Journal of Phonetics 43 (2014) 26–37

Contents lists available at ScienceDirect

Journal of Phonetics

journal homepage: www.elsevier.com/locate/phonetics

Phonetic consequences of dynamic cross-linguistic interference in proficient bilinguals

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ARTICLE INFO

Article history:
Received 3 July 2013
Received in revised form
20 January 2014
Accepted 24 January 2014
Available online 13 February 2014

ABSTRACT

This study investigates the production and perception of a Catalan-specific vowel contrast by a group of highly proficient, early-onset Catalan–Spanish bilinguals. Spanish has a mid-back vowel (/o/), while Catalan has two (/o/, /ɔ/). Most importantly, the study manipulates the amount of activation of the Spanish lexicon in two experimental sessions to examine the transient aspects of cross-linguistic phonetic interference. In the first (*unilingual*) session speakers produce words in one of their languages only, Catalan. In the second (*bilingual*) session bilinguals produce words in both of their languages, in random order. The acoustic analysis consists of comparing the height of Catalan [o] and [ɔ] in the two sessions, as well as verifying whether bilinguals possess separate categories for these two vowels in the first place. The results show that the presence (*vs.* absence) of Spanish words in the task affects the realization of the two Catalan mid-back vowels by bilinguals. In particular, the two Catalan vowels become slightly more similar to Spanish [o] when they are pronounced alongside this vowel.

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1. Introduction

People who learn a second language are highly likely to retain a nonnative accent in that language even after years of practice (Flege, Yeni-Komshian, & Liu, 1999; Oyama, 1976; Yeni-Komshian, Flege, & Liu, 2000). The characteristics of the nonnative accent are typically due to the native language, so that the accents of learners who share a native language differ from native norms in systematic, predictable ways. Interestingly, the influence of the two languages appears, under some circumstances, to be mutual—speakers who learn a new language might experience some influence of their second language on their first one, especially if they seldom use their native language or if they learned their second language in childhood (Flege, Yeni-Komshian et al., 1999; Guion, 2003). The influence of a bilingual's two languages, either uni- or bi-directional, has often been referred to as "interference." The present study explores the nature of cross-linguistic (or interlingual) phonetic interference in fluent bilinguals.

The phonetic effects of interlingual interference are well documented, and they go beyond ratings of accentedness. For instance, Flege (1987) compared the acoustics of stop consonants in two groups of French–English bilinguals with those of English and French monolinguals. Voice onset times (VOTs) of English and French voiceless stops differ in that these consonants are unaspirated (i.e., have a short-lag VOT) in French while they are aspirated (i.e., have a long-lag VOT) in English. In this study, VOTs of English /t/ were longer when produced by English monolinguals than when French–English bilinguals produced them; VOTs of French /t/ were shorter in the speech of monolingual controls than in that of English–French bilinguals. In sum, the difference between monolinguals and bilinguals was in the direction of the first language of the bilinguals. A second important finding of this study was that the French of monolingual controls and that of native French speakers who had learned English as a second language also differed—VOTs of French /t/ were longer in the bilinguals than in the controls. Also, VOTs of English /t/ were shorter for the native English speakers who had learned French as a second language than for the English monolingual controls. Therefore, the phonetic characteristics of the first language had apparently been altered by second-language experience, and this alteration was in the direction of the sounds of the second language. This study, thus, documented first-to-second as well as second-to-first interlingual phonetic interference. More recent studies complemented these findings with early-learner and simultaneous bilingual populations (Fowler, Sramko, Ostry, Rowland, & Hallé, 2008; Sundara, Polka, & Baum, 2006).

1.1. Dynamic phonetic interference

Grosjean (2011) distinguishes between two types of cross-linguistic interference in bilingualism—static and dynamic interference. According to Grosjean, linguistic features that result from static interference are "permanent traces of one language (La) on the other (Lb), … are linked to the person's *competence* in Lb, and can involve all levels of linguistic *knowledge*" (pp. 14–15; italics not in original source). An example of static

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0095-4470/$ - see front matter Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.wocn.2014.01.004

interference provided by Grosjean is the phenomenon of foreign accent discussed above—an accent is, according to Grosjean, an unavoidable characteristic of the speech of a second-language learner. On the other hand, features that result from dynamic interference are

> "ephemeral intrusions of the other language, as in the case of the accidental slip on the stress pattern of a word due to the stress rules of the other language, the one time use of a word from the other language (but pronounced in the language being spoken), the momentary use of a syntactic structure taken from the other language, etc. Dynamic interferences are linked to *processing* and have to be accounted for by *encoding* mechanisms" (p. 15; italics not in original source).

Paradis (1993) makes a similar distinction—that between competence and performance interference. In competence interference, a feature from one language is incorporated into the knowledge (i.e., grammar) of a bilingual's other language. In performance interference, on the other hand, a feature from one language is inadvertently introduced into the other language without affecting knowledge or representation—it occurs in processing as a result of the simultaneous activation of the two languages. Notice that both frameworks—Grosjean's and Paradis'—make use of the traditional distinction between representation and processing. This dichotomy has been fundamental in cognitive science research for several decades (Neisser, 1967). The dichotomy explicitly distinguishes between stable or long-term mental representations (i.e., linguistic knowledge) and the transient operations that lead to the activation and manipulation of these representations during speech production and comprehension; in other words, it distinguishes between "the nature of segmental and lexical representations in long-term memory and the processes that access those representations" (Goldinger, 2007, p. 49). (The terms 'static' and 'dynamic' are perhaps infelicitous. Few researchers would consider interlingual interactions to be static, even at the level of lexical or categorical representations; they are, almost by definition, dynamic in that they are modulated by experience and they change throughout the lifespan, as it occurs in second language learning. Henceforth we refer to these concepts as 'long-term' *vs.* 'short-term' or 'transient' interference.)

The vast majority of work on interlingual or cross-linguistic phonetic influences in bilingualism does not explicitly distinguish between long-term and transient interference. Albeit implicitly, most studies explore features that are attributed to long-term interference. Thus, bilinguals are often compared with monolingual controls, and the differences between these tend to be attributed to relatively stable differences in representation—leading to long-term differences in behavior—not to transient, circumstantial, experiment-induced processes. These studies often take a "between-subjects" approach, comparing speakers with other speakers. However, the fact is that bilinguals often fluctuate between communicative situations in which they use only one of their languages and situations in which they use both, and this presumably affects the patterns and consequences of cross-linguistic interference. This would suggest that "within-subjects" experimental designs—designs that compare the behavior of the same participants in different communicative situations, social environments or experimental conditions—might be able to provide relevant information for our understanding of the nature of interlingual interactions. Do interference patterns differ as a function of communicative or social environments? If they do, this would imply that some of these interference elements are highly transient, circumstantial, performance-driven. In particular, the present study addresses the following questions: do the acoustic–phonetic consequences of interlingual interference differ as a function of the communicative environment or situation?

The bilingual language modes framework argues explicitly that bilinguals may see their languages increase or decrease in activation level as a function of the needs of the communicative context in which they find themselves (Grosjean, 1982, 1989, 1998b, 1998a, 2001, 2008). On one hand, bilinguals may find themselves in a *unilingual mode*, such as when conversing with monolingual speakers. In this mode, the transient interference of the other language is relatively low, as the language is not activated, or it is only slightly so. On the other hand, speakers may be in a *bilingual mode*. This happens in situations that simultaneously activate the two languages, such as when all speakers in a conversation are bilingual and they code-switch constantly. By hypothesis, when bilinguals are in such a mode, the effects or consequences of transient interference should be much higher than in a unilingual mode presumably because both languages are in competition. These modes are endpoints, and communicative circumstances differ gradiently rather than discretely.

Phonetic studies of the bilinguals' language modes are rather scarce. Most studies in this line of research induce speakers into a unilingual mode (in their two languages), and then they compare their behavior cross-linguistically. These studies typically ask whether the phonetic behavior of bilinguals differs in situations that prime one language *vs.* the other. By doing so, these studies implicitly investigate the extent of long-term interlingual interference. For instance, a series of studies examined whether bilinguals have separate phonetic boundaries for phonemic contrasts shared by their two languages (e.g., /p/–/b/), but whose phonetic boundary differs in the two languages (Bohn & Flege, 1993; Caramazza, Yeni-Komshian, Zurif, & Carbone, 1973; Elman, Diehl, & Buchwald, 1977; Flege & Eefting, 1987; García-Sierra, Diehl, & Champlin, 2009; Hazan & Boulakia, 1993; Williams, 1977). In languages such as English and German, the /p/–/b/ contrast is, phonetically, one between aspiration (long-lag VOT) and no aspiration (short-lag VOT). In languages such as Spanish or French, the /p/–/b/ contrast is phonetically manifested as the difference between a voiceless unaspirated stop (short-lag VOT) and a prevoiced stop (lead VOT). In some of these studies, bilinguals classify the same stimuli, from a resynthesized or synthetic acoustic continuum that includes prevoiced and aspirated stops on the two extremes, in two linguistic contexts (e.g., English *vs.* Spanish). While an effect of language context on perception may be very small (Flege & Eefting, 1987; Hazan & Boulakia, 1993), or may not be detected at all (Caramazza et al., 1973; Williams, 1977), the effects of language context on production are robust (Antoniou, Best, Tyler, & Kroos, 2010; Magloire & Green, 1999; Sundara et al., 2006). In fact, Antoniou et al. (2010) and Magloire and Green (1999) found that their bilingual participants did not differ (or very little) from monolingual controls, suggesting that these speakers did not experience any type of interlingual phonetic interference—they could switch discretely between their two languages.

