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Testing the double phonemic boundary in bilinguals

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Abstract

It is widely known that language influences the way speech sounds are categorized. However, categorization of speech sounds by bilinguals is not well understood. There is evidence that bilinguals have different category boundaries than monolinguals, and there is evidence suggesting that bilinguals' phonemic boundaries can shift with language context. This phenomenon has been referred as the double phonemic boundary. In this investigation, the double phonemic boundary is tested in Spanish-English bilinguals ($N = 18$) and English monolinguals ($N = 16$). Participants were asked to categorize speech stimuli from a continuum ranging from /ga/ to /ka/ in two language contexts. The results showed phonemic boundary shifts in bilinguals and monolinguals which did not differ across language contexts. However, the magnitude of the phoneme boundary shift was significantly correlated with the level of confidence in using English and Spanish (reading, writing, speaking, and comprehension) for bilinguals, but not for monolinguals. The challenges of testing the double phonemic boundary are discussed, along with the limitations of the methodology used in this study.

Keywords

Double phonemic boundary; Spanish–English bilinguals; Perceptual switching; Language contexts

1. Testing the double phonemic boundary in bilinguals

One of the most relevant questions about second language acquisition is representation of multiple languages in the brain. The most common difficulty in learning a second language is caused by the phonetic differences between languages. An acoustic–phonetic cue that is relevant in one language may not be relevant in other languages (Abramson and Lisker, 1970; Polka et al., 2001; Sundara et al., 2008). For example, Spanish monolingual speakers may not distinguish English speech sounds in the same way that English monolingual speakers do. Research has shown that depending on the timing of exposure to a second language, bilinguals may develop phonemic representations that match those of monolingual speakers of both languages (Sundara and Polka, 2008). If this is the case, bilinguals can develop two phonemic representations for an acoustic–phonetic event that is present in both languages but represents a different speech sound in each of the languages. Speech perception in bilinguals may depend on the language context in which the speech sounds are encountered. Consequently, the appropriate phonemic representation depends on the language context.

Bilinguals' double phonemic representation has been tested in the well known phonetic dimension of voice onset time or VOT. VOT is one of the strongest phonetic cues for consonant discrimination and refers to the time interval between the release of the articulatory occlusion

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and the onset of vocal-fold vibration. Lisker and Abramson (1970) and Abramson and Lisker (1972) showed that VOT is sufficient to signal the phonetic contrast between voiced and voiceless stop consonants in word-initial position. Short durations of VOT signal voiced stop consonants (/b/, /d/, and /g/), and long durations of VOT represent voiceless stop consonants (/p/, /t/, and /k/). Interestingly, equal durations of VOT indicate different stop consonants among different languages. Abramson and Lisker demonstrated that English monolingual speakers perceive short VOT as voiced sounds, whereas Spanish monolingual speakers perceive short VOT as voiceless sounds. Indeed, other studies have shown that not only consonants but also the perception of vowels is influenced by one's native language (Best et al., 1988; Kuhl et al., 1992).

The phonetic ambiguity of stop consonants among certain languages make them good stimuli for investigating double phonemic representation in bilinguals. Most researchers have investigated the phonemic boundary dividing a voiced-voiceless continuum for evidence of a shift depending on the language context of the speech stimuli presented. The language effects that have been reported are small and two factors may contribute to the size of the observed effects. First, the ambiguous VOT region is no longer than 20 ms (from ~5 to ~25 ms VOT). Second, perceptual effects of normal nature, including range effects and contrast effects may interfere with the observation of language context effects. Range effects refer to the tendency of participants to split the range of stimuli into two equal halves: the perception of a particular speech token can depend on the set of VOT stimuli presented, rather than on a particular linguistic category (Brady and Darwin, 1978; Keating et al., 1981). Contrast effects refer to changes in speech sound perception as a function of the acoustic history of neighboring speech sounds although the acoustic characteristics of the target sound remain constant (Diehl et al., 1978; Eimas and Corbit, 1973; Holt and Lotto, 2002). Therefore, it is necessary to distinguish perceptual effects due to language exposure from those due to normal perceptual processes. In this investigation we report an experiment that assessed bilinguals' double phonemic representation as well as evaluating contrast effects.

1.1. The double phonemic boundary in bilinguals

The double phonemic representation in bilinguals has also been called the double phonemic boundary (Caramazza et al., 1973; Elman et al., 1977; Flege and Eefting, 1987a; Hazan and Boulakia, 1993; Williams, 1977). Research investigating the double phonemic boundary in bilinguals has reported mixed results. For example, Caramazza and colleagues (1973) asked French–English bilinguals to identify the same speech sounds in two language contexts. In one session, English was emphasized by a brief conversation in English before the experiment. In the second session, French was emphasized. Two relevant outcomes were reported. First, bilinguals' phonemic boundaries were at intermediate VOT values when compared to monolingual participants. Second, there were no significant differences in bilinguals' perceptual boundaries across language contexts. Caramazza and colleagues concluded that the phonological processors that bilinguals acquire for their second language are contaminated or interfered with by the first language. Caramazza et al. pointed that the interference is likely to be directional: from the stronger language, perhaps the first language learned, to the weaker language, perhaps the second language learned. Rather than bilinguals shifting between phonological rules, it seems that bilinguals adopt a single phonological rule that encompasses both languages' phonemic inventories.

