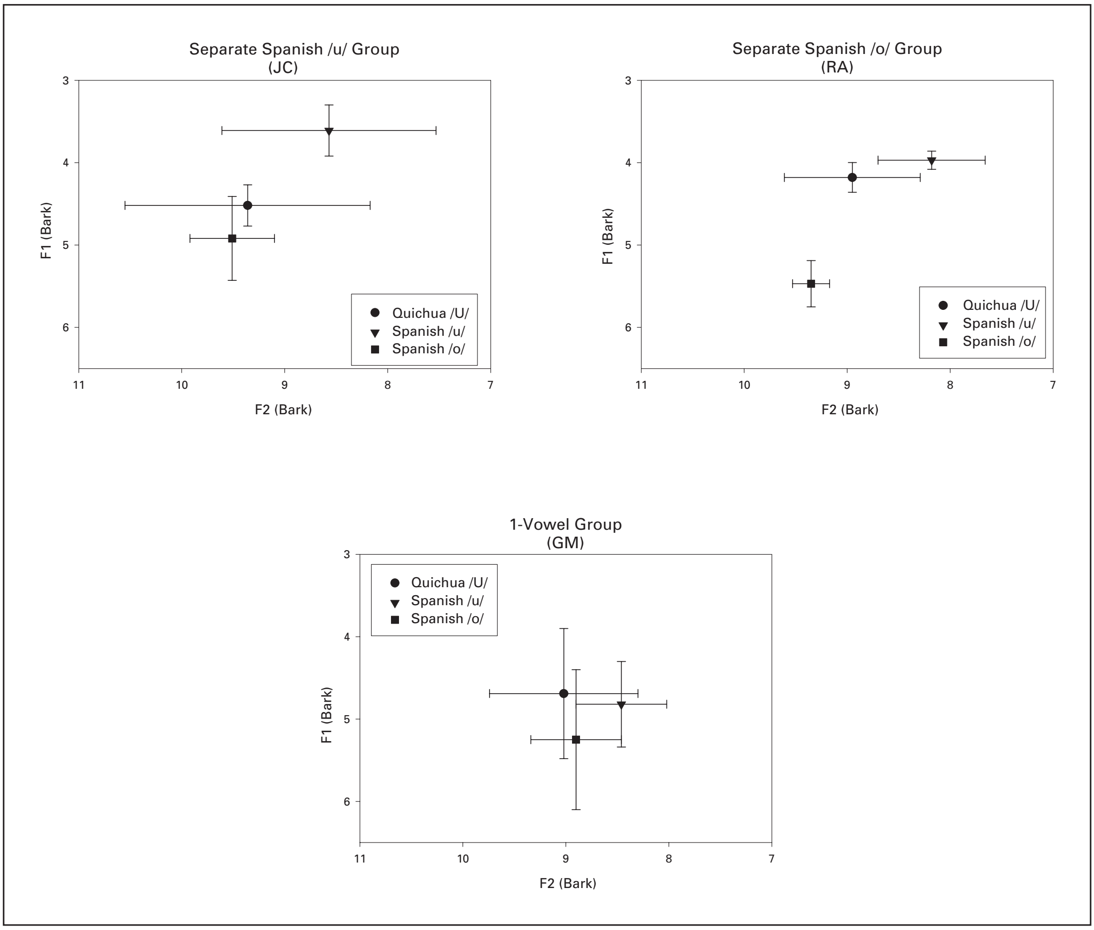

Fig. 3. F_1 and F_2 mean values (Bark) and standard deviations of back vowels for individual representative speakers from the three groups: the separate Spanish /u/ group differentiates Quichua /ʊ/ from Spanish /u/ but not Spanish /o/, the separate Spanish /o/ group differentiates Quichua /ʊ/ from Spanish /o/ but not Spanish /u/, and the 1-vowel group does not differentiate Quichua /ʊ/ from either Spanish vowel.

productions. The procedure for group formation will be detailed in the section after next.

Between-Groups Analysis: Quichua Front and Back Vowels

In this section, the formant structure of Quichua vowels produced by the bilingual speakers will be investigated. The groups defined in the previous section will be used to test the hypothesis that learning Spanish vowel contrasts will affect the production of Quichua vowels. The statistical tests reported here were designed to answer the following three questions: (1) Do the groups differ in *Quichua* vowel production overall?

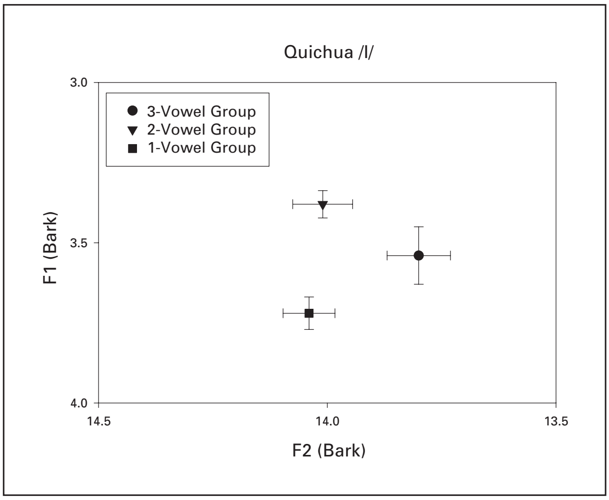

Fig. 4. F_1 and F_2 mean values and standard errors (Bark) of Quichua /ɪ/ for the three groups: the 3-vowel group differentiates Quichua /ɪ/ from both Spanish /i/ and /e/, the 2-vowel group differentiates Quichua /ɪ/ from Spanish /e/ but not Spanish /i/, and the 1-vowel group does not differentiate Quichua /ɪ/ from either Spanish vowel.

(2) If so, do they differ in F_1 and/or F_2? and (3) If a significant difference is found in (2), which groups are different from which? The data from the front vowels are presented first, followed by those from the back vowels. All analyses reported in this section use the normalized data described in the Method section.

The production of Quichua /ɪ/ was investigated using the three groups defined in the previous section: The 3-vowel group differentiated Quichua /ɪ/ from Spanish /i/ and /e/ in either (or both) the F_1 and F_2 domains; the 2-vowel group differentiated Quichua /ɪ/ from Spanish /e/ but not Spanish /i/, and the 1-vowel group did not differentiate Quichua /ɪ/ from either of the Spanish vowels. The 3- and 2-vowel groups have distinct Spanish vowels whereas the 1-vowel group does not.

A MANOVA on the F_1 and F_2 of Quichua /ɪ/ productions for the three groups returned a significant result [$F(4, 312) = 7.33$, $p < 0.001$]. Univariate analyses returned a significant result for F_1 only [$F(2, 157) = 10.37$, $p < 0.001$]. Paired comparisons were significant [Bonferroni ($n = 3$) $p < 0.01$) for the 2-vowel and 1-vowel groups with the 2-vowel having a significantly lower F_1. This indicates that the Quichua /ɪ/ is produced higher in bilinguals who equate Spanish /i/ and Quichua /ɪ/ and differentiate them from Spanish /e/ than in those bilinguals who equate all three vowels. It would seem to be a reasonable assumption that the bilinguals in the 1-vowel group have not acquired Spanish vowels and are using their native Quichua vowels in Spanish. Therefore, we can interpret this finding to mean that the acquisition of Spanish /e/ conditions a raising of the Quichua /ɪ/. See figure 4 which presents F_1 and F_2 mean values and standard errors for Quichua /ɪ/ as produced by the three groups.