Only a handful of studies have purposed to induce bilingual speakers into a bilingual mode. In these studies, experimental contexts are manipulated in an attempt to increase the effects of transient interlingual interference. Thus, these studies compare bilinguals' behaviors when in a unilingual mode with those when in a bilingual mode. Are the effects of interlingual interference stronger in a bilingual than in a unilingual mode? Is there evidence for transient interlingual interference; that is, evidence beyond that for long-term interference? Typically, these studies have investigated the effects of linguistic code-switching on speech production (Antoniou, Best, Tyler, & Kroos, 2011, 2012; Bullock, Toribio, González, & Dalola, 2006; González, 2012; Grosjean & Miller, 1994; Toribio, Bullock, Botero, & Davis, 2005). Grosjean and Miller (1994), for instance, compared the acoustic characteristics of voiceless consonants produced by French–English bilinguals in three contexts: French, English and code-switched. In code-switched context, carrier sentences were in French but speakers were instructed to read target words in English. In the other contexts, carrier sentences and target words were in the same language. There was no effect of code-switching—VOTs in English words in English sentences were similar to those in English words in French sentences (i.e., code-switched environments). This suggested that bilinguals can switch between languages at no cost; that is, no evidence was found for the existence of transient interference. It could not be detected whether these bilinguals had any long-term patterns of interference, but the fact that their behavior did not differ across conditions suggested that simultaneously processing two languages had no extra effect.

Antoniou et al. (2011) measured English and Greek voiceless-stop VOTs as produced by English-dominant (but native Greek) Greek–English bilinguals, and English and Greek monolinguals. There were two experimental conditions: "same language" *vs.* "different language" contexts. In "same language" environments, target syllables and carrier sentences were written in the same script (either Latin or Greek); in "different language" contexts, target syllables and carrier sentences were in different scripts (e.g. "say $\pi\alpha$ again"). This study found that English VOTs were shorter in "different language" (i.e., code-switched) environments than in "same language" (i.e., unilingual) English environments. However, Greek VOTs were unaffected by the experimental condition. These findings, unlike those in Grosjean and Miller (1994), suggest that the simultaneous activation of two phonetic subsystems in one experimental session triggers transient interference, and that the effects of transient interference are robust on the second language but not on the first one.

Other recent studies of the phonetic consequences of code-switching have typically found some evidence for the effects of transient interference during speech production (Bullock et al., 2006; González, 2012; Toribio et al., 2005). Taken together, these findings suggest that the effects of transient interference are not robust or systematic—they are found for some consonants, but not others; or they are found in some languages, but not others; or they are found in some sentence positions but not others. More research is needed on the effects of transient interference on phonetic behavior before we can begin to grasp how these should, or should not, impact our current understanding of phonetic cross-linguistic interactions in bilinguals.

Consider the important findings reported in the pioneering study of Sancier and Fowler (1997). In this study, a Portuguese–English bilingual was recorded in her two languages in two occasions. The first recording took place after a 4-month stay in the United States (an English environment); the second recording occurred after a 2.5-month stay in Brazil (a Portuguese environment). VOTs of voiceless stops were measured. English and Portuguese VOTs differed in both experimental occasions, demonstrating language specificity in this particular speaker. However, VOTs *in both languages*, although different, were longer in the English environment than in the Portuguese environment. Therefore, it appears that a transient increase in the use of one of her two languages affected the acoustic characteristics of the sounds of both languages. This is evidence of relatively long-term dynamic interference. Can transient phonetic interference be revealed by short-term manipulations of language activation in the laboratory?

The effects of the bilingual language modes have been recently investigated using a research paradigm borrowed from the psycholinguistic literature on lexical processing. Olson (2013) measured the acoustic characteristics (VOT) of Spanish and English voiceless stops in a language-switching, cued picture-naming task. There were two types of experimental blocks, unilingual and bilingual. In the *bilingual* block, the language switching task consisted of an equal number of words in both languages (50% Spanish, 50% English). The *unilingual* blocks contained more words of one of the languages than of the other (95% English, 5% Spanish; 5% English, 95% Spanish). Interestingly, there were no short-term, transient effects (no switch *vs.* stay effects) in the bilingual block, which suggested that phonetic switching was automatic for these bilinguals, at least in this context. However, there were longer-term transient effects: VOTs of Spanish and English voiceless stops were more similar to each other in the bilingual block in general than across blocks. The present study extends Olson's study by examining a language-specific vowel contrast (rather than VOTs in voiceless stops) in a different bilingual population, and it also uses a different research paradigm.

1.2. The present study

1.2.1. Rationale

The present study investigates the acoustic characteristics of two Catalan vowels (a Catalan-specific vowel contrast) as produced by early, highly proficient Catalan–Spanish bilinguals from Majorca, Spain. The crucial manipulation in this study is that the Catalan target words are produced in two experimental sessions. In the first experimental session, only Catalan is used. In the second one, the same bilinguals produce equal numbers of Catalan and Spanish target words in random order. The two sessions in the study are designed to manipulate the strength of the activation of both languages—Catalan is similarly activated in both sessions while Spanish is activated in only one of them. In the terminology of the Bilinguals' Language Modes framework, the first session creates the environment for a *unilingual* mode while the second one induces speakers into a *bilingual* mode.

A secondary goal of the study is to investigate the perception of the same Catalan-specific vowel contrast by the Catalan–Spanish bilinguals. An examination of perception patterns allows for a better understanding of cross-linguistic interference in this group of bilingual speakers. Sebastián-Gallés and Soto-Faraco (1999) explored the perception of several Catalan-specific phonemic contrasts, including this one, by a group of Catalan–Spanish bilinguals from Barcelona, Spain. The authors found that Spanish-dominant, but not Catalan-dominant, bilinguals experienced severe limitations in the efficiency of their on-line processing abilities of these Catalan sounds. The present study includes an examination of perceptual discrimination in order to better understand the phonetic and phonological behavior (i.e., patterns of long-term interference or interference at the level of phonemic representation) in the specific sample of participants recruited for the study. In this way, we can make more explicit comparisons between the bilinguals examined here and those examined in other studies on the bases of phonetic aspects researched in other studies (e.g., perceptual discrimination of vowel contrasts). When a basis for comparison with other studies is established, we shall be able to draw more informed conclusions regarding the aspects that are novel in the present study: the effects of language modes on speech production.

1.2.2. The sound variable

The present study analyzes the acoustics of a Catalan-specific mid-back vowel contrast, /o/–/ɔ/. In particular, the Majorcan Catalan dialect is examined. Majorcan Catalan has eight vowel categories, which contrast only in a stressed position: /i, e, ɛ, ə, a, ɔ, o, u/. The vowel inventory is categorically reduced to four vowels in an unstressed position. The two Catalan mid-back vowel phonemes are categorically reduced to [o] in the unstressed position. For instance, when a stress-bearing suffix is added to the root, both /o/ and /ɔ/ surface as [o]: *gota* 'drop' [ˈgo.tə] becomes *goteta* 'little drop' [go.ˈtə.tə] and *dona* 'woman' [ˈdɔ.nə] becomes *doneta* 'little woman' [do.ˈnə.tə]. In other words, while /o/ and /ɔ/ are contrastive in Majorcan Catalan, and thus phonemic, the contrast is neutralized in the unstressed position. This is explained to highlight that the Majorcan Catalan /o/–/ɔ/ contrast is not as robust, across the lexicon, as other vowel contrasts in the language are (e.g., /a/–/i/, since these two vowels are not involved in any phonological alternation); this may affect the learnability of this contrast by second language learners.

Spanish has only one phonemic mid-back vowel, /o/. Catalan and Spanish share a large number of cognates. Interestingly, some Catalan words with [o] correspond to Spanish cognates with [o] in the same position, and some Catalan words with [ɔ] correspond to Spanish cognates with [o]—many, however, correspond to Spanish cognates with [u̯e]. For instance, Spanish *gota* 'drop' [ˈgo.ta] and *cosa* 'thing' [ˈko.sa] correspond to

Catalan *gota* 'drop' [ˈgo.tə] and *cosa* 'thing' [ˈkɔ.zə] (from Latin GUTTA and CAUSA, respectively), but Catalan *roda* 'wheel' [ˈrɔ.ðə] corresponds to Spanish *rueda* [ˈrue̯.ða] (from Latin ROTA). This fact is explained to highlight that the purported similarities, for Catalan–Spanish bilinguals, between the two Catalan mid-back vowels, on one hand, and Spanish /o/, on the other, go beyond the acoustic realm and are further reinforced by lexical connections.

Recasens and Espinosa (2006, 2009) recently analyzed the vowel systems of several Catalan dialects. Among other findings, these authors reported that Majorcan Catalan [ɔ] was much lower (i.e., had a higher first-formant frequency) than that of most of the other Catalan dialects, thus inducing a very robust contrast with [o]. In their data, Majorcan Catalan [ɔ] was almost as low as [a].

Simonet (2011) analyzed the Majorcan Catalan /o/–/ɔ/ vowel contrast as produced by Catalan- and Spanish-dominant bilingual speakers. Simonet found that the acoustic difference, with respect to first-formant frequencies, between [o] and [ɔ] was indeed robust for the Catalan-dominant bilinguals. Spanish [o] did not differ from Catalan [o] for this group; therefore, these speakers possessed two mid-back acoustic categories, one for Catalan and Spanish [o] and one for Catalan [ɔ]. The Spanish-dominant bilinguals, on the other hand, merged both Catalan vowels—they did not produce the contrast in read aloud speech. Interestingly, the merged Catalan vowel category produced by the Spanish-dominant speakers differed slightly (in the frequency of their first formant) from their Spanish [o]; thus, this group of bilinguals possessed two vowels in their inventory, one for Catalan and one for Spanish.