In another investigation, Williams (1977) assessed Spanish–English bilinguals' speech categorization to test for the double phonemic boundary. Williams used the same methodology as Caramazza et al. (1973) to establish language contexts. While four participants showed shifts ranging from 4 to 10 ms across language contexts, the data failed to show significant differences between language contexts. Williams' results supported Caramazza and colleagues' conclusion

that becoming a bilingual may entail, among other things, a modification in the use of acoustic information present in the speech signal. She also suggested that failure of language context to produce an effect in bilinguals' speech perception may be due to the fact that the contexts were not properly established. Although studies by Caramazza et al. and Williams did not reveal evidence of a double phonemic boundary in bilinguals, other studies using a different approach to establish language contexts have provided evidence of a double phonemic boundary in bilinguals.

Elman and colleagues (1977) suggested that in order for language contexts to affect perception, bilinguals need to stay focused on the language of interest throughout the entire experiment. These researchers delivered precursor sentences during the actual perceptual task. For example, Spanish–English bilingual participants would listen to the sentence *Write the word* __, or *Escriba la palabra* __ before the presentation of each stimulus. Their results showed that bilinguals did assign identical VOT information to different phonemic categories depending on the language context. Elman et al. clearly showed that language contexts can affect perception, if they are properly established.

Other studies using Elman et al. (1977) methodology have also provided evidence for the double phonemic boundary in bilinguals. For example, Flege and Eefting (1987b) asked bilingual speakers of Dutch and English to identify a speech continuum ranging from /da/ to /ta/ in 16 VOT steps. The results showed a small but significant phonemic boundary shift across language context, no longer than 5 ms of VOT on average. In another experiment, Hazan and Boulakia (1993) used words rather than syllables to assess French–English bilinguals' double phonemic boundary. In this experiment, bilinguals and monolingual speakers of French and English were asked to identify the initial consonant of target words as 'b' or 'p'. The meaning of the target words changed as a function of VOT (e.g., *Ben* changing to *pen*). The results showed a significant phonemic boundary shift no larger than 5 ms on average. The results also showed that bilinguals voicing boundaries were at intermediate values compared with the voicing boundaries of the monolingual groups. However, it is not possible to know if language contexts affected monolinguals' phonemic boundaries since they were only tested in their native language context.

Bohn and Flege (1993) were the first investigators to test monolinguals in their native language context and in a foreign language context. Their findings showed that the double phonemic boundary might have resulted from phonetic context effects rather than from a double phonemic representation in bilinguals. Using the precursor sentence procedure, Bohn and Flege asked Spanish–English bilinguals and English monolinguals speakers to label a set of speech tokens as 'd' or 't' in two language contexts (Spanish and English). The results revealed that both bilinguals and monolinguals showed a shift in the voicing boundary in accordance with the language context. Bohn and Flege concluded that the carrier phrases played the role of 'acoustic adaptors' rather than context for the language under test. Indeed, recently Holt and Lotto (2002) showed that the phonemic boundaries obtained in speech categorization tasks can be affected by the acoustic context preceding the phonetic decisions (i.e., phonetic context effects).

Overall, Bohn and Flege's (1993) results showed that the use of precursor sentences can result in phonetic context effects. However, other investigations have shown that besides bilinguals showing a voicing boundary shift between language contexts, they also show that the size of the shift is correlated with second language (L2) proficiency. For example, Elman et al. (1977) found that the size of the shift of the voicing boundary increased as bilinguals' proficiency in L2 increased. These results suggest that weak bilinguals adopted the VOT boundary criterion of the dominant language and apply it in both language conditions, and therefore little or no boundary shift was found. On the other hand, strong bilinguals adopted

the language-appropriate VOT boundary for each language hence, a big boundary shift was found.

Unfortunately, Bohn and Flege (1993) did not report if bilinguals' and monolinguals' phonemic boundaries scores were correlated with L2 proficiency. Still, it can be hypothesized that only bilinguals but not monolinguals would have shown a correlation between the size of the voicing boundary shift and L2 proficiency. If this is the case, the shift in monolinguals' voicing boundary in Bohn and Flege's results can be explained as monolinguals not being completely naïve to Spanish. In fact, it has been reported that subjects with low proficiency in L2 (i.e., monolinguals learning a second language) show a larger voicing boundary shifts than those observed in high proficient bilinguals (Flege and Eefting, 1987b).

