Age effects and the discrimination of consonantal and vocalic contrasts in heritage and native Spanish

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This study explores the perception of consonantal and vocalic contrasts in two groups of Spanish-English bilingual speakers: heritage speakers and long-term immigrants. We test the discrimination of Spanish stops and mid and high vowels via an AX discrimination task with natural stimuli consisting of real Spanish words. Overall, results revealed no significant differences between heritage speakers and long-term immigrants in their discrimination of Spanish stops and vowels. Both groups were more accurate in their discrimination of vowels than of consonants. As for the discrimination of stops, positional and place effects were observed; i.e. a higher proportion of errors was found in word-initial position and with dorsals. We argue that contact with English does not necessarily affect the discrimination of the Spanish contrasts. Implications of these results for maturational approaches to final L2 attainment are discussed.

1. Introduction

To what extent does language contact affect our perception of consonantal and vocalic contrasts? We seek to answer this question by comparing the perception of Spanish stops and vowels (mid and high) by two groups of bilingual speakers (heritage speakers and long-term immigrants) and a group of Spanish monolinguals. The two bilingual groups tested here spoke Spanish from birth but differed in their age of onset of acquisition of English. Whereas the heritage speakers (HSs) were exposed to English early on and received formal education in English, the long-term immigrants (LTIs) were exposed to English after puberty and were educated in Spanish. In addition, participants within each group differ in their language proficiency, use, and self-reported degree of comfort using each of the languages. Thus, these populations allow us to test theories on the role that maturational constraints and age of exposure on the perception of segmental contrasts.

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Previous research shows a strong correlation between native-like attainment in a second language (L2) and age of arrival (AOA) and L2 exposure (Abrahamsson and Hyltenstam 2009; Boomershine, Birdsong, Bialystok, Mack, Sung, and Tsukada 2006; Flege, Yeni-Komshian, and Liu 1999). The argument is that after a certain age (12 to 14 for most authors) L2 learners are unable to fully acquire L2 speech patterns not present in their first language (L1) due to maturational reasons (Hyltenstam and Abrahamsson 2003). However, the extent and the sources of difficulties in the native-like attainment of phonological patterns are still not clear. Recent research documents comparable patterns of morphosyntactic (Cuza 2010; Sorace 2000) and phonetic divergence (Hopp and Schmid 2011; Major 2009) between near-native L2 learners and long-term immigrants undergoing L1 attrition, casting doubts on maturational constraints in language learning.

We contribute to existing research by comparing the effect of language contact and cross-linguistic influence (CLI) in two different types of bilingual populations largely underexplored in the literature: Spanish heritage speakers and long-term immigrants. This comparison is important for shedding light on existing proposals on the source and nature of heritage language development and for helping us understand the linguistic competence of bilingual speakers as far as phonological development is concerned. Specifically, we investigate the discrimination of segmental contrasts that have been reported to be vulnerable to CLI and L1 attrition, namely Spanish voiceless and voiced stops in initial and medial position (1a–1c) and /e/ vs. /i/ and /o/ vs. /u/ (2) in stressed and unstressed syllables, as shown in Table 1:

Table 1. Segmental contrasts under analysis

1. **Initial Position**	**Medial Position**
a. [b]ata vs. [p]ata ('robe' vs. 'foot')	a. su[β]e vs. su[p]e ('go up' vs. 'I knew')
b. [g]iso vs. [k]iso ('stew' vs. 's/he wanted')	b. pe[ɣ]ar vs. pe[k]ar ('to hit' vs. 'to sin')
c. [d]una vs. [t]una ('dune' vs. 'prickly pear')	c. me[ð]í vs. me[t]í ('I measured' vs. 'I put')
2. **Stressed syllable**	**Unstressed syllable**
a. qu[e]so vs. qu[i]so ('cheese' vs. 's/he wanted')	a. p[e]sar vs. p[i]sar ('to weigh' vs. 'to step on')
b. p[o]zo vs. p[u]so ('hole' vs. 's/he put')	b. d[o]rar vs. d[u]rar ('to tan' vs. 'to last')