The present study goes beyond Simonet (2011) in two ways: (i) it investigates the perceptual discrimination patterns involving the Catalan-specific /o/–/ɔ/ contrast of Catalan- and Spanish-dominant bilinguals, thus complementing the previous production study; and (ii) it analyzes the production of this particular contrast in two different communicative settings with the goal to better understand the nature of Catalan–Spanish sound system interactions in this group of early sequential bilinguals.

2. Method

2.1. Participants

A total of 59 people, 44 females, responded to fliers distributed on the campus of the University of the Balearic Islands, on Majorca. The study focuses exclusively on the female volunteers due to the unbalanced numbers of male and female respondents, which would make it impossible to consider "gender" a factor if both were to be included. The fact that all the selected participants are female minimizes the effects of vocal tract-size differences caused by sex on the acoustics of vowels; this, in turn, reduces the need for inter-speaker acoustic normalization procedures (Adank, Smits, & van Hout, 2004).

There were two experimental sessions. Only 35 of the 44 female volunteers came back to the second session, which means that 9 volunteers were excluded. Five of the remaining 35 female participants were excluded due to various reasons, such as having learned a third language during childhood, having a tongue piercing, or suffering from nasal congestion at the time of testing. The present study focuses on the remaining 30 females. All of these female participants were early-onset Catalan–Spanish bilinguals born and raised on the island of Majorca, and they were in their early twenties.

The 30 participants responded to a language questionnaire. The chosen questionnaire was the Bilingual Language Profile or BLP (Birdsong, Gertken, & Amengual, 2012), which has four main components: history, usage, proficiencies, and attitudes. Each component has a series of questions to which participants respond by providing numerical answers. The questions are asked regarding the two languages of the bilingual. Two scores are computed, one for each language. In the present case, the Spanish score was subtracted from the Catalan score. A positive final score indicates dominance in Catalan while a negative score indicates dominance in Spanish. The score limits of the questionnaire are −218 and 218; that is, −218 would be indicative of Spanish monolingualism and 218 would be indicative of Catalan monolingualism. With regard to the individual components, their limits are −120 to 120 for the *history* component, −50 to 50 for the *use* component, −24 to 24 for the *proficiency* component and −24 to 24 for the *attitudes* component. A score of zero represents balanced bilingualism.

The participants were assigned to groups with the help of the questionnaire scores. Ten bilinguals obtained positive dominance scores, and they were assigned to the Catalan-dominant group (Group 1, G1). A second group (Group 2, G2) was formed with the 10 Spanish-dominant participants with negative scores closer to zero. These Spanish-dominant bilinguals are closer to being "balanced" bilinguals. The remaining 10 participants were assigned to Group 3 (G3). These participants have negative BLP scores, far from zero, which suggests that they are more strongly dominant in Spanish than the speakers in G2. Table 1 provides the final dominance scores as well as the component scores as a function of speaker group.

The proficiency scores reveal that the participants consider themselves highly proficient in both languages—notice that their scores are close to zero. Interestingly, their attitudes towards their two languages are similar. The burden of the difference among the three groups is carried by their patterns of daily language use, as well as whether they grew up in Catalan- or Spanish-dominant homes. Also, since the participants in this study are all college students, it is perhaps important to highlight that the University-entrance exams at the University of the Balearic Islands require that students demonstrate their knowledge of both Spanish and Catalan at the same level that a monolingual speaker of Spanish on the Spanish mainland would have to demonstrate knowledge of Spanish to enter a public university.

The same 30 participants carried out the two experiments in this study, perception and production.

2.2. Perception experiment

The perception study is based on the categorical AXB discrimination task (Flege, 2003; Flege, MacKay, & Meador, 1999; Guion, Flege, Akahane-Yamada, & Pruitt, 2000). All three stimuli in each triad were acoustically different—they had been recorded by three different talkers. Some trials

Table 1
Results of the Bilingual Language Profile (Birdsong et al., 2012) administered to 30 Catalan–Spanish bilingual participants. Scores are provided as a function of group (G1, G2, G3); group averages and standard deviations (in parentheses) are shown. The table provides the final dominance scores, as well as the history, use, proficiency and attitudes scores. Positive digits indicate a leaning towards Catalan; negative digits indicate a preference for Spanish.

Group	Total	History	Use	Proficiency	Attitudes
G1	22 (27)	20 (22)	22 (16)	0 (2)	3 (2)
G2	−46 (17)	−13 (15)	−28 (12)	−3 (3)	−2 (3)
G3	−91 (16)	−28 (16)	−46 (3)	−5 (2)	−8 (5)

played stimuli from two different phonemic categories (/o/, /ɔ/) and some played stimuli from only one phonemic category. The experiment was an *oddity* task—listeners had to detect the "odd" stimulus in the triad rather than the "matching" one.

2.2.1. Design and procedure

The listeners carried out the task twice, once at the end of the first session and once at the end of the second session. The results of the two tasks are pooled—they are considered repetitions. There were a total of 96 trials in each session, 192 trials in total. Half of the trials in the task were "change" trials—stimuli of two different phonemic categories were played—and half were "same" trials—the three stimuli belonged to the same phonemic category. In change trials, listeners had to detect which of the stimuli was the "odd one out". Change trials could be of the form ABB, BAA, AAB and BBA; that is, only the first or the last stimulus in the triad could be the "odd" stimulus. There were 12 different trials for each of the four "change"-trial combinations: $12 \times 4 = 48$. There were 24 AAA and 24 BBB trials in the task. The three stimuli in each trial were acoustically different, as they each belonged to a different talker. The three talkers' stimuli appeared equally in the first, second or third position in the triad.

The stimuli were played over closed-circumaural headphones (AKG K 240 mkII), which were connected to a MOTU Ultralite mk3 Firewire audio interface, responsible for digital-to-analog conversion. The listeners introduced their responses by interacting with a numeric keyboard connected to a laptop computer running Praat. The listeners pressed "0" if they considered the three stimuli as members of the same phonemic category; they pressed "1" if they thought the first stimulus did not belong to the category to which the other two belonged; they pressed "3" if they thought that the third stimulus was the "odd one out".

2.2.2. Stimuli

Three Catalan-dominant male talkers were recorded producing the Catalan target words. These male talkers had been brought up in Catalan-speaking homes and reported to use Catalan much more frequently than Spanish in their daily lives. The target Catalan phonemic contrast was recorded in a Catalan lexical minimal pair—*dones* [ˈdɔ.nəs] 'women', *dónes* [ˈdo.nəs] '(you) give'. The stimuli were recorded in short meaningful sentences—*dones i nines* 'women and little girls' and *dónes i compres* '(you) give and (you) buy.'

The target stimuli (*dones*, *dónes*) were cut from their carrier sentences, they were archived as separate sound files, and they were normalized for average intensity. Catalan has a phonological rule according to which word-final /s/, when followed by a vowel-initial word, surfaces as [z]. Thus, /ˈdɔ.nəs/ becomes [ˈdɔ.nəz] and /ˈdo.nəs/ becomes [ˈdo.nəz] in the present materials. The stimuli consisted of 6 tokens of [ˈdɔ.nəz], two per talker, and 6 tokens of [ˈdo.nəz], two per talker. Table 2 provides the $F1$ values at the midpoint of the target vowels in the stimuli. The table shows that all three talkers robustly produced the Catalan /o/–/ɔ/ contrast in their speech ($t(8.4) = 5.2$, $p < 0.001$). It also shows that the schwa in the two lexical items is similar across tokens ($t(10) = 1.2$, $p > 0.1$).

2.3. Production experiment

The crucial manipulation of the present study is that participants were asked to come to two experimental sessions. In both sessions, participants carried out a production and a perception task. In the first session, participants responded to the language profile questionnaire, then carried out the production task and finished by participating in the perception experiment. In the second session, the production task was also done first, followed by the perception task.

In the first session, hereafter the *unilingual* session, participants produced words only in the target language of the study, Catalan. The Catalan materials included words with /o/ and words with /ɔ/. In the second session, the *bilingual* session, they produced equal numbers of Catalan and Spanish words, in random order, in one block. The same Catalan words were produced in both sessions, which took place at least 48 h apart.

It needs to be acknowledged that it is unlikely that the first session was successful in fully inhibiting the activation of Spanish; that is, the first session was probably not fully *unilingual*. A number of limitations are as follows. First, the two experimental sessions were run in the same setting and by the same experimenter, himself a Catalan–Spanish bilingual born and raised on Majorca, and the same speakers participated in both. Bilingual speakers were recruited from (and tested in) a highly bilingual speech community. During the *unilingual* session, instructions were given in Catalan; however, speakers responded in their preferred language, even after being asked to address the experimenter only in Catalan. In sum, both sessions probably induce speakers in a *bilingual* mode, but the present study acts on the assumption that one of the two sessions is "more" bilingual than the other. This assumption is based on the materials produced in each of the two sessions.

2.3.1. Materials

Fourteen Catalan words with either /o/ or /ɔ/ were chosen. Seven had /o/ in the stressed syllable and 7 had /ɔ/. None of the words resulted in a minimal pair. The target vowels were placed among different consonants, representing several places of articulation. (The materials are listed in Table 3.) Fourteen Spanish words with /o/ in the stressed syllable were chosen for the *bilingual* session. All target words, both in Catalan and in Spanish, were placed in meaningful carrier sentences—different for each word but of similar length. The 14 Catalan sentences were interspersed among 33 filler sentences of similar length; the 7 Spanish target sentences appeared among 40 other Spanish sentences. The materials were adapted from some of those used in Recasens and Espinosa (2006, 2009) and Simonet (2011).