To our knowledge, the correlation between L2 proficiency and the degree of shift in the phonemic boundary has not been tested in monolinguals. However, it is likely that this correlation would only be present in bilinguals and not in monolinguals. To date, research concerned with bilinguals' double phonemic representation has been inconclusive. The methods used to establish language contexts differ considerably across investigations, including the number of stimulus used in the perceptual task. Only few of these investigations used monolingual speakers as a control group, and only one investigation tested monolinguals in two language contexts. The current experiment was designed to determine whether bilinguals possess a double phonemic representation. Bilinguals and monolinguals were asked to label a speech continuum in two language contexts. The possibility that context effects could have influenced participants' phonetic judgments is reported, and the correlation between the perceptual shift and the level of confidence in using English and Spanish are reported for both monolinguals and bilinguals.

2. Method

2.1. Participants

Eighteen female bilingual speakers of Spanish and English, and 16 female monolingual speakers of English participated in the study. Only 30 participants were retained for subsequent analysis – 3 failed to show clear phonetic boundaries, 1 failed the hearing test. The final sample included 15 bilinguals (mean age 20.13 = SD 2.95) and 15 monolinguals (mean age = 19.6, SD 1.8). All participants were students at the University of Texas at Austin. Participants were recruited by flyers and through word of mouth, and were paid \$15.00 for their participation.

Participants were defined as bilinguals or monolinguals based on the language or languages they were exposed to throughout their lives. Bilingual candidates were exposed to Spanish and English during childhood and considered themselves fluent in both languages. Monolingual candidates were exposed to English only during childhood, and they did not consider themselves fluent in any other language than English. Participants were asked to answer a language questionnaire that assesses L2 proficiency and percent-usage of English and Spanish.

Participants usage of English and Spanish—Thirteen of the bilingual participants were born in the US and two were born in Mexico. Twelve bilingual participants reported that the first language learned was Spanish and three reported it was English. All bilinguals reported exposure to Spanish and English throughout childhood (3–12 years of age). Thirteen bilinguals reported that they used more Spanish than English during childhood, and two bilinguals reported that they used more English than Spanish. At the time of the experiment, bilinguals reported that they used English to talk to siblings, teachers, class mates, and friends, and they used Spanish primarily with their parents.

All fifteen monolingual participants were born in the US, reported that they were exposed to English only during early development, and reported that they used English only from 3 to 12 years of age. Monolinguals reported that they used Spanish less than 2% of the time to talk to others (see Table 1 for more information on language usage).

Participants' level of bilingualism—Confidence in English and Spanish was assessed by self-reports. Participants were asked to rate themselves in four factors: confidence in speaking, reading, writing, and listening comprehension. Confidence scores in each factor was quantified using a Likert scale from 0 to 7 (0 = “none” and 7 = “like a native speaker”, passing through a 4 = “fair”). The average of the four factors showed that bilinguals reported being slightly more confident in English (6.53, SD = .144) than in Spanish (5.60, SD = .45). Monolinguals showed a marked confidence for English (English = 7.00, SD = 0.0; Spanish = 1.85, SD = .11). More information about participants' language proficiency is shown in Table 1.

2.2. Stimuli

A speech continuum ranging from /ga/ to /ka/ was synthesized in 27 VOT steps. The range varied from −100 ms to +100 ms of VOT in 10 ms steps, except from 0 to 60 ms where it varied in 5 ms steps. The continuum was generated using the cascade method described by Klatt (1980). The duration of each stimulus was 500 ms with vowel length varying from 490 to 390 ms depending on the duration of VOT.

The formant transitions were linearly interpolated from values appropriate for a velar stop consonant (F1 = 180 Hz, BW1 = 250 Hz; F2 = 1725 Hz, BW2 = 160 Hz; F3 = 1725 Hz, BW3 = 330 Hz; F4 = 3200 Hz, BW4 = 500 Hz; F5 = 3500 Hz, BW5 = 500 Hz) to values suitable for vowel /a/ (F1 = 750 Hz, BW1 = 130 Hz; F2 = 1200 Hz, BW2 = 70 Hz; F3 = 2450, BW3 = 70 Hz; F4 = 3200 Hz, BW4 = 500; F5 = 3500 Hz, BW5 = 500 Hz). A turbulent noise source of 10 ms (AF) duration with 60 dB amplitude was applied to simulate the consonant release.

Aspiration (+VOT) was simulated by setting the aspiration source (AH) at 62 dB subsequent to the consonant release and before vowel onset. In the case of speech tokens with pre-voicing or − VOT, the vocal-fold vibration was simulated by applying a low-frequency (125 Hz) sinusoid before the release of the consonant at 46 dB (Flege and Eefting, 1987b). The fundamental frequency (F_0) was interpolated from 45 to 65 dB during the first 100 ms formant transition period and held constant at 60 dB until near the end of the vowel. F_0 was set at 150 Hz and dropped to 90 Hz in a time range of 380 ms. The stimuli were delivered to both ears through headphones and were presented at a comfortable listening level.