If maturational approaches to final L2 attainment are correct, we would expect HSs and LTIs to behave similarly, as both groups acquired Spanish before puberty. However, if prolonged exposure to a second language before maturation affects perception, HSs might have difficulties in their discrimination of Spanish contrasts due to reduced Spanish input and use. In particular, it should prove difficult for these speakers to discriminate Spanish voiced and voiceless stops because they map onto one English phonetic category (i.e. voiced stops); these participants are also expected to confuse mid-vowels (front-vowels in particular) because the Spanish [e] overlaps with the English [i] (Bradlow 1995). LTIs, in contrast, should behave closer to the attested monolingual patterns, as they were exposed to English after maturation (MacKay, Flege, Piske, and Schirru, 2001).

In what follows, we review the background research (Section 2) necessary for supporting our hypotheses (Section 3) and motivating our methodology (Section 4). Results are reported in Section 5 followed by Sections 6 and 7, in which we evaluate our hypotheses and present our conclusions.

2. Background

2.1 English and Spanish stops and mid/high vowels

Spanish and English have a system of six stop phonemes that contrast in place and voicing. Although from a phonological point of view the systems are rather similar, the phonetic implementation of the voicing contrast is different. In Spanish, voiceless stops are not aspirated and voiced stops are prevoiced; i.e. the vocal folds keep vibrating throughout the closure. These differences have several acoustic correlates (duration of preceding vowel, duration of stop closure, F0 patterns at the offset of the closure) but the phonetic differences in voicing have been mostly analyzed in the literature in terms of the Voice Onset Time or VOT (Abramson and Lisker 1970, 1973; Lisker and Abramson 1964, 1970). VOT is the temporal relation between the release of the stop consonant and the onset of glottal pulsing (or periodicity). This acoustic parameter has been shown to capture cross-linguistic differences in stop voicing in production and perception. Both English and Spanish voiceless stops have positive VOTs. Yet, one important difference between these two languages is that English VOT is longer than Spanish VOT; i.e. the vocal folds start vibrating earlier in Spanish than in English. As for voiced stops in Spanish, VOT is negative; that is, periodicity starts before the release. Yet, in English, the VOT of /b, d, g/ is short and positive.[1] Thus, the boundaries for the perception of a given stop as voiced or voiceless are different in each language. In Spanish, the cross-over point, that is, the point at which perception of a voiced stop changes to voiceless and vice versa, has been reported to be around 14 ms (Abramson and Lisker 1973), but later studies showed that this point varies from dialect to dialect, with a reported cross-dialectal range from -10ms to -5ms (Rosner, López-Bascuas, García-Albea and Fahey 2000; Williams 1977b). In English, stops with a VOT of 25ms

1. Space limitations preclude our presentation of examples and spectrograms of voiced and voiceless stops. For more detailed discussion, please see Thomas (2011) for English and Hualde (2005) for Spanish.

or higher have been reported to be perceived as voiceless (Lisker and Abramson 1970). VOT differences are sensitive to place of articulation. Specifically, differences are larger for labials and dentals than for velars (Williams 1977a; Rosner et al. 2000). The above discussion, however, is relevant only for Spanish stops in absolute word-initial position. In word medial position, there is an additional manner contrast. Voiced stops are realized as approximants (for a more detailed analysis of the distribution of stop and approximant alternations, see Hualde (2005) and Perissinotto (1975), although the latter used the term 'fricative' instead of 'approximant'). Thus, VOT is not relevant here to distinguish voiced and voiceless stops; voicing and duration, instead, continue to distinguish both types of stops.