Table 2
$F1$ (Hz) of Catalan [o] in [ˈdo.nəz] '(you) give' and [ɔ] [ˈdɔ.nəz] 'women', the stimuli used in the categorical perception study. The talkers are three male native speakers of Catalan.

Talker	ˈdɔ.nəz		ˈdo.nəz	
	ɔ	ə	o	ə
CT1	680	535	505	461
	716	486	469	486
CT2	813	635	644	647
	749	659	635	535
CT3	748	573	567	523
	751	597	572	535

Table 3
Catalan and Spanish materials with either /o/ or /ɔ/ in the stressed position. Target words are in italics, and they are followed by their English translation.

Catalan /ɔ/		Catalan /o/	
posa-li *nota*	'grade'	s'home la *toma*	'tumble'
no li té *fòbia*	'fear'	buiden sa *copa*	'glass'
forada sa *roda*	'wheel'	un punt i una *coma*	'coma'
vas a *s'escola*	'school'	sa proa i sa *popa*	'stern'
arrabassa una *soca*	'trunk'	menja una *poma*	'apple'
ell li *destrossa*	'destroys'	lleva't ses *botes*	'boots'
viu tota *sola*	'alone'	escalfa sa *sopa*	'soup'
Spanish /o/			
una mala *nota*	'grade'	ponte las *botas*	'boots'
quita la *capota*	'hood'	a nade una *coma*	'coma'
le tiene *fobia*	'fear'	llena la *copa*	'glass'
vaya *casota*	'big house'	salpica una *gota*	'drop'
vive muy *sola*	'alone'	limpia la *lona*	'tarpaulin'
me dice una *cosa*	'thing'	abre del *pomo*	'knob'
el ave se *posa*	'to perch'	la proa y la *popa*	'stern'

Table 4
Means (and standard deviations) of $F1$ (Hz) of Catalan /o/- and /ɔ/-words used as auditory models in the production study. Values in each cell are calculated from 7 words. The talkers are three male native speakers of Catalan.

Talker	o	ɔ
CT1	638 (36)	502 (18)
CT2	732 (48)	612 (26)
CT3	734 (14)	554 (11)

In order to produce the target materials speakers shadowed stimuli (auditory models) that had been previously recorded by six male speakers. The same three talkers that produced the Catalan auditory stimuli for the perception experiment also recorded the Catalan stimuli for the production study. Three additional talkers were recruited to record the Spanish materials; these talkers had been raised by Spanish-dominant families, used Spanish almost exclusively with family and friends and considered that they used Spanish more frequently than Catalan in their daily lives. The six talkers were given a quasi-randomized printed list of the materials, which they were asked to read out loud. The recordings were obtained with professional equipment, in a quiet room, and they were digitized at 44.1 kHz, 16-bit quantization. Each target sentence was recorded twice. The second iteration of each sentence was selected as auditory models. Each chosen auditory model was placed in an individual sound file, and all the sound files were normalized for average intensity.

The $F1$ values provided in Table 4 show that the three Catalan-speaking talkers produce a difference between [o] and [ɔ]. Therefore, the Catalan-specific /o/–/ɔ/ contrast was manifest in the specific auditory models used in the present study: CT1 ($t(9.5)=6.48$, $p<0.001$), CT2 ($t(7.7)=4.7$, $p<0.01$), CT3 ($t(9.6)=28.3$, $p<0.001$).

2.3.2. Procedure and recordings

The 30 speakers shadowed the speech materials previously recorded by the six male talkers. This method has been widely used in second-language speech research (Flege, Munro, & Mackay, 1995; Guion, 2003) as well as in studies of imitation (Goldinger, 1998). The speakers were asked to listen to each sentence and only then produce their own iteration of the sentence—auditory models and participants' repetitions did not overlap in time. Therefore, there was a significant time lapse between the auditory model and the participant's production of the target sound; also, other sounds were heard (and words processed) in between. The delay and the presence of intervening sounds are hypothesized to reduce the effects of mere acoustic imitation (Goldinger, 1998). The use of full sentences, actual words and a time lapse between model and repetition is hypothesized to induce the activation of the participant's own phonological encoding of the words involved (Flege et al., 1995; Guion, 2003).

Regarding the Catalan materials, each of the 14 target words was recorded by three male talkers, and each of the 30 speakers shadowed all of the auditory models—i.e., each participant produced each word three times in response to three different auditory models. Each of the 30 participants heard the auditory materials in a different random order, and each produced (14×3) 42 tokens. Since there were 30 participants, the experiment collected a total of (42 tokens $\times$ 30 subjects) 1260 tokens in the *unilingual* session. A total of 20 tokens were excluded because of recording errors or other problems, such as coughing, creak or background noise. A total of 1260 Catalan word tokens were recorded during the *bilingual* session. These were the same word items recorded during the *unilingual* session. Of the 1260 tokens, 22 were excluded due to recording errors or other problems.

In addition to the Catalan materials, (14 words $\times$ 3 iterations) 42 Spanish target word tokens were recorded in the *bilingual* session by the same 30 Catalan–Spanish bilinguals. The (42×30) 1260 Spanish tokens were produced as a shadow to the Spanish auditory models pronounced by the three Spanish-dominant talkers. No Spanish word tokens had to be excluded. In sum, the present study is based on a total of 2478 Catalan tokens and 1260 Spanish tokens. While the study is focused on the production of the Catalan vowels as a function of the two sessions (*unilingual*, *bilingual*), Spanish /o/ is examined alongside Catalan /o/ and /ɔ/ for reference.

The experiment was run in Praat software (Boersma, 2001), version 5.3.12. The auditory models were played over earbud headphones. A portable digital speech recorder (Marantz PMD660) stored speech productions. The speakers used a medium-sensitivity head-worn condenser microphone

(Audix HT5) and a microphone pre-amplifier (Sound Devices MM-1) connected to the speech recorder. The signal was digitized at 44.1 kHz and 16 bit quantization. The digital sound files were later transferred to a computer for acoustic analysis.

2.3.3. Acoustic analysis

The feature that distinguishes Catalan /o/ and /ɔ/ is vowel height (Recasens & Espinosa, 2006, 2009; Simonet, 2011). First-formant ($F1$) frequency values are commonly taken as an adequate acoustic correlate of vowel height. Some scholars also measure acoustic vowel height as the difference between the fundamental ($F0$) and the $F1$ frequencies (Tsukada et al., 2005; Syrdal & Gopal, 1986). This is the approach taken here because it reduces inter-speaker variation due to global or local pitch.

Frequency values were transformed to the *mel* scale (Stevens, Volkman, & Newman, 1937). In the present study, acoustic vowel height is measured as the distance between *mel*-converted $F0$ and *mel*-converted $F1$, similarly to Tsukada et al. (2005) and Syrdal and Gopal (1986). (These two studies measured the difference between $F0$ and $F1$ in *Bark* units while the present study uses *mel* units.) The conversion of Hz to *mel* was carried out using Praat's *hertzToMel*(x) built-in function, with the below formula

$$550 \cdot \ln \cdot \left(\frac{1+x}{550}\right) \tag{1}$$

$F0$ and $F1$ values were extracted from the temporal midpoint of each vowel token. Vowel onsets and offsets were manually marked by plotting synchronized sound wave and spectrographic displays, using Praat software. The onset of a vowel was marked on the first pitch period in which the second formant ($F2$) was clearly visible—after stops and voiceless fricatives—or it had an intensity similar to that found in the vowel's steady state—after nasals. A vowel offset was marked on the last pitch period in which $F2$ was visible—before stops, it had an intensity similar to that in the vowel's steady state—before nasals and laterals—or it dropped dramatically—before a voiced approximant. A vowel midpoint was calculated as the 50% time point between the onset and the offset.

$F1$ values were extracted automatically, using Praat software. The procedure extracted five formants with the Burg algorithm (Anderson, 1978)—as built in Praat—from a 25-ms Hanning window placed centrally on the vowel's midpoint. In /o/ tokens (both Catalan and Spanish /o/) 5 formants were extracted under 5 kHz, and in /ɔ/ tokens 5 formants were extracted under 5.5 kHz (Chlàdkovà, Escudero, & Boersma, 2011; Escudero, Boersma, Rauber, & Bion, 2009). Only $F1$ was retained for analysis.

$F0$ values were calculated with the cross-correlation method because this method is more reliable than the auto-correlation method for short vowels (Escudero et al., 2009). The pitch range for the analysis was set between 75 Hz and 400 Hz. The other parameters for the analysis were the default ones used by Praat.

Analyses were carried out with by-subjects and by-items ANOVAs. The statistical models used medians rather than means to circumvent the possible problems caused by outliers, which could be due to formant tracking errors rather than actual production outliers (Chlàdkovà et al., 2011; Escudero et al., 2009). Regarding the Catalan data, the by-subjects dataset consists of 120 observations, all of them medians over subject (30), vowel (2) and session (2). Thus, each of the 30 speakers contributes 4 observations to the dataset, one per vowel (/o/, /ɔ/) per session (*unilingual*, *bilingual*). The by-items dataset consists of 84 observations, all of them medians over word (14), session (2) and group (3). Therefore, each of the 14 lexical items contributes 6 observations to the dataset, one per session (*unilingual*, *bilingual*) per group (G1, G2, G3).