The data from the production of Quichua back vowels provide more evidence for the effect of learning Spanish vowels on the production of Quichua vowels. The production of Quichua /ʊ/ was investigated using the three groups defined in the previous section: the separate Spanish /u/ group differentiated Quichua /ʊ/ from Spanish /u/ but not /o/; the separate Spanish /o/ differentiated Quichua /ʊ/ from Spanish /o/ but not /u/, and the 1-vowel group did not differentiate Quichua /ʊ/ from either of the Spanish

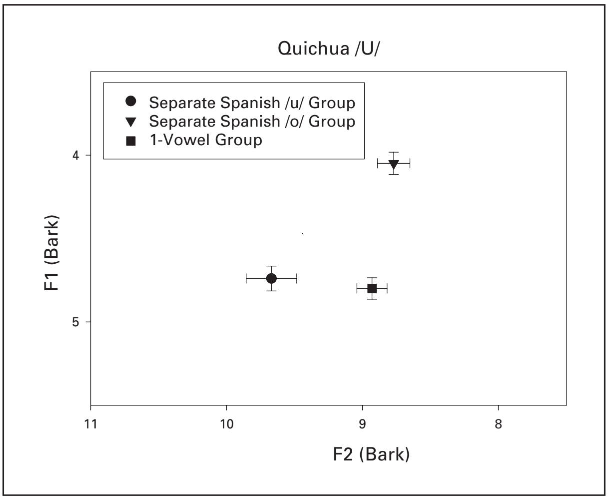

Fig. 5. F_1 and F_2 mean values and standard errors (Bark) of Quichua /ʊ/ for the three groups: the separate Spanish /u/ group differentiates Quichua /ʊ/ from Spanish /u/ but not Spanish /o/, the separate Spanish /o/ group differentiates Quichua /ʊ/ from Spanish /o/ but not Spanish /u/, and the 1-vowel group does not differentiate Quichua /ʊ/ from either Spanish vowel.

vowels. The separate Spanish /u/ and /o/ groups have distinct Spanish vowels whereas the 1-vowel group does not.

A MANOVA on the F_1 and F_2 of Quichua /ʊ/ productions for the three groups returned a significant result [$F(4, 280) = 22.75$, $p < 0.001$]. Univariate analyses returned a significant result for F_1 [$F(2, 141) = 39.71$, $p < 0.001$) and F_2 [$F(2, 141) = 10.44$, $p < 0.001$]. Paired comparisons for F_1 values were significant [Bonferroni ($n = 3$) $p < 0.01$] for the separate Spanish /u/ group and the separate Spanish /o/ group and for the separate Spanish /u/ group and the 1-vowel group, with the separate Spanish /o/ group having a significantly lower F_1 than either of the other two groups. This indicates that the Quichua /ʊ/ is produced higher by bilinguals who equate Spanish /u/ and Quichua /ʊ/ and differentiate them from Spanish /o/ than by those bilinguals who equate all three vowels or equate Quichua /ʊ/ to Spanish /o/. These findings indicate that the acquisition of Spanish /o/ conditions a raising of the Quichua /ʊ/. Paired comparisons for F_2 values were significant [Bonferroni ($n = 3$) $p < 0.01$] for the separate Spanish /u/ group as compared to the separate Spanish /o/ group and the 1-vowel group. The separate Spanish /u/ group had a significantly higher F_2 than the other two groups. This indicates that Quichua /ʊ/ is more fronted for participants who differentiate this vowel from Spanish /u/ than for those participants who equate it with Spanish /u/. Figure 5 presents F_1 and F_2 mean values and standard errors for Quichua /ʊ/ as produced by the three groups.

Between-Groups Analysis: The Low Vowels

As reported above, significant differences for Spanish and Quichua /a/ vowel production were found for only two out of 20 Quichua-Spanish bilinguals. However, the production of all the bilinguals' vowels is of theoretical interest. It is important to have an idea of how the total vowel system works to answer the research questions posed here. Therefore, an analysis with more power is performed in this section. The groups defined by the analysis of the front and back vowels are used to determine whether or not participants made differences in the production of the Quichua and Spanish vowels.

The following groups were formed: the 3-vowel group produced three distinct vowels (two Spanish and one Quichua) in *either* the front or back region (participants JC, RA, HC, CC, VC). The raised Quichua vowel group was formed from the remaining participants and included those who had two distinct front *or* back vowels *and* produced Quichua vowels higher than those participants who showed no sign of learning Spanish vowels (AY, MC, ZM, LM, HQ, MA). Finally, the no Spanish vowel group had only one vowel in the front and one vowel in the back region that did not differ for Quichua or Spanish production (JMA, GM, NQ, ECM, MEA, MRQ).

The statistical tests were designed to answer the following questions: (1) Do any of the three groups produce Spanish and Quichua /a/ differently? (2) If so, do the groups differ in their Quichua vowel production? (3) If so, which groups differ from which? In the following tests, only the first formant was designated as a dependent variable. The decision to only investigate F_1 was motivated by the results from the individual speakers: the only differences between Spanish and Quichua low vowels were found in vowel height.

An ANOVA was performed on the normalized Bark value for the first formant of Quichua and Spanish /a/ vowels. The factors of Language (Spanish or Quichua, with repeated measures) and Group (3) were used. The overall effect of Group was significant [$F(2, 133) = 19.97$, $p < 0.001$]. Pairwise comparisons [Bonferroni ($n = 3$) $p < 0.01$) revealed that the no Spanish vowel group had higher F_1 values than the other two groups. The overall effect of Language was also significant [$F(1, 133) = 21.82$, $p < 0.001$), with the Spanish F_1 values being higher. In addition, the interaction was significant [$F(2, 133) = 4.49$, $p < 0.013$).

The interaction was explored by testing the effect of Language on each of the three groups separately and by testing the effect of Group on the Quichua vowel productions. (The Spanish vowel productions will be presented in the next section.) The effect of Language was not significant for the no Spanish vowel group [$F(1, 47) = 0.13$, mean Quichua /a/ = 6.77 and mean Spanish /a/ = 6.80 Bark]. However, the effect of Language was significant for the 3-vowel group [$F(1, 39) = 9.22$, $p < 0.004$, mean Quichua /a/ = 6.29 and mean Spanish /a/ = 6.60 Bark] and the raised Quichua vowel group [$F(1, 47) = 23.56$, $p < 0.001$, mean Quichua /a/ = 6.07 and mean Spanish /a/ = 6.42 Bark]. The Spanish vowels were produced with higher F_1 values than the Quichua vowels. These results indicate that the participants who have acquired Spanish vowels in the front and back regions have also acquired a Spanish /a/ vowel that is produced lower than the Quichua /a/ vowel.

In a further investigation of the interaction, the effect of Group (3) was investigated for the Quichua /a/ F_1 data. The results were significant [$F(2, 133) = 12.32$, $p < 0.001$). Pairwise comparisons [Bonferroni ($n = 3$) $p < 0.01$] revealed that the no Spanish vowel group had higher F_1 values than either of the other two groups (6.77 vs. 6.29 and 6.07 Bark). These results indicate that the participants who have acquired Spanish vowels produce the Quichua /a/ higher than those who have not acquired Spanish vowels.