Stimulus presentation—Each stimulus was delivered 10 times using a randomized sequence. The sequence also contained precursor sentences (in Spanish or English) that were presented before each speech token. Specifically, five sentences were recorded from a native female speaker of either Spanish or English. The sentences served as brief reminders of what to do during the task. For example, *what syllable did you hear? make your best choice, select the sound you heard*, etc. In total, precursor sentences were delivered 13% of the times in random order before the speech presentations. The time interval between the offset of a precursor sentence and the onset of a speech token was 1 s, and the time interval between the offset-onset of two consecutive speech tokens also was 1 s.

2.3. General procedure

Potential participants were asked to participate in two experimental language sessions (i.e., one session was in English and another in Spanish, counterbalanced). Sessions were separated by at least three days and lasted approximately 30 min. In the first experimental session, participants completed the consent form and self-reports on language usage and proficiency.

A hearing screen was performed immediately after. Participants with auditory thresholds that exceeded 20 dB at any frequency .25, .5, 1, 2, 4, 6, and 8 KHz received \$5.00 and were excused from the experiment. If retained, participants were asked to take part in the experimental session. The experimental session was conducted in a sound-treated room. Participants sat at a computer and wore headphones. They listened to instructions about how to use the computer to make phonetic judgments. The instructions were recorded by two female native speakers of Spanish and English.

Four practice trials followed the instructions. At the end of the practice trials, the researcher asked if there were any questions. The behavioral task lasted approximately 15 min.

Language contexts—Although both bilinguals and monolinguals participated in two language sessions, there were minor differences between groups. The interactions that occurred before the experimental task between the experimenter and bilingual participants were in the language of interest, whereas interactions between the experimenter and monolingual participants were always in English. Also, bilinguals listened to the general instructions through the headphones in the language of interest, and monolinguals always listened to instructions in English.

3. Results

3.1. Did bilinguals, but not monolinguals, show a shift in the phonemic boundary?

It was expected that bilinguals would show a shift in the phonemic boundary toward the voiced end of the VOT continuum in the Spanish language context and toward the voiceless end of the VOT continuum in the English language context. Monolingual speakers of English, on the other hand, were not expected to show a shift in the phonemic boundary across language contexts.

Each participant's 'ga' cumulative distribution was transformed into a cumulative probability distribution by means of a Probit function (Finney, 1971). Probit analysis fits a line to Z-score transforms of the percentage of 'ga' responses per stimulus. The VOT value at the 50% crossover was calculated by obtaining the VOT value associated with .5 probability of being judged as 'ga'. The participants' crossover points were derived for both language contexts.

Fig. 1 depicts how monolinguals and bilinguals categorized the stimuli as a function of VOT. The figure shows the percent 'ga' (squares) and the probability 'ga' (line) associated to each stimulus. The left panel shows the bilinguals' phonemic boundary and the right panel shows monolinguals' phonemic boundaries. The figure shows that bilinguals show a larger shift in the voicing boundary between language contexts when compared with monolinguals.

The VOT values at the 50% crossover point were compared via a 2×2 (group $\times$ language context) analysis of variance with repeated measures (language context). The ANOVA results showed a significant main effect for language ($F(1, 28) = 12.117, p = .002$). The main effect for language context revealed a 50% crossover at 23.03 ms ($SD = 8.12$) for the English language context and, a 50% crossover at 19.03 ms ($SD = 9.12$) for the Spanish language context. Pair-wise comparisons with Bonferroni correction showed that the English language context produced a significant larger VOT value than the Spanish language context (mean difference 4.0 ms, $p = .002$). These results show that language contexts affected the placement of the phonemic boundary regardless of language status. The group effect was marginally significant ($F(1, 28) = 3.1561, p = .086$) with bilinguals showing a voicing boundary at 18.51 ms of VOT ($SD = 9.24$) and monolinguals showing it at 23.54 ms of VOT ($SD = 7.68$). There was no significant interaction between language context and group.

Language effects were expected to occur only in the stimuli near or at the phonemic boundary (i.e., ambiguous stimuli). However, because the VOT values at the 50% crossover were calculated using probit analysis, shifts that take place away from the boundary can affect the fit of the underlying function and change the 50% point. For this reason further analyses were performed using the raw scores (percent judged as 'ga'). These analyses can provide information about the stimuli that were the strongest contributors to the Probit function and examine whether percent 'ga' varied across language contexts for both groups. Independent 2×2 (group $\times$ language context) analyses of variance with repeated measures (language context) were performed for the 27 stimuli. Only the stimuli showing significant main effect for group and language context or an interaction between group and language context are reported.

Main effects for language context were found for +5, +15, +20, and +25, of VOT (see Table 2 for details). A marginal main effect for group was found for +20 ms of VOT ($F(1, 28) = 3.21, p = .084$), and an interaction between group and language context was found in +5 ms of VOT ($F(1, 28) = 6.56, p = .016$). Pair-wise comparisons with Bonferroni correction showed a significant language context effect for +5 ms of VOT in bilingual subjects (mean difference in percent 'ga' = 10, $p = .001$). Monolingual subjects did not exhibit a significant language context effect (mean difference in percent 'ga' = 0.0, $p = 1$). These results show that the stimuli near or at the phonemic boundary were the only stimuli making a significant contribution to the fit of the underlying function calculated by Probit analysis. In addition, it was shown that the perception of +5 ms of VOT was affected by the language context in use for bilingual subjects, but not for monolingual subjects.