As opposed to stop consonants, Spanish and English have largely different vocalic inventories. Whereas Spanish has five phonemic vowels, general American English has been described as having a system of either 11 or 10 vowels (see Stockwell and Bowen 1965 for a comparison of both systems). In particular, English has four high vowels /i u ɪ ʊ/ whereas Spanish has only two /i u/. The mid vowels /e o/ are diphthongized in English but not in Spanish. Beyond these phonological differences, additional phonetic differences have been reported for some varieties of American English and Peninsular Spanish. In a comparative study in which only the vowels that are present in both languages were analyzed, Bradlow (1995) found that English vowels were more fronted than the corresponding vowels in Spanish. Morrison (2006) obtained similar results when comparing only English and Spanish front vowels.

2.2 Cross-linguistic speech perception: Stops and vowels

A recurrent question in L2 acquisition and bilingualism research is how bilinguals handle the different languages. Are the languages separated or integrated? Experimental studies that have looked at early bilinguals have reported evidence for and against integration (Genesee, 1989; Paradis and Genesee 1996; Volterra and Taeschner 1978).

The integration hypothesis suggests that bilinguals, albeit showing differences in performance when tested in the different language contexts, consistently differ from monolinguals, showing identification scores that are somewhere between the values obtained for the monolinguals of each of the languages. This hypothesis has been proposed by Caramazza, Yeni-Komshian, Zurif and Carbone (1973) as a result of their study of English-French bilinguals. The authors tested bilingual speakers on their ability to identify French and English voicing contrasts using synthetic CV syllables with the consonant, which could be any of the six stops, being followed by the vowel [a]. Their results revealed that French-English bilinguals showed scores that were between those reported for each monolingual group. In other words, the perception of bilinguals showed interference from one language to the other. Williams (1977b) confirmed Caramazza et al.'s results with a group of Spanish-English bilinguals. This study, which involved discrimination and identification tasks, used stimuli consisting of synthetic /pa ~ ba/ syllables. The two groups of monolingual subjects showed different perceptual crossovers with those of bilinguals occupying an intermediate position.

Elman, Diehl, and Buchwald (1977), using natural speech and CV stimuli (/ba pa/), proposed an alternative hypothesis. Three groups of subjects, monolingual English speakers, monolingual Spanish speakers, and English-Spanish bilinguals, were asked to label stimuli embedded in different language contexts according to the subjects' native language. Bilingual subjects heard the test stimuli in both English and Spanish. Their results showed that the two monolingual groups differed substantially in their identification performance, with English speakers tending to label most of the syllables as /ba/ and Spanish speakers tending to label most of them as /pa/. The bilingual subjects perceived a reliably greater number of the test items as /ba/ in the English than in the Spanish context. Based on these results, Elman et al. concluded that bilinguals vary their placement of category boundaries as a function of language context in which the stimuli were presented. These results were recently confirmed by García-Sierra, Diehl and Champlin (2009) in a similar study that used /ga/ ~ /ka/ synthetic syllables.

Differences in the results have been attributed to the use of synthetic vs. natural stimuli (i.e., Elman et al. 1977) and identification vs. discrimination tasks. This claim has been recently supported by Antoniou, Tyler and Best (2012) who argued that differences reported in the literature could be the consequence of not controlling for language mode or language dominance. Participants were tested separately on an English and Greek mode on their perception of labial and coronal stops in word-initial and intervocalic position. Stimuli were recorded by native speakers of each language and used for a categorization task (with goodness of fit ratings) and an ABX discrimination task. Results revealed that speakers behaved differently in each of the tasks. In the ABX discrimination task, bilinguals patterned with monolinguals of the same dominant language. In the categorization task bilinguals instead behaved more like monolinguals of the language that was activated during the experiment. Crucially, there was no evidence that participants mixed the phonological categories of the respective language. This study has interesting implications for our work. First, it shows that task-effects are expected and that language dominance plays a crucial role in discrimination tasks. Second, results revealed that participants were able to keep the categories apart in word initial and medial position. Finally, these results further demonstrate the flexibility of bilinguals.