To summarize the findings for the low vowels, the Quichua-Spanish bilinguals who have acquired distinct Spanish front and back vowels have also acquired a distinct Spanish low vowel. The Spanish vowel is produced in a more open manner (i.e., lower) than the Quichua vowel. In addition, the participants who have acquired a Spanish /a/ produce their Quichua /a/ higher than those participants who do not distinguish Spanish and Quichua /a/.

Table 6. F_1 values for front vowels in Spanish words

Group	/i/ mean	/i/ SD	/e/ mean	/e/ SD	n
3-vowel group	3.18	0.43	4.61	0.34	32
2-vowel group	3.17	0.52	4.86	0.43	56
1-vowel group	3.62	0.62	3.93*	0.74	72
Monolingual Spanish	3.39	0.43	4.86	0.45	40

* Significantly different from the monolingual Spanish group.

Between-Groups Analysis: Spanish Vowels and Their Comparison to Quichua Vowels

In this section a comparison of *Spanish* vowels produced by monolingual Spanish speakers and Quichua-Spanish bilinguals is presented. The analyses detail the extent to which the bilinguals produce Spanish vowels in a native-like way. The differences between the Spanish and Quichua vowel systems are also explored by comparing the vowels of Spanish monolinguals to the Quichua vowels of speakers who show no sign of acquiring Spanish vowels. These analyses provide evidence that the differences between the Quichua and Spanish vowel systems illustrated in figure 1 are statistically reliable. The analysis of the front vowels will be presented, then the analysis of the back vowels, then the analysis of the low vowels.

For the analysis of the front vowels, the three groups defined by the within-subject analysis of front vowel production were used: the 3-vowel group, the 2-vowel group and the 1-vowel group. The productions of Spanish /i/ and /e/ by these three groups were compared to the productions by monolingual Spanish participants. An overall ANOVA on the F_1 of Spanish /i/ for the four groups returned a significant finding [$F(3, 196) = 9.36$, $p < 0.001$]. Surprisingly, none of the comparisons of monolingual Spanish /i/ to the three bilingual groups were significant. However, there was a trend for the 1-vowel group to have a higher F_1 (lower vowel) than the Spanish speakers. An overall ANOVA on the F_1 of Spanish /e/ for the four groups also returned a significant finding [$F(3, 196) = 37.13$, $p < 0.001$]. A comparison of the monolingual Spanish /e/ to the three bilingual groups returned one significant [Bonferroni ($n = 3$) $p < 0.01$] comparison: the 1-vowel group, those who did not differentiate Quichua and Spanish front vowels in their production, had a significantly lower F_1 than the monolingual Spanish participants. In other words, the 1-vowel group produces Spanish /e/ significantly higher than the monolingual Spanish speakers. The means for the four groups are presented in table 6.

To summarize the findings for front Spanish vowels: The Spanish /i/ produced by the three bilingual groups is not different from that produced by monolingual Spanish speakers. However, the 1-vowel group produces a Spanish /e/ that is higher than the monolinguals produce. This indicates that speakers from this group use their Quichua /ɪ/ for both Spanish /i/ and /e/.

The monolingual production of the Spanish /i/ and /e/ was then compared to the production of *Quichua* /ɪ/ by the 1-vowel group. The production of Quichua /ɪ/ differed significantly from the productions of Spanish /i/ [$F(1, 110) = 14.77$, $p < 0.001$] and Spanish /e/ [$F(1, 110) = 168.57$, $p < 0.001$] as measured in the F_1 domain (fig. 1). The

Table 7. F1 values for back vowels in Spanish words

Group	/u/ mean	/u/ SD	/o/ mean	/o/ SD	n
Separate Spanish /u/ group	4.14	0.51	5.09	0.34	32
Separate Spanish /o/ group	3.83	0.41	5.28	0.37	56
1-vowel group	4.57*	0.64	4.93*	0.63	56
Monolingual Spanish	3.86	0.34	5.40	0.34	40

* Significantly different from the monolingual Spanish group.

Quichua /ɪ/ (mean = 3.72) falls in between the two Spanish vowels, but closer to Spanish /i/ (table 6).

Turning to the back vowels, the same three groups used in previous sections and based on the within subject analysis of back vowel production were investigated: the separate Spanish /u/ group, the separate Spanish /o/ group and the 1-vowel group. The productions of Spanish /u/ and /o/ by these three groups were compared to the productions by monolingual Spanish participants. An overall ANOVA on the F_1 of Spanish /u/ for the four groups returned a significant finding [$F(3, 180) = 25.21$, $p < 0.001$]. A comparison of the monolingual Spanish /u/ to the three bilingual groups returned one significant [Bonferroni ($n = 3$) $p < 0.01$] comparison: the 1-vowel group had significantly higher F_1 than in the monolingual Spanish group. In other words, the /u/ for the 1-vowel group was lower than in the monolingual Spanish group. An overall ANOVA on the F_1 of Spanish /o/ for the four groups returned a significant finding [$F(3, 180) = 9.88$, $p < 0.001$]. A comparison of the monolingual Spanish /o/ to the three bilingual groups returned one significant [Bonferroni ($n = 3$) $p < 0.01$] comparison: the 1-vowel group had a significantly lower F_1 than the monolingual Spanish participants. In other words, the 1-vowel group produced Spanish /o/ significantly higher than the monolingual Spanish speakers. The means for the four groups are presented in table 7.

To summarize the findings for the back Spanish vowels: the 1-vowel group produces both Spanish /o/ and /u/ at a height intermediate to the monolingual Spanish /u/ and /o/. The Separate Spanish /u/ and /o/ Groups produce Spanish vowels /u/ and /o/ that are not different from Spanish monolinguals.

The monolingual production of the Spanish /u/ and /o/ was then compared to the production of *Quichua* /ʊ/ by the 1-vowel group. The production of Quichua /ʊ/ differed significantly from the productions of Spanish /u/ [$F(1, 94) = 110.99$, $p < 0.001$] and Spanish /o/ [$F(1, 94) = 43.05$, $p < 0.001$] as measured in the F_1 domain (fig. 1). The Quichua /ʊ/ (F_1 mean = 4.78) is almost exactly intermediate between the two Spanish vowels (table 7).

The results from the front and back vowel analyses indicate that bilinguals who do not differentiate the Quichua vowels from the corresponding Spanish vowels produce Spanish vowels that differ from monolingual Spanish speakers' vowels. The vowels are intermediate between the high and low Spanish vowels. Assuming that the mid and late bilinguals in the 1-vowel groups considered here are using their native Quichua vowel categories for both Quichua and Spanish, we can reasonably conclude that for the two languages overall, the Quichua high vowels /ɪ/ and /ʊ/ are not as high as the

Table 8. F_1 values for low vowels in Spanish words

Group	/a/ mean	/a/ SD	n
3-vowel group	6.59*	0.45	40
Raised Quichua vowel group	6.42*	0.39	48
No Spanish vowel group	6.80	0.64	48
Monolingual Spanish	7.06	0.58	40

* Significantly different from the monolingual Spanish group.

Spanish vowels /i/ and /u/. Furthermore, the Quichua /ʊ/ is lower than /ɪ/ relative to the Spanish vowels.