3. Results

3.1. Perception experiment

A one-way ANOVA with accuracy (% correct) as the dependent variable and *group* as the main factor yielded a significant result ($F(2,27) = 7.47$, $p < 0.01$). Three Welch two-sample *t*-tests explored the pairwise contrasts. The *alpha* level was appropriately adjusted using the Bonferroni correction ($0.05/3 = 0.016$). In these planed comparisons, the listeners in G1 were found to outperform, as a group, those in G2 ($t(10.7) = 3.5$, $p < 0.01$), as well as those in G3 ($t(10.9) = 4.0$, $p < 0.01$); however, the listeners in G2 did not differ from those in G3 ($t < 0.5$).

An examination of the individual accuracy values (see Table 5) shows that some of the Spanish-dominant bilinguals have high scores, some as high as the Catalan-dominant listeners. Others, however, are much lower in accuracy. Five of the listeners in the G2 group and 3 of those in the G3 group were found to fall within two standard deviations ($SD = 5.3\%$) of the Catalan-dominant accuracy scores distribution (82.2% or above). The accuracy scores of the rest of the listeners in both groups were much smaller.

Table 5
Accuracy scores (% correct) in the discrimination experiment (3AFC, AXB) as a function of individual listener, further classified as a function of participant group.

Listener	G1	G2	G3
p01	92.4	51.5	60.6
p02	99.2	56.7	92.1
p03	87.7	89.8	95.5
p04	81.2	54.6	53.3
p05	89.8	63.5	91.6
p06	95.8	84.3	64.8
p07	95.3	89.8	60.9
p08	96.3	59.8	65.1
p09	97.6	95.8	73.9
p10	92.9	82.2	54.1
M	92.8	72.8	71.1

In sum, the perception study found that the bilinguals differed with respect to their discrimination of the Catalan-specific vowel contrast examined here. The two groups of Spanish-dominant participants were found to be much less accurate than the Catalan-dominant bilinguals. However, a cursory observation of the individual results suggested that some Spanish-dominant participants performed almost at ceiling while others did not.

3.2. *Production experiment*

3.2.1. *Catalan-specific vowel contrast*

This section is concerned exclusively with an analysis of the Catalan vowel data. The two Catalan vowels produced by the three groups of bilinguals are compared with each other and across two experimental sessions. The following section analyzes the Spanish vowels produced by these participants in the *bilingual* session.

The acoustic ($F1$–$F0$) data were submitted first to a by-subjects ANOVA. The ANOVA had a (2)×(2)×3 mixed design, with *vowel* (/o/, /ɔ/) and *session* (unilingual, bilingual) as within-subjects factors, and with *group* (G1, G2, G3) as a between-subjects factor. This ANOVA yielded a significant effect of *vowel* ($F(1,27)=196.8$, $p<0.001$), a significant effect of *session* ($F(1,27)=4.86$, $p<0.05$), and a significant interaction between *vowel* and *group* ($F(2,27)=4.68$, $p<0.05$). No other effects or interactions were detected by this ANOVA.

The second analysis was a mixed-design 2×(2)×(3) by-items ANOVA, in which *vowel* (/o/, /ɔ/) was a between-items factor, and *session* (unilingual, bilingual) and *group* (G1, G2, G3) were within-items factors. This ANOVA produced significant *vowel* effects ($F(1,12)=246.8$, $p<0.001$), significant effects of *group* ($F(2,24)=35.1$, $p<0.001$), and a significant *vowel* by *group* interaction ($F(2,24)=52.63$, $p<0.001$). Importantly, the ANOVA also detected a significant effect of *session* ($F(1,12)=6.89$, $p<0.05$).

Taken together, the two ANOVA models yield significant effects of *vowel* (/o/, /ɔ/), significant effects of *session* (unilingual, bilingual), and a significant interaction between *vowel* and *group*. (Note that only the effects detected in both analyses are considered.)

The effects of *vowel* are due to the fact that, overall, [o] has a lower height index ($F1$–$F0$) than [ɔ], as expected. In the main dataset—the one including all the values, not just the medians—the mean height index for [o] is 240.4 *mel* ($SD=42.4$) and the mean height index for [ɔ] is 323.3 *mel* ($SD=48.7$).

The interaction between *vowel* and *group*, plotted in Fig. 1, was explored in two ways. First, a series of planned comparisons, by means of paired *t*-tests, analyzed the possible effects of *vowel* for the three speaker groups, separately. Second, another series of ANOVAs analyzed the possible effects of *group* for the two vowels, separately. According to three by-subjects, paired *t*-tests, all three groups of speakers maintained a difference between /o/ and /ɔ/: G1 ($t(19)=-27.2$, $p<0.001$), G2 ($t(19)=-9.24$, $p<0.001$), G3 ($t(19)=-7.2$, $p<0.001$). (Note that all three findings are significant at the adjusted *alpha* level: 0.05/3=0.016.) This difference was greater for the G1 speakers ($M=110$ *mel*) than for the G2 ones ($M=83.5$ *mel*), and smallest for the speakers in G3 ($M=64.4$ *mel*). A by-subjects ANOVA did not detect any effects of *group* with respect to the height of /o/, but a similar ANOVA yielded a significant effect of *group* in the height of /ɔ/ ($F(2,57)=10.9$, $p<0.001$). According to three by-subjects, paired *t*-tests, this effect was due to a difference between the speakers in G1 and those in G3 ($t(19)=4.24$, $p<0.001$), and significant trends regarding comparisons with G2 and the other two groups: G1 ($t(19)=2.1$, $p=0.04$), G3 ($t(19)=2.3$, $p=0.03$). (Note that only the first result remains significant after appropriate adjusting of the *alpha* level (0.05/3=0.016). Thus, only G1 and G3 differ from each other in this analysis.)

The *vowel* by *group* interaction was subsequently explored with similar by-items statistical analyses. Three by-items, paired *t*-tests, found that, for all three groups of speakers, there was a difference between /o/ and /ɔ/: G1 ($t(13)=-24.97$, $p<0.001$), G2 ($t(13)=-19.09$, $p<0.001$), G3 ($t(13)=-1389$, $p<0.001$). (The findings remain significant after a Bonferroni correction of the *alpha* level.) This difference, once again, was greater for the G1 speakers ($M=107$ *mel*) than for the G2 ones ($M=88.1$ *mel*), and smallest for the speakers in G3 ($M=69.7$ *mel*). A by-items ANOVA did not yield any significant results of *group* regarding the height of /o/. However, when /ɔ/ was examined, a significant effect of *group* was detected ($F(2,39)=25.58$, $p<0.001$). This effect was caused by the fact that all pairwise comparisons were significant; i.e., they reached the Bonferroni-corrected *alpha* level: G1 *vs.* G2 ($t(13)=3.04$, $p<0.01$), G1 *vs.* G3 ($t(13)=7.57$, $p<0.001$), and G2 *vs.* G3 ($t(13)=9.69$, $p<0.001$).

In sum, the results of by-subjects and by-items explorations of the *vowel* by *group* interaction show that, although all three groups of speakers maintain an acoustic contrast between the two Catalan mid-back vowels, this difference is smaller the more Spanish-dominant the group is. The reduction in the magnitude of this difference is due to an acoustic approximation of [ɔ] to [o], rather than vice versa.

An exploration of the individual differences shows that 8 of the participants in the G2 group and 5 of those in the G3 group fall within two standard deviations ($SD=19$ *mel*) of the Catalan-dominant height mean for [ɔ], 340 *mel*. When the threshold is reduced to one standard deviation from the Catalan-dominant height mean, the number of native-like speakers in G2 is reduced to 5 and that in G3 is reduced to 3.

The most important finding of the present study is that both by-subject and by-item ANOVAs detected significant effects of *session*. These effects, plotted in Fig. 2, are due to the fact that both [o] and [ɔ] have a lower height index ($F1$–$F0$) in the bilingual session (S2) than in the unilingual session (S1).

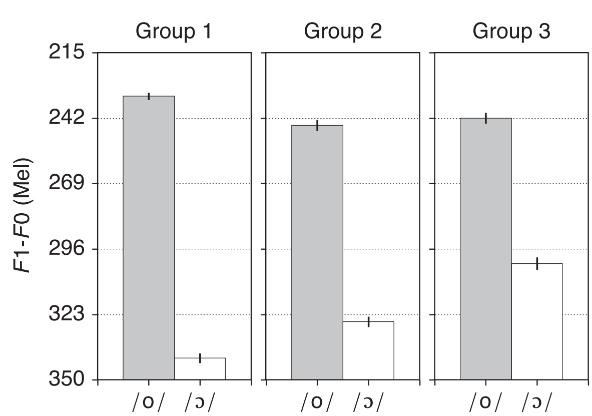

Fig. 1. Acoustic vowel height ($F1$–$F0$ in *mel* units) means (±SEM) as a function of Catalan vowel phoneme (/o/, /ɔ/) and speaker group (G1=Catalan-dominant bilinguals; G2=moderately Spanish-dominant bilinguals; G3=strongly Spanish-dominant bilinguals). Each group is represented by 10 female Catalan–Spanish bilinguals.