3.2. Did the precursor sentences influence participants' responses?

The second goal of this investigation was to test whether the methodology implemented generated context effects (Diehl et al., 1978; Eimas and Corbit, 1973; Holt, 2005; Holt and Lotto, 2002). The stimuli in this analysis were those near or at the phonemic boundary and occurred at least once after a precursor sentence. The stimuli that met these conditions were: 0, +5, +10, +15, +20, +25, and +35 ms of VOT. Percent 'ga' was obtained under two conditions: once when it occurred immediately after a precursor sentence, and once when it occurred as the second stimulus following the precursor sentence. Significant differences across positions were considered an indication of context effects. For the sake of clarity, the terms first and second position are used to indicate the position of the stimulus relative to a precursor sentence.

Separate analyses of variance were performed for stimuli with 0, +5, +10, +15, +20, +25, and +35 ms of VOT. Percent 'ga' was compared in a $2 \times 2 \times 2$ (group $\times$ language context $\times$ stimulus position after precursor sentence) analysis of variance with repeated measures (language context $\times$ stimulus position after precursor sentence). We were interested in the effect of precursor sentences (i.e., language context) on participants' phonetic judgments regardless of their language status (monolingual or bilingual). Table 3 shows the percent response of judging 'ga' in first and second positions relative to a precursor sentence for both bilinguals and monolinguals in the two language contexts, and the interaction of interest (language context $\times$ stimulus position).

The results showed that percent 'ga' in second position was in general larger than percent 'ga' in first position (Table 3). However the interaction between language context and stimulus position was not significant, indicating that phonetic judgments were not affected by the acoustic history in the precursor sentences.

3.3. Did the level of confidence in English and Spanish influence the magnitude of the phonemic boundary shift?

The third goal of the present investigation was to relate the magnitude of the shift in the phonemic boundary to the level of confidence in using Spanish and English. It was expected that bilinguals will adopt the language-appropriate VOT boundary criterion of the language context in use. On the other hand, monolinguals will adopt the VOT boundary criterion of their native language regardless of the language context. The confidence in using English and Spanish was defined by 4 fields: confidence in speaking, reading, comprehending, and writing in English and Spanish. Participants responded using a Likert scale from 0 to 7 (7 = “like a native speaker”, and 0 = “none”; see Section 2).

A metric based on participants' proficiency in both languages was established. The obtained self-reports from both languages were added and divided by the maximum outcome (56). However, this approach has the inconvenience that it does not control for the fact that different self-reports in English and Spanish confidence can produce the same final score. For example, a person with a score of 6 in confidence in speaking Spanish and a score of 7 in confidence in speaking English would add to score of 13. On the other hand, another person rating him self 7 in Spanish and 6 in English will add to the same result. For this reason, the first step in creating the language metric was to give an extra “weight” to each of the Spanish fields. Specifically, the scores in the Spanish fields were multiplied by a constant of 2. In this way, the first person in the previous example will end having a score of 19 and the second person will end with a score of 20.

Finally, the scores obtained in the English fields were added with those obtained in the Spanish fields and divided by 84 (maximum score). The final scale ranged from .3 to 1, but in order to make the scale friendlier the metric was rescaled to range from 0% to 100%; where 0% indicates no confident in Spanish and 100% means equally confident in English and Spanish.

The English–Spanish proficiency scores obtained from each participant were correlated with the magnitude of the phonemic boundary shift, and with the magnitude of percent change in judging ambiguous stimuli as ‘ga’ (0, +5, +10, +15, +20, +25, and +30 ms of VOT). Both scores, 50% crossover and changes in judging ‘ga’, are similar in the sense that represent the degree by which speech perception changed as a function of language contexts. The 50% crossover corresponds to the shift of the phonemic boundary by taking into account the 27 stimuli. On the other hand, changes in judging ‘ga’ represent the raw scores given to individual stimulus.

The magnitude of shift in the phonemic boundary was defined as the difference between the 50% crossover obtained in the Spanish and in the English language context (English minus Spanish). A positive VOT-difference indicates a phonemic boundary shift in the expected direction, and a negative VOT-difference indicates a phonemic boundary shift in the opposite direction. In a similar way, the magnitude of change in the percent in which ambiguous stimuli were judged as ‘ga’ was done by obtaining the percent-average from the 7 stimuli and subtracting it between language contexts (English minus Spanish). A positive value would indicate that ambiguous stimuli were judged more times as ‘ga’ in the English language context when compared with the Spanish language context.