Now let us consider the low vowels. The same three groups used in the previous section to investigate low vowels were used: the 3-vowel group, raised Quichua vowel group and no Spanish vowel group. The productions of Spanish /a/ by these three groups were compared to the productions by monolingual Spanish participants. An overall ANOVA on the F_1 of Spanish /a/ for the four groups returned a significant finding [$F(3, 172) = 11.81$, $p < 0.001$]. Table 8 presents the mean F_1 values for the groups. A comparison of the monolingual Spanish /a/ to the three bilingual groups returned two significant [Bonferroni ($n = 3$) $p < 0.01$] comparisons: the 3-vowel group and the raised Quichua vowel group had lower F_1 values than the native Spanish speakers. In other words, the groups who had established separate Spanish and Quichua low vowels produced their Spanish vowels higher than native Spanish speakers.

In a separate analysis, the *Quichua* /a/ produced by the no Spanish vowel group was compared to monolingual Spanish speakers' /a/. The two vowels were marginally different [$F(1, 86) = 4.96$, $p = 0.028$]. The Spanish speakers tended to have a higher F_1 than the Quichua speakers (mean = 6.77). In other words, the Spanish vowel is marginally lower than the Quichua vowel. See figure 1 for an illustration.

In summary, the results presented in this section illustrate that Spanish vowels are, in general, more dispersed relative to Quichua vowels for monolingual (or near monolingual) speakers. Bilinguals who do not distinguish Spanish and Quichua vowels in their production produce Spanish vowels in a non-native-like way. They seem to be using their Quichua vowels in Spanish. Bilinguals who have separate Spanish and Quichua vowels, however, produce the front and back Spanish vowels similarly to monolingual Spanish speakers. On the other hand, for the low vowels, bilinguals who have separate Spanish and Quichua vowels produce the Spanish vowel higher than monolingual Spanish speakers. Interestingly, as presented in the previous section, these speakers also produce Quichua /a/ higher than the Quichua speakers who have not acquired a separate Spanish vowel.

Discussion and Conclusion

The results of the acoustic analyses indicate that the earlier in life one is exposed to a language, the greater the chance of acquiring the vowels of that language and producing them in a native-like fashion. All of the simultaneous, most of the early

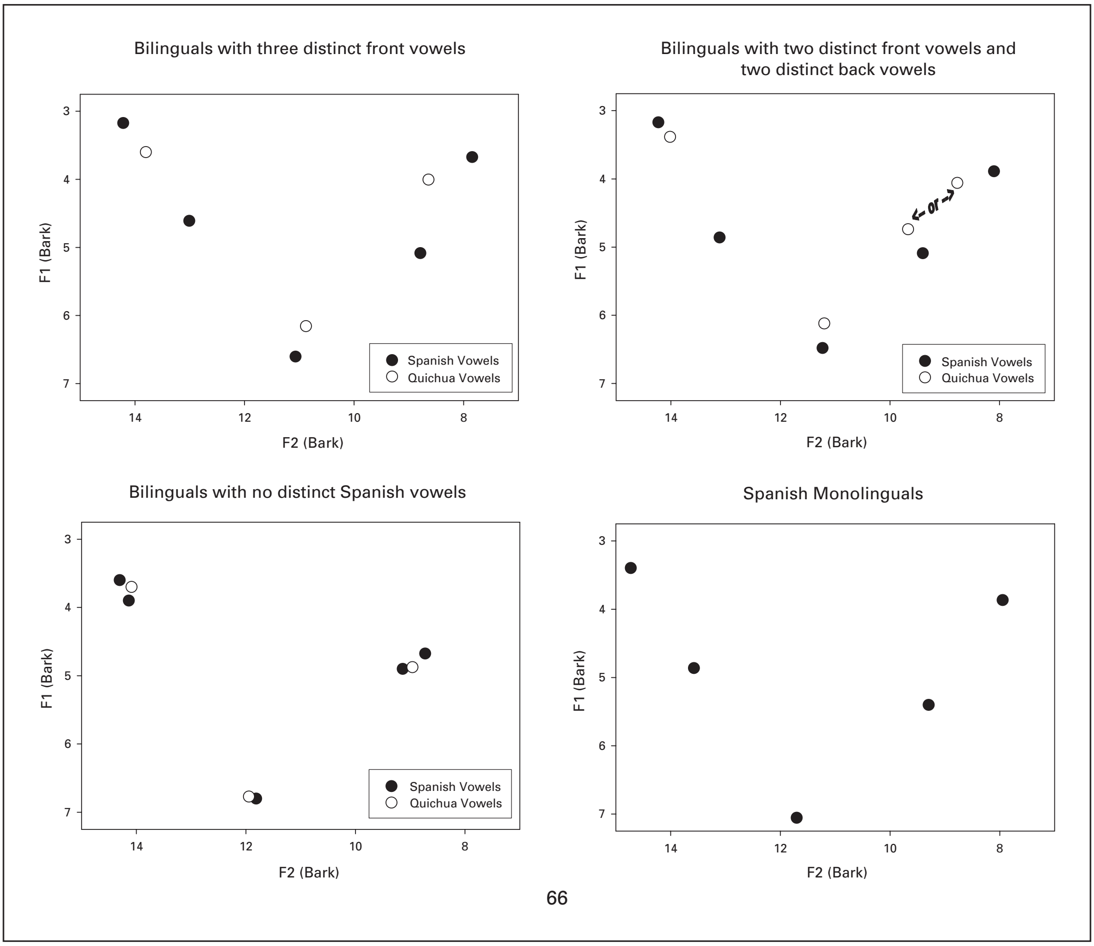

Fig. 6. F_1 and F_2 mean values (Bark) of Quichua and Spanish vowel productions for four groups of speakers. The top left graph presents mean values for bilingual speakers who produced three significantly different front vowels: Quichua /ɪ/, Spanish /i/ and Spanish /e/. The top right graph presents mean values for bilingual speakers who produced two significantly different front vowels (Quichua /ɪ/ and Spanish /i/ were not produced differently) and two significantly different back vowels. The Quichua /ʊ/ was produced either like the Spanish /o/ *or* the Spanish /u/. The two different Quichua /u/ pronunciations are both presented and marked with '← or →'. The bottom left graph presents mean values for bilingual speakers that did not produce significantly different Quichua and Spanish vowels. Finally, the bottom right graph presents mean values for Spanish monolingual speakers.

and roughly half of the mid bilinguals distinguished Spanish and Quichua vowels in their production, whereas only one of the late bilinguals did. The other half of the mid bilinguals and the late bilinguals did not differentiate Quichua and Spanish vowels. They seemed to be using Quichua vowels in both Spanish and Quichua productions.

As shown in figure 6, participants who did not differentiate Quichua and Spanish vowels produced the Spanish front and back vowels in a non-native-like fashion: they seemed to be using their native Quichua vowels for Spanish words. On the other hand, those speakers who *did* make a difference between the Quichua and Spanish front and back vowels produced the Spanish vowels in a native-like way. The low vowels presented a different story. Those speakers who had separate Quichua and Spanish low vowels produced their Spanish vowel higher than Spanish monolinguals.