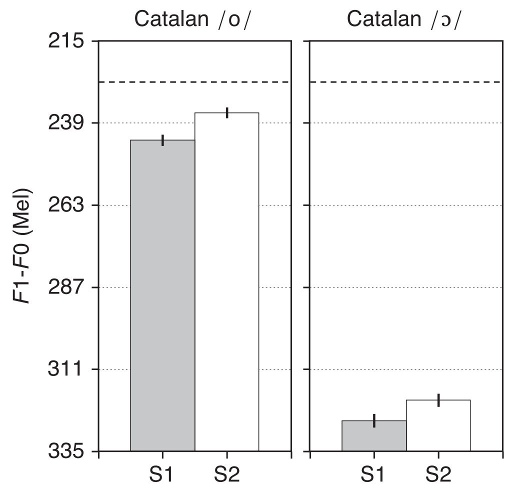

Fig. 2. Acoustic vowel height ($F1$–$F0$ in *mel* units) means (±SEM) as a function of vowel category (/o/, /ɔ/) and experimental session (S1 = *unilingual* session; S2 = *bilingual* session). Data come from 30 female Catalan–Spanish bilingual speakers. The horizontal dashed line plots the median vowel height of Spanish /o/ for these 30 bilinguals.

There is no interaction with *group*, which suggests that speakers in all groups slightly displace their [o] and [ɔ] phonetic categories when in a bilingual mode, with respect to a unilingual mode.

3.2.2. Spanish and Catalan vowels

This section analyzes the two Catalan mid-back vowels alongside the Spanish mid-back vowel. The two sessions are explored separately. First, the two Catalan vowels produced during the *unilingual* session are compared with the Spanish vowels produced during the *bilingual* session. Second, the Catalan vowels produced during the *bilingual* session are compared with the Spanish vowels produced during the same session.

A dataset was created comprising the by-subject medians of the Catalan vowel tokens produced during the *unilingual* session as well as the Spanish vowel tokens produced during the *bilingual* session. There were thus (30 × 3) 90 observations in this dataset. A by-subjects ANOVA explored these data. The ANOVA examined the height index ($F1$–$F0$) data as a function of a within-subjects factor, *vowel* (Catalan /o/, Catalan /ɔ/, Spanish /o/), and a between-subjects one, *group* (G1, G2, G3). The ANOVA revealed significant effects of *vowel* ($F(2,54) = 172.8$, $p < 0.001$); the *vowel* by *group* interaction approached but did not reach the *alpha* level ($F(4,54) = 2.1$, $p = 0.08$). The main effect of *vowel* is likely to be caused by the fact that Catalan [ɔ] is compared with higher mid-back vowels. The difference between Catalan [ɔ] and Catalan [o] has already been established for all three groups, and this difference is reported in the preceding section. What remains to be investigated is whether Catalan [o] and Spanish [o] differ from each other. Therefore, a follow-up analysis was conducted in which the Catalan [ɔ] data were excluded. An ANOVA analyzed the height data as a function of *vowel* (Catalan /o/, Spanish /o/) and *group* (G1, G2, G3). The ANOVA yielded significant *vowel* effects ($F(1,27) = 5.6$, $p < 0.05$) but no significant interaction ($F(2,27) = 1.6$, $p > 0.1$). In sum, Spanish [o] ($M = 240$ *mel*) has a lower height index than Catalan [o] ($M = 228$ *mel*).

A second dataset comprised the by-subject medians of the Catalan [o] and [ɔ] vowel tokens produced during the *bilingual* session. These were compared with the Spanish [o] tokens produced during the same session. The dataset had 90 observations. An ANOVA investigated the possible effects of *vowel* (Catalan /o/, Catalan /ɔ/, Spanish /o/) as a within-subjects factor and those of *group* (G1, G2, G3). The ANOVA detected significant effects of *vowel* ($F(2,54) = 180.3$, $p < 0.001$) and a significant interaction ($F(4,54) = 4.2$, $p < 0.01$). In order to focus the analysis on Catalan [o] and Spanish [o], the tokens corresponding to Catalan [ɔ] were excluded from the dataset. A follow-up analysis with *vowel* (Catalan /o/, Spanish /o/) and *group* (G1, G2, G3) as factors was not able to detect any main effects at all.

To summarize, in addition to the *session* (unilingual, bilingual) effects reported in the preceding section, the analyses reported in this section show that Catalan [o] differed from Spanish [o] when the former was produced during the unilingual session but not when it was produced during the bilingual session. Therefore, the raising effects reported in the preceding section, which affected both Catalan [o] and [ɔ], caused Catalan [o] to be fully assimilated to Spanish [o].

4. Discussion

4.1. Transient interference

May we "isolate, and then differentiate" the phonetic consequences of long-term (static) and transient (dynamic) cross-linguistic interference in bilinguals (Grosjean, 2011)? The present study aimed to investigate whether the setting or context of speech production episodes would affect the acoustic characteristics of sounds produced, in one language, by highly proficient bilinguals. The reasoning was as follows: if phonetic consequences of cross-linguistic interference are affected by the communicative setting (a circumstance), then these might be transient or circumstantial, rather than long-term or representational (in the sense described in Section 1), at least in part. Is there evidence for short-term, transient, circumstantial patterns of cross-linguistic phonetic interference? To what extent do they affect speech behavior, beyond the well-attested patterns of long-term interference?

In order to operationalize the effects of communicative settings on bilingual speech behavior, we used the principles of the Bilinguals' Language Modes framework (Grosjean, 1982, 1989, 1998b, 1998a, 2001, 2008). According to this framework, communicative contexts affect the relative level of activation of the bilinguals' two languages; in turn, the activation strength of languages may affect speech behavior in bilinguals. The evidence, so far, for the effects of bilingual's language modes on phonetic behavior is inconclusive. On one hand, transient activation effects appear to be modest or are not found at all (Antoniou et al., 2011; Grosjean & Miller, 1994; Olson, 2013); on the other hand, long-term (but still dynamic) activation effects are robust (Flege, 1987; Olson, 2013; Sancier & Fowler, 1997). How plastic, then, are patterns of transient interference?

The present study investigated three groups of highly proficient Catalan–Spanish bilinguals. The participants in each of the three groups had been classified as a function of their patterns of language dominance, from Catalan-dominant to strongly Spanish-dominant. The study examined the production and perception of the Catalan-specific /o/–/ɔ/ vowel contrast alongside a similar Spanish vowel, /o/. By comparing the phonetic behavior of speakers in the three groups it was possible to identify some of the patterns of long-term interference—between-speaker differences are likely to be due, at least in part, to relatively stable, speaker-specific "limitations". This is the (implicit) assumption of many phonetic studies of bilingualism and second language learning. For instance, Pallier, Bosch, and Sebastián-Gallés (1997) found that Spanish-dominant Catalan–Spanish bilinguals did not perceive the Catalan-specific /e/–/ε/ contrast in a categorical manner, unlike Catalan-dominant listeners, who did. Pallier, Colomé, and Sebastián-Gallés (2001) further found that Spanish-dominant bilinguals experienced repetition priming effects for minimal pairs involving these vowels (e.g., *déu* 'god' [ˈdeu̯], *deu* 'ten' [ˈdεu̯]), indicating that they treated the minimal pair as homophones. The authors inferred that Spanish-dominant bilinguals did not appear to have developed accurate phonological (i.e., long-term memory) representations—they did not possess accurate phonolexical entries. However, it appears reasonable to propose that between-participant differences could also be due to *performance*, rather than *competence*, limitations. Thus, it is possible that the listeners in Pallier et al. (2001) had accurate phonolexical entries but were "inefficient" when processing words manifesting the difficult /e/–/ε/ contrast—see Darcy et al. (2012). In sum, some between-speaker differences may result from behaviors inherent to the speakers (or long-term interference), while others may result from circumstantial, transient patterns of interference (or short-term interference) due to the communicative setting or to patterns of lexical activation in a particular situation.

A possible way to differentiate the two types of interference is to accompany between-speaker comparisons with the within-speaker ones. Thus, an important aspect of the present study is that it compared the production of a specific Catalan contrast by three groups of bilinguals in two experimental environments. The study manipulated the level of activation of the two lexicons of bilinguals. Speakers provided speech data in two sessions: (i) a *unilingual* session in which they produced words in only one language (Catalan), and (ii) a *bilingual* session in which they produced words in two languages (Catalan and Spanish).

The most important finding of the present study concerns the fact that bilingual participants shifted, albeit slightly, the acoustic distribution of both of their Catalan mid-back vowels when they produced the target Catalan words in the context of a bilingual Catalan–Spanish production task. In other words, the acoustics of Catalan [o] and [ɔ] differed as a function of the experimental session or the speech production setting in which the words were uttered. Interestingly, both of these vowels were shifted to become more similar to Spanish [o]—they were both raised. This finding provides evidence for the existence of transient patterns of cross-linguistic interference; it shows that the assimilation (or acoustic attraction) of the Catalan mid-back vowels to Spanish [o] is in part due to performance-based, circumstantial interference processes.

It is important to highlight that the evidence for transient interference was similar across speaker groups, so that the three groups shifted their vowels. Therefore, the between-speaker differences may be primarily due to differences in long-term phonological representation. These differences are not obviously affected by processes of transient interference. These processes, however, affect the patterns of similarity of Catalan and Spanish vowels; in other words, cross-linguistic phonetic interactions are affected, at least in part, by transient interference, which suggests that interlingual phonetic interactions take place *during speech processing*.

4.2. Long-term interference

The present study found differences, across bilingual participants, in their production and perception patterns of a Catalan-specific vowel contrast. Regarding perception, it was found that the participants differed in their categorical discrimination accuracy. In particular, Catalan-dominant bilinguals were found to discriminate the Catalan /o/–/ɔ/ contrast very accurately (i.e., above 90%), while the two groups of Spanish-dominant subjects were much less accurate (i.e., around 70% for both groups). Interestingly, there were no accuracy differences between the two groups of Spanish-dominant listeners, which suggests that the effects of Spanish dominance on the perception of Catalan vowels are not gradient. A comparison of the individual accuracy rates showed that some Spanish-dominant bilinguals were able to discriminate the contrast with native-like abilities, and this was not expected based on the group to which they had been assigned.