Fig. 2 plots the 50% crossover VOT difference on the *x*-axis and level of English–Spanish confidence on the *y*-axis. The figure also includes the fitted line obtained by using linear regression analysis. The bilingual results showed a significant correlation between the phonemic displacement and the degree of confidence in using English and Spanish ($r = .518$, $p = .048$): participants with high confidence in using English and Spanish showed larger phonetic boundary shifts between language contexts. Monolinguals' phonemic boundaries

shifts were not related with the level of confidence in using English and Spanish ($r = .311$, $p = .260$). A similar outcome was found when correlating the percent in judging 'ga' with the level of confidence in using English and Spanish. Bilinguals, but not monolinguals showed a significant correlation between percent judging 'ga' and the degree of confidence in using English and Spanish ($r = .562$, $p = .029$; $r = .249$, $p = .371$, respectively).

Both results are in agreement with previous investigations that have revealed that the shift of the voicing boundary is correlated with L2 proficiency (Elman et al., 1977). That is, experienced Spanish-English bilinguals (early L2 learners) show larger language context effects than late L2 learners. The present results also showed that even though some monolinguals presented a shift in the voicing boundary across language context, their shifts were not correlated with L2 proficiency.

4. Discussion

Studies assessing the double phonemic boundary in bilinguals have reported dissimilar results. There is evidence suggesting that bilinguals have different phonemic boundaries from monolinguals and that the phonemic boundaries are constant across language context (e.g., Caramazza et al., 1973; Williams, 1977). Other researchers have suggested that the double phonemic boundary can be observed if bilinguals focus on the language of interest throughout the entire experiment (e.g., by using precursor sentences, see Elman et al., 1977). Indeed, using the precursor sentences procedure, several researchers have found that the phonemic boundary shifts depending on the language context (Flege and Eefting, 1987a; Hazan and Boulakia, 1993). Bohn and Flege (1993), however, found that the phonemic boundary for voicing shifted for both bilinguals and monolinguals according to the language context. Their results suggested that the shift in the voicing boundary might be the consequence of context effects caused by the precursor sentence methodology (Diehl et al., 1978; Eimas and Corbit, 1973; Holt, 2005; Holt and Lotto, 2002).

The general aim of this investigation was to assess the double phonemic boundary in bilinguals while examining possible phonetic context effects that may influence participants' phonetic judgments during the perception task. In order to accomplish this goal two methodologies were implemented. First, bilingual and monolingual speakers of Spanish and English performed the task in two language contexts. Second, participants' phonetic judgments occurring in first position and second position following a precursor sentence were compared.

4.1. Double phonemic boundary and phonetic context effects

The first aspect investigated was the effect of language contexts on participants' responses. There was a significant main effect for language context whether the shift in the phonetic boundary was calculated by Probit analyses or by the percent change in judging a stimulus to be 'ga'. Both methods showed a perceptual shift in the expected direction: (a) the voicing boundary shifted toward the voiced end of the VOT continuum in the Spanish language context, and toward the voiceless end of the VOT continuum in the English language context, and (b) ambiguous stimuli were less likely to be labeled as 'ga' in the Spanish language context than in the English language context. These results are in agreement with previous research showing that language contexts can affect the perception of speech sounds that are close or at the phonemic boundary (Elman et al., 1977; Flege and Eefting, 1987a; Hazan and Boulakia, 1993; Bohn and Flege, 1993).

Phonetic context effects were investigated by comparing the percent 'ga' for stimuli occurring immediately after a precursor sentence and percent "ga" for the same stimuli occurring in a subsequent position. The results showed that the precursor sentences did not affect participants' phonetic judgments. This outcome implies that rather than precursor sentences affecting only

the phonetic judgments followed by them, it implies that the sentences were successful in establishing a language context. However, it was intriguing that monolingual English speakers showed a shift in the phonetic boundary. It is possible that monolinguals' low confidence in Spanish (Mean = .26, SD = 0.15) was sufficient to produce a shift in the phonemic boundary. This would be consistent with reports that monolinguals learning a second language show shifts in the phonemic boundary between language contexts (Flege and Eefting, 1987b).

Interpretation of the results of monolingual participants is complicated by the fact that Texas has a large population of Spanish speakers, and therefore Spanish is part of daily life for "English monolingual" participants. In addition, Spanish language precursor sentences were grammatically simple and with clear enunciation and may have been understood by monolingual participants. Nonetheless, the effect of language context was inclined to be larger in bilinguals' 50% crossover (English mean = 21.19 ms, SD = 9.04; Spanish mean = 15.82, SD = 8.92) than in monolinguals' 50% crossover (English mean = 24.85 ms, SD = 6.89; Spanish mean = 22.22 ms, SD = 8.40).