In the case of the front vowels, the simultaneous bilinguals maintained three separate vowels. Quichua /ɪ/ was significantly different from both Spanish /i/ and /e/ in terms of F_1 (height), F_2 (frontedness), or both. This differed from the early and mid bilinguals who equated Quichua /ɪ/ with Spanish /i/ and differentiated these two vowels from Spanish /e/ in terms of F_1 and sometimes also F_2.

For the back vowels, only one simultaneous bilingual maintained three categories. Most of the simultaneous, early, and some mid bilinguals had two separate vowels in terms of F_1. However, they varied in the ways Spanish and Quichua vowels mapped onto each other. Roughly half of them equated Quichua /ʊ/ with Spanish /u/ and the other half equated Quichua /ʊ/ with Spanish /o/.

The difference between the mappings of the Quichua and Spanish vowels for the front vowels as opposed to the back vowels is predicted by an acoustic investigation of the Spanish and Quichua vowels. The nature of the Spanish and Quichua vowel systems was exemplified by the vowels produced by Spanish monolinguals on the one hand, and mid and late Quichua-Spanish bilinguals who did not differentiate Quichua and Spanish vowels on the other hand. In the case of the front vowels, the Quichua /ɪ/ is produced between the Spanish /i/ and /e/, but closer to /i/. In the case of the back vowels, Quichua /ʊ/ is produced almost exactly intermediate between Spanish /u/ and /o/. These findings suggest that, during the acquisition of Spanish vowels, Quichua speakers perceptually equate Quichua /ɪ/ with Spanish /i/ and equate Quichua /ʊ/ with either Spanish /u/ or /o/. Of course, the cross-language mapping would have to be established empirically [see Strange et al., 1998; Guion et al., 2000; Best et al., 2001 for examples of such studies]. This equation or perceptual assimilation [see, e.g., Best, 1995] of Quichua and Spanish vowels could lead to merged categories that are shared by the two languages. Such categories would be equivalent to the diaphones proposed by Weinreich [1957] and incorporated into the Speech Learning Model of Flege [1995].

Turning to the low vowels, simultaneous, early, and some mid bilinguals have two separate vowels in terms of F_1: The Spanish /a/ is lower than the Quichua /a/ for these speakers. Note that, for (near-) monolingual speakers of the respective languages, the Spanish /a/ is lower than the Quichua /a/. This suggests that Quichua learners of Spanish are sensitive to the differences between the vowels of the two languages and establish a distinct, lower Spanish category. Again, a cross-language mapping study would need to be carried out to empirically test this hypothesis.

The results just reported suggest that the first-language system is important in mediating the acquisition of the second-language. A related question is: what effect does learning a second-language have on the first? Bilinguals who had distinct phonetic categories for the vowels of their two languages (as indicated by significantly different productions) were found to have native vowels that differed from bilinguals who did not have distinct phonetic categories for the vowels of their two languages.

Specifically, bilinguals who acquired a distinct Spanish /e/ (and equated Quichua /ɪ/ with Spanish /i/) produce their native Quichua /ɪ/ higher than bilinguals who had not acquired the Spanish vowel. In the case of the back vowels, the bilinguals who had acquired a distinct Spanish /o/ (and equated Quichua /ʊ/ with Spanish /u/) produced their native Quichua /ʊ/ higher than bilinguals who had either equated Quichua /ʊ/ with Spanish /o/ or had not acquired any distinct Spanish back vowels. For the low vowels, bilinguals who had distinct Quichua and Spanish vowels produced their Quichua /a/ higher than bilinguals who did not have distinct vowels for the two languages.

It seems that the two phonetic systems of bilinguals can influence each other. Importantly, this influence is not unidirectional. The language acquired second (in the case of early and mid bilinguals) can influence the language acquired first. Thus it appears that phonetic systems retain some measure of plasticity even after the first-language vowels have been acquired.

The production of the front vowels by the simultaneous bilinguals is also of great interest. These bilinguals were able to differentiate all three front vowels (Quichua /ɪ/, Spanish /i/, and Spanish /e/) in their productions. Thus, it seems that the simultaneous bilinguals were able to keep their phonetic categories independent from each other in a way that even early bilinguals could not. Importantly, the simultaneous bilinguals produced *both* Spanish and Quichua vowels in a way consistent with (near-) monolingual speakers of the two languages. The early and mid bilinguals, on the other hand, produced their second-language Spanish vowels in a way similar to Spanish monolinguals, but their native Quichua vowels in a way different from near-monolingual Quichua speakers. It seems that, in this case, only the simultaneous bilinguals were able to establish monolingual-like categories for both of their languages.

These results are also consistent with the proposal that different aspects of linguistic knowledge are differentially affected by delayed exposure to the second language [see, e.g., Weber-Fox and Neville, 1999]. In an early effect of age of acquisition, the simultaneous bilinguals were able to acquire more tightly packed vowels than the early or mid bilinguals. The early and mid bilinguals were able to acquire new vowels, but not able to partition the vowel space in the same fine-grained way. In a later effect of age of acquisition, many of early and mid bilinguals were able to acquire new vowels, whereas most of late bilinguals showed no signs of Spanish vowel acquisition.

How do these results help answer the question about merged or separate phonological systems in bilinguals? It would seem that there is evidence of merged vowel systems for the bilinguals investigated here. The finding that the acquisition of a second-language vowel conditions the movement of a first-language vowel suggests that the two systems are merged or at least interrelated. Movement in the Quichua vowels was found for early and mid bilinguals for the front vowels and for the simultaneous, early and mid bilinguals for the back and low vowels.

The finding that the simultaneous bilinguals maintained three vowel categories for the front vowels suggest that they are less likely to merge vowel categories cross-linguistically. In other words, they are more likely to establish separate categories for each language and less likely to have diaphones. This may be due to developmental differences between simultaneous and early bilinguals (here defined as acquiring the second language at 5–7 years old). Studies investigating infant development of perceptual discrimination have shown that a perceptual reorganization takes place within the first year of life. After about 10–12 months of age, the ability to discriminate phonetic contrasts not found in the child's linguistic environment decreases. It has been argued that this is not a loss in auditory capabilities, but rather a reorganization of perceptual space [e.g., Werker and Tees 1984; Werker, 1989; Werker and Pegg, 1992; Kuhl, 1991, 2000; Kuhl et al., 1992]. Following work by Nosofsky [1986], Pisoni et al. [1994] have proposed that the reorganization happens as perceptual dimensions are modified by experience. Namely, differences along attended dimensions expand and differences along unattended dimensions contract [see also Kuhl, 2000, for a discussion about the 'warping' of perceptual space].

If this is indeed the case, then the early bilinguals studied here had already tuned their system based on Quichua input and minimized the importance of perceptual dimensions underutilized in the Quichua vowel system. It seems that once the perceptual system was tuned to Quichua, a finer partitioning of the vowel space to accommodate Spanish vowels was not possible for even the early bilinguals. The finding that only the simultaneous bilinguals were able to partition the vowel space to allow three front vowels may be due to their exposure to both Quichua and Spanish vowels during the first year of life.

A parallel to these findings may be found in the work of Bosch et al. [2000] and Sebastián-Gallés and Soto-Faraco [1999] with Catalan-Spanish bilinguals. They found that delays in language exposure of less than 5 years adversely affected the ability of native Spanish, highly fluent bilinguals to perceive Catalan vowel and consonant contrasts not found in Spanish. It seems that early exposure to Spanish tuned their perceptual system, affecting their ability to distinguish nonnative perceptual contrasts, even in the case of early and extensive exposure.