The perception study complements a previous production study of the same Catalan-specific vowel contrast in the same bilingual population (Simonet, 2011). Simonet showed that Spanish-dominant bilinguals had a merged category for Catalan vowels /o/ and /ɔ/, and the perception study reported here shows that Spanish-dominant bilinguals indeed experience difficulties when asked to discriminate minimal pairs involving this specific vowel contrast of Catalan. This is significant because the acoustic–phonetic manifestation of the Catalan /o/–/ɔ/ contrast has been found to be much more robust in Majorcan Catalan (Recasens & Espinosa, 2006, 2009), the dialect investigated here, than in other Catalan dialects where the perception of the /o/–/ɔ/ contrast had been investigated before (Sebastián-Gallés & Soto-Faraco, 1999). Interestingly, Amengual (2013) found that Spanish-dominant bilinguals from Majorca identified tokens on an [o]-to-[ɔ] resynthesized continuum in a manner that suggested that they perceived these vowels categorically, like Catalan-dominant bilinguals did. While it appears that the perception of the Catalan-specific contrast by Spanish-dominant bilinguals is not fully impaired, the present study suggests that it is challenged, at least when the task involves minimal lexical pairs. Since a categorical AXB task with minimal lexical pairs is more likely than a perceptual identification task (using single vowel tokens) to illuminate the nature of phonolexical representations in listeners, it is possible that the challenge Spanish-dominant bilinguals were found to experience in the former suggests that they have less detailed or robust mental representations of Catalan words containing vowels /o/ and /ɔ/ than Catalan-dominant bilinguals do.

The fact that large individual differences were found within the two Spanish-dominant groups but not within the Catalan-dominant group suggests that being dominant in Spanish does not preclude individuals from developing a native-like (off-line) discriminatory command of Catalan-specific vowel contrasts. However, it does trigger important individual differences, which suggests that it affects the formation of separate sound categories for these learners, at least at some level of representation. Therefore, a conclusion of the perception study reported here is that "a crucial difference between native and non-native speech perception … is that the ultimate second language performance level shows great individual variability even in the case of early acquisition" (Sebastián-Gallés & Díaz, 2012, p. 132).

Regarding production, the study found that all three speaker groups maintained a robust acoustic difference between Catalan /o/ and /ɔ/. However, an examination of the magnitude of the acoustic difference between the two vowels showed that the difference was smaller for the Spanish-dominant bilinguals than for the Catalan-dominant ones. Furthermore, strongly Spanish-dominant speakers produced a smaller acoustic difference than moderately Spanish-dominant ones. It is reasonable to conclude that, even for highly proficient Catalan–Spanish bilinguals who are able to produce the Catalan mid-back vowel contrast in their speech, dominance in Spanish affects the pronunciation of the Catalan contrast. The effects of Spanish dominance on the production of the Catalan-specific vowel contrast appears to be gradient. The differences across speaker groups were due to a displacement of the acoustic distribution of [ɔ], while [o] was not affected.

The results of the present production study are only partially in line with those reported in Simonet (2011). As mentioned above, Simonet found that Spanish-dominant speakers produced a merged mid-back vowel instead of the Catalan-specific /o/–/ɔ/ contrast. This indicated that these two Catalan vowels had been assimilated to the Spanish mid-back vowel. However, notice that the Spanish-dominant speakers in the present study, although showing evidence of Spanish interference, were able to produce the contrast. It is not possible to determine *a posteriori* what may have caused this difference, but two possible explanations suggest themselves. First, it is possible that the participants in Simonet (2011) were more strongly dominant in Spanish than those in either of the two Spanish-dominant groups analyzed here. A second possibility is that the behavior of the bilinguals in both studies was affected by the task. The speakers in Simonet (2011) were asked to read aloud a list of Catalan target words. (Note that both /o/ and /ɔ/ are spelled with "o" in Catalan.) The speakers in the present study, on the other hand, shadowed speech materials produced by native Catalan speakers. The auditory models provided to these participants may have facilitated their production of the Catalan-specific contrast.

Consider the following related finding. Bosch and Ramon-Casas (2011) recorded the speech of a group of Catalan–Spanish bilinguals from Barcelona which were assigned to two groups as a function of their linguistic background. In Bosch and Ramon-Casas' study, the focus was on the Catalan-specific mid-front vowel contrast (/e/–/ɛ/), rather than the mid-back contrast studied here. The authors asked their speakers to read aloud a list of sentences with /e/- and /ɛ/-words. An acoustic analysis of the target vowels in these two lists found that Catalan-dominant speakers robustly produced the /e/–/ɛ/ contrast in their speech, while the Spanish-dominant ones did not—they produced a merged vowel. Interestingly, the researchers also asked a phonetically trained native speaker of Catalan to categorize in two groups ([e], [ɛ]) the vowels produced by the speakers, irrespective of the word in which they were produced. An acoustic examination of the vowels classified as [e] and those classified as [ɛ] showed that both groups of participants produced a difference between these two phonetic categories—vowel productions were, in all cases, bimodal. A further examination of the production errors showed that Spanish-dominant speakers, but not Catalan-dominant ones, produced /ɛ/-words with [e] and, sometimes, /e/-words with [ɛ]. In sum, the acoustic merger detected in the Catalan productions of Spanish-dominant speakers was due, not to an inability to distinctively produce the two phonetic categories, but to that fact that they "had less stable representations for these vowels in their lexicon" (p. 522). In other words, they had separate phonetic categories, but not accurate phonolexical entries.

The results in Bosch and Ramon-Casas (2011) suggest the possibility that the merger captured in Simonet (2011) was due to the fact that the speakers in the study were reading the materials from a printed list. They may have had separate phonetic categories while not having robust phonolexical representations. By providing natively produced auditory models to the speakers in the present study (i.e., letting participants "know which word had which vowel"), the study may have circumvented possible phonolexical limitations and allowed us to focus on phonetic category representations. At any rate, it is important to highlight once again that the phonetic categories were not identical across groups. In other words, although all speakers produced the contrast, the phonetic manifestation of the contrast differed as a function of linguistic experience.

5. Conclusion

This study investigated the acoustics of two Catalan vowels ([o], [ɔ]) as produced by a group of highly proficient, early Catalan–Spanish bilinguals. Speech materials were collected in two experimental sessions. In the first (*unilingual*) session speakers produced Catalan words exclusively. In the second (*bilingual*) session speakers produced words in both Catalan and Spanish, in random order. The study also obtained perceptual discrimination data from the participants. While the study explored the patterns of cross-linguistic interference as revealed by both production and perception data, the main research question was concerned with transient patterns of interference, or *interference due to processing*. The question was as follows: would an increase in the circumstantial or transient activation of the Spanish lexicon affect the acoustic characteristics of Catalan sounds?

The results showed that the presence of Spanish words in the task led to an increase in the acoustic similarity between Spanish [o] and Catalan [o] and [ɔ]. In other words, the acoustic characteristics of the two Catalan vowels were slightly affected by the presence of Spanish words in the production task; in particular, both Catalan vowels had lower first-formant frequencies in the bilingual environment than in the unilingual one. It is interesting to point out that this effect was not different for the two vowels ([o], [ɔ]), even though only Catalan [ɔ] differs robustly from Spanish [o], and it was not further modulated by the patterns of linguistic dominance of the speakers—i.e., it affected the three groups similarly. In conclusion, the most important finding of the present study is that the presence of Spanish words in production tasks involving Catalan words triggered an attraction of the acoustic distribution of the Catalan mid-back vowels towards Spanish [o].

The present findings support a view of interlingual interference in which there is a place for transient, dynamic effects (Grosjean, 2011; Paradis, 1993). Such a view could make use of episodic representations of words and sounds (Goldinger, 1996, 1998, 2007) or it would make use of lexical activation levels during speech processing. In an exemplar model, recently experienced, phonetically detailed episodes would be responsible for interfering with other nearly experienced, phonetically detailed episodes, even across languages. Interference of this type would occur during processing rather than necessarily depend on (or even impact) phonological knowledge or representation.

Acknowledgments

The author wishes to express his gratitude to Ocke-Schwen Bohn, Associate Editor of *Journal of Phonetics*, and to two anonymous reviewers for constructive comments that served to improve the quality of the present article. The author is grateful to the volunteers that participated in the research reported here and to the two institutions that made it possible: The University of Arizona and the University of the Balearic Islands.

References

Adank, P., Smits, R., & van Hout, R. (2004). A comparison of vowel normalization procedures for language variation research. *Journal of the Acoustical Society of America*, *116*, 3099–3107.
Amengual, M. (2013). *An experimental approach to phonetic transfer in the production and perception of early Spanish–Catalan bilinguals* (Ph.D. thesis). University of Texas at Austin.
Anderson, N. (1978). On the calculation of filter coefficients for maximum entropy spectral analysis. In *Modern speech analysis*. New York: IEEE.
Antoniou, M., Best, C., Tyler, M., & Kroos, C. (2010). Language context elicits native-like stop voicing in early bilinguals' productions in both L1 and L2. *Journal of Phonetics*, *38*(4), 640–653.
Antoniou, M., Best, C., Tyler, M., & Kroos, C. (2011). Inter-language interference in VOT production by L2-dominant bilinguals: Asymmetries in phonetic code-switching. *Journal of Phonetics*, *39*(4), 558–570.
Antoniou, M., Tyler, M., & Best, C. (2012). Two ways to listen: Do L2-dominant bilinguals perceive stop voicing according to language mode? *Journal of Phonetics*, *40*(4), 582–594.