Research on vowels clearly points to the influence of the L1 on the L2 even in the case of early and fluent Spanish-Catalan bilinguals (Sebastián-Gallés and Soto Franco 1999; Bosch and Sebastián-Gallés 2003). Most of the studies that have compared the perception of Spanish and English vowels have focused on English, which is not surprising given the differences described in the previous section.[2] Of those studies, the majority has explored the perception of English vowels by L2 Spanish speakers (Fox, Flege and Munro 1995). A recent exception to this tendency is the work by Boomershine (2013), where she analyzes the perceived similarity between minimal pairs of English front vowels by different bilingual groups (native English-Advanced L2 Spanish, native Spanish-Advanced L2 English and heritage Spanish speakers). An interesting finding is that Spanish heritage speakers patterned with Spanish monolingual speakers, when judging the degree of similarity between the members of a given English minimal pair. Research on L1 English-L2 Spanish speakers (Morrison 2003, 2006) reveals more confusion with front than with back Spanish vowels. In particular, Morrison reports a bi-directional confusion with front mid-high vowels, with /i/ being confused with /e/ more often than /e/ with /i/. Back vowels also showed some instances of misperceptions but only in one direction (/o/ was perceived as /u/). The number of errors in perception, however, was rather small. The roles of inventory size and language experience repeatedly occur as factors in L2 and bilingualism research. As in the case of consonants, perceptual flexibility has also been demonstrated for vowels (e.g. Fox et al. 1995).

As a whole, these studies show the importance of (i) controlling for speakers' variables, such as language proficiency, use and dominance; (ii) language modes (or context); (iii) task effects (identification vs. discrimination); and (iv) type of stimuli (natural vs. synthetic). Thus, in the present study, we controlled for participants AOA and length of residency (LOR) in the U.S.; we tested our participants in Spanish and used a discrimination task with natural stimuli. However, we departed from previous studies in the use of minimal pairs, which tested the target contrasts in a variety of phonetic environments.

3. Research questions and hypotheses

Based on previous research on bilingualism and the existing differences between English and Spanish, we pose the following research questions:

> RQ1: Do Spanish HSs and LTIs differ in their discrimination of Spanish stops and mid and high vowels to the point of not being able to fully discriminate them?
> RQ2: If differences are found, can they be attributed to differences in language-use patterns, age of onset of bilingualism, and knowledge of Spanish (as reflected in their proficiency scores)?

2. Catalan was the target language in previous research with Spanish-Catalan bilinguals, which also has a larger phonemic inventory than Spanish.

If maturational constraints play a role, we hypothesize that Spanish HSs and LTIs should behave similarly since both groups acquired Spanish before puberty. However, if contact with English plays a role, then Spanish HSs should differ from the other two groups, since they were exposed to English before puberty.

With regard to the specific contrasts under study, based on previous descriptions and on the analysis of our own perception stimuli, we pose the following hypotheses:

1. For consonants, there will be more confusion between voiced and voiceless stops in word-initial than in word-medial position. With regard to their place of articulation, there will be more confusion with dorsals than with labials and coronals.
2. For vowels, we expect more confusion with front vowels than with back vowels. In addition, we anticipate more confusion with unstressed vowels than with stressed ones.

4. The Study

4.1 Participants

A total of forty-five participants (n=45) took part in the study: 25 HSs, 6 LTIs and 14 recent arrivals serving as controls. The participants resided in West Lafayette/Lafayette, Indiana, and in El Paso, Texas. All of them were university students enrolled in different programs at two major universities. Following previous research (Montrul 2008; Silva-Corvalán 2003), the HSs were second or first generation immigrants who acquired their native language (Mexican Spanish) during early childhood at home or in another natural context where a majority language (English) was spoken. They were either born and raised in the U.S. or immigrated permanently to the U.S. at or before the age of 12.[3] The LTIs arrived from Mexico after the age of 13 with a fully developed L1 grammar.