Returning to the effect of the second-language on the first, the difference in production of Quichua vowels between those who have and have not learned Spanish vowels could be interpreted in three ways. The first interpretation is that the raising of the Quichua vowels is an effect of merging with the Spanish high vowels. Since the 1 Spanish vowels are produced higher than the Quichua vowels (due to the need to differentiate them from the mid vowels), the Quichua vowels come to be produced higher as well. On this view, the raising of the Quichua vowels is merely a reflection of the greater dispersion of the Spanish system as compared to the Quichua system. However, this account does not explain the results for the low vowels. Here the Quichua vowel was raised even though it was not merged with a Spanish vowel.

Another possibility is that the Quichua vowels are shifted for maximal differentiation from the Spanish vowels. In the case of the high vowels, the combined Spanish- 2 Quichua vowels would be dispersed with respect to the Spanish mid vowels. In the case of the low vowel, the Quichua vowel would be raised for sufficient discrimination between the Quichua and Spanish /a/. This possibility also has a problem. A maximal dispersion explanation would predict that the Spanish low vowel of the bilinguals would also lower to facilitate discrimination between the two low vowels. This was not found to be the case. In fact, the bilinguals with two low vowels produced Spanish vowels that were higher than monolingual Spanish speakers'.

A third possibility is that the bilingual participants in this study differentiated 3 the Quichua and Spanish vowels by shifting their Quichua systems to be produced systematically higher than the Spanish vowels /e/ /o/ and /a/. Such a general raising of the Quichua vowels relative to the Spanish vowels would seem to be the best explanation for the data presented here. This interpretation is consistent with the fundamental theoretical proposal of Adaptive Dispersion Theory. Namely, vowel inventories are adapted to constraints of perception and production. The result is *sufficient* discrimination among vowels in the system. In other words, the extent of the perceptual dispersion is weighted by the expense to the motor system [Lindblom and Maddieson, 1988].

In the data presented here, a lower-cost behavior entailed enlarging the vowel system in only one direction. The basic Quichua vowel space was raised to accommodate new Spanish vowels. The net effect is a combined vowel system that is expanded upwards in the height dimension relative to a monolingual Quichua system. No expansion downwards in the height dimension has occurred. Shifting the Quichua vowels upward created sufficient space for the Spanish vowels.

It is interesting to note that the Quichua vowels were all transformed in the same way, namely upward. This finding may be related to the proposal that languages can have different bases of articulation [see Bradlow, 1995] in which the vowels of one language are uniformly shifted in with respect to the vowels of another language. Perhaps the movement of the Quichua vowels is a unitary, systemic effect in which the whole Quichua system was transformed with respect to the Spanish system.

An important question is raised by the data presented here: are vowel systems plastic, dynamic environments that change within the lifespan? The results of the current study indicate that acquisition of a second language vowel can trigger reorganization even after the first language has been learned. The type of reorganization, however, depends on the age of acquisition. As mentioned above, even early (nonsimultaneous) learners are not able to partition vowel space in the way simultaneous learners are. However, child and pubescent learners are able to acquire new vowels and this can lead to changes in the native vowel systems. Older learners, on the other hand, did not acquire new vowels at all. Whether or not the vowel system would reorganize in postpubescent learners cannot be answered by these data. One would have to consider cases in which adults had learned new vowel categories.

The interpretation that first-language vowels are affected by the acquisition of second-language vowels is only possible if the early and mid bilinguals had Quichua vowels similar to the late bilinguals prior to learning Spanish. It is assumed here that this is the case, but a definitive answer could only be obtained by a longitudinal study. In such a study the vowels of children would be measured before going to school and after learning Spanish at school over, e.g., a 3 year period. As this is the most common acquisition pattern for children in the indigenous communities surrounding Otavalo, such a study would be quite possible.

A reasonable interpretation of the findings is that observations about typological universals, such as the inventories of vowel systems, have their origins in on-line processing and memory constraints, such as the need for sufficient discrimination. Perhaps these constraints are only effective in the early part of the lifespan. Or perhaps more exposure to and training of the second-language vowels (in the case of adults) would result in learning and eventual reorganization of the combined vowel system. In either case, the results from the study provide an example of linguistic systems being shaped by functional production/perception considerations. The addition of new vowels to a system results in the reorganization of that system to allow for sufficient discrimination between the vowels.

The study also confirms that fine-grained phonetic information is key to a rigorous, empirical investigation of typological and bilingual effects on vowel systems. Even though the usual transcription of the Quichua vowels is /i a u/, the so-called high vowels are lower and the low vowel higher than the vowels of a five-vowel system such as Spanish. Indeed, an investigation that only considered the structural position of the Quichua vowels as 'high' or 'low' would not have found the dispersion effects reported here. In addition, the fact that the back vowel was found to be lower than the front vowel in Quichua (as compared to the Spanish vowels), lines up well with a potential prediction of the Dispersion-Focalization Theory [Schwartz et al., 1997b]. Under some circumstances, the focalization component might predict a system with a more peripheral front than back vowel, as [i] has a higher focalization term than the other front vowels, whereas [u] has the same focalization term as other back vowels.

On a final note, let us consider the impact of bilingualism on the phonetic systems of the language(s) in a long-term contact situation. For the Quichua-Spanish case in Otavalo, the height of Quichua /ɪ/, /ʊ/, and /a/ could end up being higher than in previous generations due to the relatively new pattern of schooling in Spanish beginning around age 5. The early bilinguals studied here seem to have raised the Quichua /ɪ/, /ʊ/ and /a/ to allow for sufficient discrimination of Spanish /e/ and /o/ and /a/. As early bilingualism becomes more and more the norm, the Quichua vowels could raise in most or all Quichua speakers. A similar proposal was made for Canadian-French bilinguals by Caramazza and Yeni-Komshian [1974]. They suggested that differences in VOT between the French of Canada and France could be due to heavy contact with English in Canada.

The change to the Quichua vowel system, namely the raising of the Quichua vowels, could be expected in a generation's time. The pattern of early bilingualism is becoming almost universal as education in Spanish-speaking schools becomes more and more prevalent. The simultaneous and early bilinguals in this study were raised by late bilinguals, near-monolinguals, or even true monolinguals. So, we can assume that their Quichua input had the relatively lower vowels. However, the children currently being born, who are likely destined to be simultaneous and early bilinguals, will be raised largely by early bilinguals and will, hence, receive Quichua input with the relatively higher vowels. This could lead to a situation in which contact-induced change is brought about by the transmission of bilinguals' reorganized phonetic systems.