A second aim of this investigation was comparison of perception along the stimulus continuum for bilinguals and monolinguals. We expected that bilinguals' L2 phonological processors would be contaminated by their first language (i.e., Spanish see Caramazza et al., 1973; Williams, 1977). That is, bilinguals' phonemic boundary was expected to be at intermediate VOT values from those of monolinguals speakers of English and Spanish. However, in this study we found that bilinguals showed an "English-like" phonemic boundary even though their first language was Spanish. This suggests that perhaps bilinguals were more English dominant the time when they were tested. In a relevant study, Kohnert et al. (1999) assessed L2 proficiency from a sample of bilinguals that had learned Spanish as their first language. The participants' ages ranged from 5 years old to young adults. It was shown that participants' dominant language changed from Spanish to English as a function of age. The pattern changed from Spanish dominant (ages 5–7) to English dominant (adolescents and young adults) transitioning through a period of relatively balanced proficiency in Spanish and in English (ages 8–13). Indeed, bilinguals in the present study reported that they used English more percent of the time to talk to teachers, classmates and friends than Spanish (see Table 1), which indicates that at the time they participated in the study, they were more English dominant.

We also investigated group effects for phonemic boundary shifts across language contexts. The interaction between group and language context for the 50% crossover was not significant. However, there was a significant group by language context interaction for one stimulus, +5 ms of VOT (percent judged as 'ga'). Bilinguals, but not monolinguals, were significantly more likely to judge +5 ms of VOT as 'ga' in the English language context than in the Spanish language context. However, an effect observed for single stimulus in the ambiguous VOT zone is weak support for double phonemic representation.

4.2. The double phonemic boundary and confidence in english and spanish

The final goal of the present study was to determine whether the perceptual switching was contingent on English–Spanish confidence. We expected bilinguals would show a language-appropriate VOT boundary for each language context, hence a big boundary shift. Monolinguals in the contrary were expected to adopt the VOT boundary criterion of their native language and hence no boundary shift across language contexts. The results of this investigation were consistent with this prediction. Specifically, we obtained a significant positive correlation between the magnitude of the voicing boundary shift and the degree of English–Spanish confidence for bilinguals, but not for monolinguals. Close examination of Fig. 2 shows that some of the monolingual participants presented a shift in the voicing boundary, but overall there was no significant correlation between their English–Spanish confidence and the magnitude of their voicing shifts.

In the present investigation, the degree of bilingualism was assessed based on Flege et al. (2002). Flege and colleagues showed that self-ratings on the ability to speak, understand, read, and write in L1 and L2 correlated positively with the age at which bilinguals were exposed to L2. The authors concluded that to some extent these measures accurately quantify the degree of bilingualism. Still, assessing the degree of bilingualism is not straightforward. In the present investigation bilinguals' English–Spanish level of confidence varied across participants. In fact the three lowest confidence-values come from the three bilingual participants that reported to have learned English as their first language and Spanish as their second language. Researchers have agreed that finding bilinguals who are equally fluent in both languages is the exception rather than the rule (Grosjean, 1982).

To our knowledge this is the first investigation in which monolinguals' confidence in English and Spanish is assessed and compared with their perceptual shifts. However, the monolingual data should be interpreted with caution since the results showed that nearly all monolinguals reported a certain degree of confidence in Spanish (see Fig. 2). Defining monolingualism can be as complicated as defining a bilingualism. When college students are used as monolingual participants, they have rarely been exposed only to their native language. In most cases, these participants learned the basics of a second language during high school and/or college.

4.3. The establishment of the language contexts

Although language context were properly established by means of the precursor sentence methodology, two suggestions are mention to improve future research involving the assessment of bilinguals' double phonemic boundary.

First, it may not be ideal to test the double phonemic boundary in bilinguals with a speech continuum that includes three phonetic contrasts (voicing lead, short-lag, and long-lag). It may be more informative to test bilinguals on two speech continua: (1) voicing lead and short-lag speech tokens; and (2) short-lag and long-lag speech tokens. In this way, the phonetic rules embedded in the speech continua will be in agreement with each of the language contexts (e.g., Spanish and English). For example, Keating and colleagues (1981) showed that Polish speakers (who are comparable with Spanish speakers in terms of stops consonants' manner of articulation) placed the phonemic boundary at different VOT values depending on the VOT range used in the speech continuum. Polish speakers placed the phonemic boundary at +5 ms of VOT when using a VOT range from −100 to +20 ms. The same Polish participants placed the phonemic boundary at +20 ms of VOT when tested in a VOT range from −20 to +80 ms. In contrast, monolingual speakers of English did not showed shifts in the phonetic boundary across the speech continua. Although Keating and collaborators' experiment was designed to test range effects, these results suggest that it may be productive to test bilinguals and monolinguals on a Spanish-like continuum and an English-like continuum for the purpose of assessing the double phonemic boundary.

Second, establishing a language context is not a simple task. First, the language context must be constant throughout the perceptual task (Elman et al., 1977; Flege and Eefting, 1987a,b; Hazan and Boulakia, 1993), yet not influence participants' phonetic judgments (Bohn and Flege, 1993). Perhaps, future investigations assessing bilinguals' double phonemic boundary should use methods which do not depend on attending to the stimuli. For example, use of electrophysiological measures associated with pre-attentive auditory discrimination (Näätänen, 1992) can establish a language context since participants can read a book in the language of interest while auditory discrimination is assessed.