Birdsong, D., Gertken, L., & Amengual, M. (2012). *Bilingual language profile: An easy-to-use instrument to assess bilingualism*. COERLL, University of Texas at Austin. ⟨https://sites.la.utexas.edu/bilingual⟩.

Boersma, P. (2001). Praat, a system for doing phonetics by computer. *Glot International*, *5*(9/10), 341–345.

Bohn, O.-S., & Flege, J. (1993). Perceptual switching in Spanish–English bilinguals. *Journal of Phonetics*, *21*, 267–290.

Bosch, L., & Ramon-Casas, M. (2011). Variability in vowel production by bilingual speakers: Can input properties hinder the early stabilization of contrastive categories? *Journal of Phonetics*, *39*, 514–526.

Bullock, B., Toribio, A., González, V., & Dalola, A. (2006). Language dominance and performance outcomes in bilingual pronunciation. In: M. O'Brien, C. Shea, & J. Archibald (Eds.), *Proceedings of the 8th generative approaches to second language acquisition: The Banff conference* (pp. 9–16). Somerville, MA: Cascadilla.

Caramazza, A., Yeni-Komshian, G., Zurif, E., & Carbone, E. (1973). The acquisition of a new phonological contrast: The case of stop consonants in French–English bilinguals. *Journal of the Acoustical Society of America*, *54*, 421–428.

Chlàdkovà, K., Escudero, P., & Boersma, P. (2011). Context-specific acoustic differences between Peruvian and Iberian Spanish vowels. *Journal of the Acoustical Society of America*, *130*, 416–428.

Darcy, I., Dekydtspotter, L., Sprouse, R., Glover, J., Kaden, C., McGuire, M., & Scott, J. (2012). Direct mapping of acoustics to phonology: On the lexical encoding of front rounded vowels in L1 English–L2 French acquisition. *Second Language Research*, *28*(1), 5–40.

Elman, J., Diehl, R., & Buchwald, S. (1977). Perceptual switching in bilinguals. *Journal of the Acoustical Society of America*, *62*, 971–974.

Escudero, P., Boersma, P., Rauber, A., & Bion, R. (2009). A cross-dialect acoustic description of vowels: Brazilian and European Portuguese. *Journal of the Acoustical Society of America*, *126*, 1379–1393.

Flege, J. (1987). The production of "new" and "similar" phones in a foreign language: Evidence for the effect of bilingual classification. *Journal of Phonetics*, *15*, 47–65.

Flege, J. (2003). A method for assessing the perception of vowels in a second language. In: E. Fava, & A. Mioni (Eds.), *Issues in clinical linguistics* (pp. 19–43). Padova, Italy: Unipress.

Flege, J., & Eefting, W. (1987). Cross-language switching in stop consonant perception and production by Dutch speakers of English. *Speech Communication*, *6*, 185–202.

Flege, J., MacKay, I., & Meador, D. (1999). Native Italian speakers' perception and production of English vowels. *Journal of the Acoustical Society of America*, *106*, 2973–2987.

Flege, J., Munro, M., & Mackay, I. (1995). Effects of age of second-language learning on the production of English consonants. *Speech Communication*, *16*, 1–26.

Flege, J., Yeni-Komshian, G., & Liu, S. (1999). Age constraints on second-language acquisition. *Journal of Memory and Language*, *41*(1), 78–104.

Fowler, C., Sramko, V., Ostry, D., Rowland, S., & Hallé, P. (2008). Cross language phonetic influences on the speech of French–English bilinguals. *Journal of Phonetics*, *36*, 649–663.

García-Sierra, A., Diehl, R., & Champlin, C. (2009). Testing the double phonemic boundary in bilinguals. *Speech Communication*, *51*, 369–378.

Goldinger, S. (1996). Words and voices: Episodic traces in spoken word identification and recognition memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *22*, 1166–1183.

Goldinger, S. (1998). Echoes of echoes? An episodic theory of lexical access. *Psychological Review*, *105*, 251–279.

Goldinger, S. (2007). A complementary-systems approach to abstract and episodic speech perception. In *Proceedings of the international conference on phonetic sciences* (Vol. XVI). Saarbrücken, Germany.

González, V. (2012). Spanish and English word-initial voiceless stop production in code-switched vs. monolingual structures. *Second Language Research*, *28*, 243–263.

Grosjean, F. (1982). *Life with two languages: An introduction to bilingualism*. Cambridge, MA: Harvard University Press.

Grosjean, F. (1989). Neurolinguists, beware! The bilingual is not two monolinguals in one person. *Brain and Language*, *36*(1), 3–15.

Grosjean, F. (1998a). Studying bilinguals: Methodological and conceptual issues. *Bilingualism: Language and Cognition*, *1*(2), 131–149.

Grosjean, F. (1998b). Transfer and language mode. *Bilingualism: Language and Cognition*, *1*(3), 175–176.

Grosjean, F. (2001). The bilinguals' language modes. In: J. Nicol (Ed.), *One mind, two languages: Bilingual language processing* (pp. 1–22). Oxford, UK: Blackwell Publishing.

Grosjean, F. (2008). *Studying bilinguals*. Oxford: Oxford University Press.

Grosjean, F. (2011). An attempt to isolate, and then differentiate, transfer and interference. *International Journal of Bilingualism*, *16*(1), 11–21.

Grosjean, F., & Miller, J. (1994). Going in and out of languages: An example of bilingual flexibility. *Psychological Science*, *5*(4), 201–202.

Guion, S. (2003). The vowel systems of Quichua–Spanish bilinguals. *Phonetica*, *60*, 98–128.

Guion, S., Flege, J., Akahane-Yamada, R., & Pruitt, J. (2000). An investigation of current models of second language speech perception: The case of Japanese adults' perception of English consonants. *Journal of the Acoustical Society of America*, *107*, 2711–2724.

Hazan, V., & Boulakia, G. (1993). Production of a voicing contrast by French–English bilinguals. *Language and Speech*, *36*, 17–38.

Magloire, J., & Green, K. (1999). A cross-language comparison of speaking rate effects on the production of voice onset time in English and Spanish. *Phonetica*, *56*, 158–185.

Neisser, U. (1967). *Cognitive psychology*. New York, NY: Apple-Century-Crofts.

Olson, D. (2013). Bilingual language switching and selection at the phonetic level: Asymmetrical transfer in VOT production. *Journal of Phonetics*, *41*, 407–420.

Oyama, S. (1976). A sensitive period for the acquisition of a nonnative phonological system. *Journal of Psycholinguistic Research*, *5*, 261–283.

Pallier, C., Bosch, L., & Sebastián-Gallés, N. (1997). A limit on behavioral plasticity in speech perception. *Cognition*, *64*, B9–B17.

Pallier, C., Colomé, A., & Sebastián-Gallés, N. (2001). The influence of native-language phonology on lexical access: Exemplar-based versus abstract lexical entries. *Psychological Science*, *12*, 445–449.

Paradis, M. (1993). Linguistic, psycholinguistic, and neurolinguistic aspects of 'interference' in bilingual speakers: The activation threshold hypothesis. *International Journal of Psycholinguistics*, *9*, 133–145.

Recasens, D., & Espinosa, A. (2006). Dispersion and variability of Catalan vowels. *Speech Communication*, *48*, 645–666.

Recasens, D., & Espinosa, A. (2009). Dispersion and variability in Catalan five and six peripheral vowel systems. *Speech Communication*, *51*, 240–258.

Sancier, M., & Fowler, C. (1997). Gestural drift in a bilingual speaker of Brazilian Portuguese and English. *Journal of Phonetics*, *25*(4), 421–436.

Sebastián-Gallés, N., & Díaz, B. (2012). First and second language speech perception: Graded learning. *Language Learning*, *62*, 131–147.

Sebastián-Gallés, N., & Soto-Faraco, S. (1999). Online processing of native and non-native phonemic contrasts in early bilinguals. *Cognition*, *72*, 111–123.

Simonet, M. (2011). Production of a Catalan-specific vowel contrast by early Spanish–Catalan bilinguals. *Phonetica*, *68*, 88–110.

Stevens, S., Volkman, J., & Newman, E. (1937). A scale for the measurement of psychological pitch. *Journal of the Acoustical Society of America*, *8*, 185–190.

Sundara, M., Polka, L., & Baum, S. (2006). Production of coronal stops by simultaneous bilingual adults. *Bilingualism: Language and Cognition*, *9*, 97–114.

Syrdal, A., & Gopal, H. (1986). A perceptual model of vowel recognition based on the auditory representation of American English vowels. *The Journal of the Acoustical Society of America*, *79*(4), 1086–1100.

Toribio, A., Bullock, B., Botero, C., & Davis, K. (2005). Perseverative phonetic effects in bilingual code-switching. In: R. Gess, & E. Rubin (Eds.), *Theoretical and experimental approaches to romance linguistics* (pp. 291–306). Amsterdam: John Benjamins.

Tsukada, K., Birdsong, D., Bialystok, E., Mack, M., Sung, H., & Flege, J. (2005). A developmental study of English vowel production and perception by native English adults and children. *Journal of Phonetics*, *33*, 263–290.

Williams, L. (1977). The perception of stop consonant voicing by Spanish–English bilinguals. *Perception & Psychophysics*, *21*, 289–297.

Yeni-Komshian, G., Flege, J., & Liu, S. (2000). Pronunciation proficiency in the first and second languages of Korean–English bilinguals. *Bilingualism: Language and Cognition*, *3*(2), 131–149.