Appendix

Translation of the Quichua and Spanish words used in the study

Quichua	English Translation	Spanish	English Translation
hɪta	'skittish'	kita	's/he/it takes off'
rɪʃa	'I will go'	pika	's/he/it chops'
sɪsa	'flower'	pisa	's/he/it steps on'
sɪkʊ	'type of bird'	kito	'I take off'
sɪpʊ	'pleat/wrinkle'	piko	'I chop'
sɪsʊ	'an illness'	biro	'I turn'

Appendix (continued)

Quichua	English Translation	Spanish	English Translation
pɪkɪ	‘flea’	kite	‘take off!’ (2nd formal imp.)
sɪkɪ	‘butt’	pike	‘chop!’ (2nd formal imp.)
papa	‘potato’	bata	‘s/he/it beats’
pata	‘riverbank’	saka	‘s/he/it takes out’
taka	‘a blow/hit’	bara	length measurement (~ 83 cm)
hakʊ	‘let’s go’	bato	‘I beat’
rakʊ	‘fat’	sako	‘I take out’
rasʊ	‘snow’	baso	‘glass’
katɪ	expression used to call cattle	bate	‘beat!’ (2nd formal imp.)
takɪ	‘music’	sake	‘take out!’ (2nd formal imp.)
kʊsa	‘husband’	kuka	Nickname for Concepción
pʊka	‘red’	tusa	‘corn cob’
tʊta	‘night’	kura	‘priest’
kʊtʊ	‘goiter’	kuko	‘devil’
sʊkʊ	‘gray’	supo	‘s/he/it knew’
tʊpʊ	‘shawl pin’	buso	‘pullover (sweater)’
fʊtɪ	‘ripe fruit’	buke	‘ship’
sʊpɪ	‘fart’	supe	‘I knew’
		beta	‘s/he/it vetoes’
		seka	‘s/he/it dries’
		peka	‘s/he/it sins’
		beto	‘I veto’
		seko	‘I dry’
		seso	‘brain’
		bete	‘go!’ (2nd formal imp.)
		seke	‘dry!’ (2nd formal imp.)
		bota	‘s/he/it throws away’
		toka	‘s/he/it touches’
		kosa	‘thing’
		boto	‘I throw away’
		toko	‘I touch’
		koro	‘choir’
		bote	‘throw away!’ (2nd formal imp.)
		toke	‘touch!’ (2nd formal imp.)

Acknowledgements

This research was partially supported by a grant (DC00257) to the University of Alabama at Birmingham from the National Institutes of Health (National Institute on Deafness and Other Communication Disorders) and by a grant from the University of Oregon. Facilities and other support were also provided by the Instituto Otavaleño de Anthropología in Otavalo, Ecuador. Many thanks are extended to Jonathan Loftin and Yolanda Maldonado Quinchuquí for all their help in locating and running participants and to the participants themselves. The presentation of the work has benefited from comments, criticisms and suggestions by Jim Flege, Björn Lindblom, Jonathan Loftin, Eric Pederson, two anonymous reviewers and audiences at the Linguistic Society of America and the University of Oregon.

References

Anisfeld, M.; Anisfeld, E.; Semogas, R.: Cross-influences between the phonological systems of Lithuanian-English bilinguals. J. verbal Learn. verbal Behav. *8:* 257–261 (1969).

Anisfeld, M.; Gordon, M.: An effect of a German-language course on English. Lang. Speech *14:* 289–292 (1971).

Best, C.T.: Emergence of language-specific constraints in perception of non-native speech: a window on early phonological development; in de Boysson-Bardies, de Schonen, Jusczyk, MacNeilage, Morton, Developmental neurocognition: speech and face processing in the first year of life, pp. 289–304 (Kluwer, Dordrecht 1993).

Best, C.T.: A direct realist view of cross-language speech perception; in Strange, Speech perception and linguistic experience: issues in cross-language research, pp. 171–204 (York, Timonium 1995).

Best, C.T.; McRoberts, G.W.; Goodell, E.: Discrimination of non-native consonant contrasts varying in perceptual assimilation to the listeners' native phonological system. J. acoust. Soc. Am. *109:* 775–794 (2001).

Best, C.T.; McRoberts, G.W.; Sithole, N.M.: Examination of perceptual reorganization for nonnative speech contrasts: Zulu click discrimination by English-speaking adults and infants. J. exp. Psychol. hum. Perception Performance *14:* 345–360 (1988).

Birdsong, D. (ed.): Second language acquisition and the critical period hypothesis (Erlbaum, Mahwah 1999).

de Boer, B.: Self-organization in vowel systems. J. Phonet. *28:* 441–465 (2000).

Bohn, O.-S.; Flege, J.E.: The production of new and similar vowels by adult German learners of English. SSLA *14:* 131–158 (1992).

Bosch, L.; Costa, A.; Sebastián-Galles, N.: First- and second-language vowel perception in early bilinguals. Eur. J. cogn. Psychol. *12:* 189–221 (2000).

Bradlow, A.R.: A comparative acoustic study of English and Spanish vowels. J. acoust. Soc. Am. *97:* 1916–1924 (1995).

Caramazza, A.; Yeni-Komshian, G.H.: Voice onset time in two French dialects. J. Phonet. *2:* 239–245 (1974).

Caramazza, A.; Yeni-Komshian, G.H.; Zurif, E.B.; Carbone E.: The acquisition of a new phonological contrast: the case of stop consonants in French-English bilinguals. J. acoust. Soc. Am. *54:* 421–428 (1973).

Chee, M.; Tan, E.; Thiel, T.: Mandarin and English single word processing studies with functional magnetic resonance imaging. J. Neurosci. *19:* 3050–3056 (1999).

Cole, P.: Imbabura Quechua; in the Lingua Descriptive Studies series (North-Holland, Amsterdam 1982).

Crothers, J.: Typological and universals of vowel systems; in Greenberg, Universals of human language, vol. 2, Phonology, pp. 93–152 (Stanford University Press, Stanford 1978).

Disner, S.: Vowel quality: the relation between universal and language-specific factors. UCLA Working Papers Phonet. *58:* (1983).

Flege, J.E.: The production of 'new' and 'similar' phones in a foreign language: evidence for the effect of equivalence classification. J. Phonet. *15:* 47–65 (1987).

Flege, J.E.: Second-language speech learning: theory, findings and problems; in Strange, Speech perception and linguistic experience: issues in cross-language research, pp. 233–273 (York, Timonium 1995).

Flege, J.E.; Eefting, W.: Production and perception of English stops by native Spanish speakers. J. Phonet. *15:* 67–83 (1987a).

Flege J.; Eefting, W.: Cross-language switching in stop consonant perception and production by Dutch speaker of English. Speech Commun. *6:* 185–202 (1987b).

Flege, J.; Hillenbrand, J.: Limits on phonetic accuracy in foreign language speech production. J. acoust. Soc. Am. *76:* 708–721 (1984).

Fujisaki, H.; Kawashima, T.: The roles of pitch and the higher formants in the perception of vowels. IEEE Trans. Audio Electroacoust. *16:* 73–77 (1968).

Grosjean, F.: Life with two languages (Harvard University Press, Cambridge 1982).

Guion, S.G.; Flege, J.E.; Akahane-Yamada, R.; Pruitt, J.C.: An investigation of current models of second language speech perception: The case of Japanese adults' perception of English consonants. J. acoust. Soc. Am. *107:* 2711–2724 (2000).

Haugen, E.: Bilingualism in the Americas: a bibliography and guide for research (Publications of the American Dialect Society, No. 26, 1957).

Hazan, V.L.; Boulakia, G.: Perception and production of a voicing contrast by French-English bilinguals. Lang. Speech *36:* 17–38 (1993).

Honikman, B.: Articulatory settings; in Abercrombie, In Honour of Daniel Jones, pp. 73–84 (Longmans, London 1964).