5. Conclusion

Overall, four outcomes deserve mention: (1) Language contexts produced an effect on the placement of the phonemic boundary which was in accordance with the language context. (2) The acoustic history in the precursor sentences showed not to be the source affecting participants' phonetic judgments. (3) It was found that bilinguals', but not monolinguals' magnitude of the shift in the phonemic boundary varied as a function of level of confidence in English and Spanish. (4) Although bilinguals did not show a significant shift in the phonemic boundary *per se*, the correlation outcome suggests that a perceptual shift is associated with high level of confidence in English and Spanish. This outcome is in agreement with Sundara and colleagues (2008) who reported that highly confident L2 bilinguals (balanced bilinguals) are more likely to possess a double phonemic representation.

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Fig. 1.

Phonemic boundaries (50% point) in two language contexts derived from curves fitted via Probit analysis. Left panel shows data from bilinguals; right panel shows data from monolinguals. Note: percent values (left y-axis) are indicated with squares and probability values (right y-axis) are indicated with lines. Magnified squares represent stimulus +5 ms VOT.

Fig. 2.

L2 proficiency and magnitude of the phonemic boundary shift scatterplots. Note: L2 proficiency is plotted against VOT difference for bilinguals and monolinguals.

Table 1

Participants' self-reported language proficiency and language usage.

Self-reported language proficiency											
	N	Speak		Read		Write		Comprehend		Total	
		English		Spanish		English		Spanish		English	
		English	Spanish	English	Spanish	English	Spanish	English	Spanish	English	Spanish
Bilingual	15	6.67 SD 0.16	5.73 SD 0.32	6.60 SD 0.16	5.80 SD 0.43	6.33 SD 0.21	4.93 SD 0.40	6.53 SD 0.17	5.93 SD 0.27	6.53 SD 0.144	5.60 SD 0.45
Monolingual	15	7.00 SD 0.00	1.80 SD 0.24	7.00 SD 0.00	2.00 SD 0.31	7.00 SD 0.00	1.73 SD 0.40	7.00 SD 0.00	1.87 SD 0.26	7.00 SD 0.0	1.85 SD 0.11
Self-reported language usage											
	N	With parents		With siblings		With teachers		With classmates		With friends	
		English%		English%		English%		English%		English%	
		English%	Spanish%	English%	Spanish%	English%	Spanish%	English%	Spanish%	English%	Spanish%
Bilingual	15	26	74	59	41	89	11	85	15	74	26
Monolingual	15	99	1	100	0	100	0	100	1	99	1

Table 2

Mean percent of judging ‘ga’ as a function of VOT.

Stimulus VOT (ms)	Language contexts			Effects		
	English	Spanish		Group	Language	G × L
	Bilingual N = 15	Monolingual N = 15	Bilingual N = 15	Monolingual N = 15	df = (1,28)	
	M(SD) %	M(SD) %	M(SD) %	M(SD) %	F	F
0	94.7 (9.9)	99.3 (2.6)	91.3 (15.1)	95.3 (10.6)	1.81	3.06
5	96.7 (6.2)	96.7 (8.2)	86.7 (19.1)	96.7 (7.2)	1.83	6.56*
10	89.3 (13.9)	92 (10.8)	84 (25.3)	91.3 (14.1)	0.83	1.13
15	72.7 (26.6)	80 (24.8)	58.7 (27.7)	68 (26.8)	0.82	18.68*
20	40 (30.7)	62 (36.3)	29.3 (30.6)	46.7 (28.9)	3.21	12.17*
25	34 (32.2)	52 (34.1)	26.7 (27.7)	37.3 (29.6)	1.78	9.53*
30	22.7 (29.4)	29.3 (19.4)	10.7 (14.9)	26 (24.7)	2.36	3.30
						1.05

Note: df = degrees of freedom; G × L = interaction between group and language.

* .05 ≥ p ≥ .01.

Table 3
Mean percent of judging ‘ga’ as a function of stimuli position relative to a precursor sentence.

Stimulus VOT (ms)	Language contexts				Interaction	
	English <i>N</i> = 30	Spanish <i>N</i> = 30		<i>L</i> × <i>P</i> df = (1,28)	<i>F</i>	
		1st	2nd			
	<i>M</i> (SD) %	<i>M</i> (SD) %	1st <i>M</i> (SD) %	2nd <i>M</i> (SD) %		
0	95 (15)	96 (13)	86 (26)	92 (23)	0.384	
5	93 (25)	100 (0)	86 (34)	96 (18)	0.318	
10	80 (41)	93 (25)	83 (38)	93 (25)	0.14	
15	75 (39)	80 (41)	50 (43)	70 (46)	1.734	
20	52 (44)	60 (50)	30 (34)	46 (51)	0.39	
25	48 (40)	43 (50)	25 (36)	40 (50)	2.8	
35	23 (43)	6 (17)	10 (30)	6 (17)	2.01	

Note: None of the *F*-tests showed a *p*-value ≤ .05; *df* = degrees of freedom; *L* × *P* = interaction between language and stimuli position after precursor sentence.