Illes, J.; Francis, W.; Desmond, J.; Gabrieli, J.; Glover, G.; Poldrack, R.; Lee, C.; Wagner, A.: Convergent cortical representation of semantic processing in bilinguals. Brain Lang. *70:* 347–363 (1999).

Jongman, A.; Fourakis, M.; Sereno, J.A.: The acoustic vowel space of modern Greek and German. Lang. Speech *32:* 221–248 (1989).

Kim, K.; Relkin, N.; Lee, K.-M.; Hirsch, J.: Distinct cortical areas associated with native and second languages. Nature *388:* 171–174 (1997).

Kuhl, P.K.: Human adults and human infants show a 'perceptual magnet effect' for prototypes of speech categories, monkeys do not. Perception Psychophysics *50:* 93–107 (1991).

Kuhl, P.K.: A new view of language acquisition. Proc. Nat. Acad. Sci. USA *97:* 11850–11857 (2000).

Kuhl, P.K.; Williams, K.A.; Lacerda, F.; Stevens, K.N.; Lindblom, B.: Linguistic experience alters phonetic perception in infants by 6 months of age. Science *255:* 606–608 (1992).
Lado, R.: Linguistics across cultures: applied linguistics for language teachers (University of Michigan Press, Ann Arbor 1957).
Liljencrants, J.; Lindblom, B.: Numerical simulations of vowel quality systems: the role of perceptual contrast. Language *48:* 839–862 (1972).
Lindblom, B.: Phonetic universals in vowel systems; in Ohala, Jaeger, Experimental phonology, pp. 13–44 (Academic Press, New York 1986).
Lindblom, B.: Systemic constraints and adaptive change in the formation of sound structures; in Hurford, Studdert-Kennedy, Knight, Approaches to the Evolution of Language: Social and Cognitive Bases, pp. 242–264 (Cambridge University Press, Cambridge 1998).
Lindblom, B.; Engstrand, O.: In what sense is speech quantal? J. Phonet. *17:* 107–121 (1989).
Lindblom, B.; MacNeilage, P.F.; Studdert-Kennedy, M.: Self-organizing processes and the explanation of phonological universals; in Butterworth, Comrie, Dahl, Explanations for language universals, pp. 181–203 (Mouton, Berlin 1984).
Lindblom, B.; Maddieson, I.: Phonetic universals in consonant systems; in Hyman, Li, Language, speech, and mind, pp. 62–78 (Routledge, New York 1988).
Mack, M.: Phonetic transfer in a French-English bilingual child; in Nelde, Attitudes and language conflict, pp. 107–124 (Duemmler, Bonn 1990).
Maddieson, I.: Patterns of sounds. Cambridge studies in speech science and communication (Cambridge University Press, Cambridge 1984).
Mendez, A.: Production of American English and Spanish vowels. Lang. Speech *25:* 191–197 (1982).
Nearey, T.: Static, dynamic, and relational properties in vowel perception. J. acoust. Soc. Am. *85:* 2088–2113 (1989).
Nosofsky, R.M.: Attention, similarity, and the identification-categorization relationship. J. exp. Psychol.: Gen. *115:* 39–57 (1986).
Peng, S.-H.: Cross-language influence on the production of Mandarin /f/ and /x/ and Taiwanese /h/ by native speakers of Taiwanese Amoy. Phonetica *50:* 245–260 (1993).
Perani, D.; Dehaene, S.; Grassi, F.; Cohen, L.; Cappa, S.F.; Duboux, E.; Fazio, F.; Mehler, J.: Brain processing of native and foreign languages. NeuroReport *7:* 2439–2444 (1996).
Pisoni, D.; Lively, S.; Logan, J.: Perceptual learning of nonnative speech contrasts: implication of theories of speech perception; in Goodman, Nusbaum, The development of speech perception: the transition from speech sounds to spoken words, pp. 121–166 (MIT Press, Cambridge 1994).
Sancier, M.L.; Fowler, C.A.: Gestural drift in a bilingual speaker of Brazilian Portuguese and English. J. Phonet. *35:* 421–436 (1997).
Schouten, M.: Imitation of synthetic vowels by bilinguals. J. Phonet. *5:* 273–283 1977.
Schwartz, J.-L.; Boë, L.-J.; Vallée, N.; Abry, C.: Major trends in vowel system inventories. J. Phonet. *25:* 233–253 (1997a).
Schwartz, J.-L.; Boë, L.-J.; Vallée, N.; Abry, C.: The dispersion-focalization theory of vowel systems. J. Phonet. *25:* 255–286 (1997b).
Sebastián-Galles, N.; Soto-Faraco, S.: Online processing of native and non-native phonemic contrasts in early bilinguals. Cognition *72:* 111–123 (1999).
Stevens, K.: On the quantal nature of speech. J. Phonet. *17:* 3–45 (1989).
Stockwell, R.; Bowen, J.: The Sounds of English and Spanish (University of Chicago Press, Chicago 1965).
Strange, W.; Akahane-Yamada, R.; Kubo, R.; Trent, S.; Nishi, K.; Jenkins, J.: Perceptual assimilation of American English vowels by Japanese listeners. J. Phonet. *26:* 311–344 (1998).
Swadesh, M: Observations of pattern impact on the phonetics of bilinguals; in Spier, Hallowell, Newman, Language, culture, and personality: essays in memory of Edward Sapir, pp. 59–65 (Sapir Memorial Publication Fund, Menasha 1941).
Traunmüller, H.: Analytical expression for the tonotopic sensory scale. J. acoust. Soc. Am. *88:* 97–100 (1990).
Wardaugh, R.: The contrastive analysis hypothesis. TESOL Q. *4:* 123–130 (1970).
Weber-Fox, C.; Neville, H.: Functional neural subsystems are differentially affected by delays in second language immersion: ERP and behavioral evidence in bilinguals; in Birdsong, Second language acquisition and the critical period hypothesis, pp. 23–38 (Erlbaum, Mahwah 1999).
Weinreich, U.: Languages in contact (Mouton, The Hague 1974) (Publication of the Linguistic Circle of Yew York, New York 1953).
Weinreich, U.: On the description of phonetic interference. Word *13:* 1–11 (1957).
Werker, J.F.: Becoming a native listener. Am. Scient. *77:* 54–59 (1989).
Werker, J.F.; Pegg, J.E.: Infant speech perception and phonological acquisition; in Ferguson, Menn, Stoel-Gammon, Phonological development: models, research, implications, pp. 285–311 (York, Timonium 1992).
Werker, J.F.; Tees, R.C.: Cross-language speech perception: evidence for perceptual reorganization during the first year of life. Infant Behavior Dev. *7:* 49–63 (1984).
Williams, L.: The perception of stop consonant voicing by Spanish-English bilinguals. Perception Psychophysics *21:* 289–297 (1977).

Williams, L.: The modification of speech perception and production in second-language learning. Perception Psychophysics *26:* 95–104 (1979).
Winkler, I.; Kujala, T.; Tiitinen, H.; Sivonen, P.; Alku, P.; Lehtokoski, A.; Czigler, I.; Csépe, V.; Ilmoniemi, R.J.; Näätänen, R.: Brain responses reveal the learning of foreign language phonemes. Psychophysiology *36:* 638–642 (1999).
Yang, B.: A comparative study of American English and Korean vowels produced by male and female speakers. J. Phonet. *24:* 245–261 (1996).