Participants completed an adult language background questionnaire, which elicited information on place of birth, primary language of schooling, and patterns of language use. This questionnaire also elicited a self-proficiency judgment in both English and Spanish in the four linguistic skills via a Likert scale, ranging from basic/limited (1) to excellent/native (4). In addition to the self-proficiency measure, participants completed an independent proficiency task, adapted from the *Diploma de Español*

3. For the purpose of this study, we took the age of 12 as the cut-off point to differentiate HSs from LTIs. This classification is based on previous research in the L2 acquisition of phonology, which suggests significant long-term effects in the lack of native-like attainment past this age (Long 1990; Scovel 1988).

como Lengua Segunda (DELE). Following previous research using the same methodology, participants were grouped as advanced (scores between 40 and 50 points), intermediate (scores between 30 and 39), and beginners (scores between 0 and 29) (Cuza, Pérez-Leroux and Sánchez 2013).

The HSs were divided into two groups based on their proficiency score in the DELE test (see Table 2): advanced HSs (n=19; DELE score, 44/50) and intermediate HSs (n=6; DELE score 35/50). The advanced group included participants born and raised in the U.S. and participants who came to the U.S. at an early age (Table 2). Of those participants not born in the U.S., all of them except for one came from the state of Chihuahua, Mexico. Table 2 shows their self-proficiency ratings and language use.

LTIs (n=6) included first generation immigrants from the state of Chihuahua, Mexico (age at testing, *M*= 39; AOA, *M*=26; LOR, *M*=15), except from one participant who came from Mexico City.[4] Participants were tested in El Paso, Texas. See Table 2.

The control group consisted of fourteen (n=14) recent arrivals to El Paso, Texas, from the state of Chihuahua, Mexico. They were all university students enrolled in an ESL program (age at testing, *M*= 21; AOA, M=21; LOR, *M*=9 months). See Table 2.

4.2 Stimuli

Stimuli consisted of real Spanish words. For the voiced and voiceless stops, 43 minimal pairs were used, which were controlled for place of articulation (/b/ vs. /p/, /d/ vs. /t/, /g/ vs. /k/), position in the word (initial vs. medial), following vowel (/a, e, i, o u/) and stress (tonic vs. post-tonic). For vowels, 36 minimal pairs were used, controlled for type of vowel (/e/ vs. /i/, /o/ vs. /u/) and stress (tonic vs. post-tonic). Stimuli are included in Appendix A.

Stimuli were recorded twice by a native Spanish speaker from Ciudad Juárez, Chihuahua, Mexico. All stimuli, with the exception of those for stop consonants in initial position (which were recorded using a list form) were produced in a carrier phrase: *Digo X para ti* (‘*I say X again*’). Stimuli were extracted from the list of isolated words or from the carrier phrase and presented in pairs to participants. Below, we summarize the acoustic characteristics of the stimuli.

4.2.1 *Acoustic analysis of our own perception stimuli*

The stimuli used to design the experiment were acoustically analyzed with PRAAT (Boersma 2001) to ensure that the voiced and voiceless stops were sufficiently different.

4. The higher number of HSs compared to LTIs stems from the fact that recruitment took place in Spanish courses attended mostly by HSs who wanted to increase their knowledge of Spanish.

Table 2. Participants' demographic information

	Advanced HSs (n=19)			Intermediate HSs (n=6)			LTIs (n=6)			Controls (n=14)		
Mean age at testing (SD)	22 (2.33)			24 (7.4)			32(13.19)			21 (6.85)		
Place of birth	US		Mexico	US		Mexico	Mexico			Mexico		
Mean AOA	–		10	–		6	23			21		
Mean LOR	–		14	–		20	10			0;9		
DELE score	44/50			35/50			44/50			44		
	SPAN	ENG	BOTH	SPAN	ENG	BOTH	SPAN	ENG	BOTH	SPAN	ENG	BOTH
Language use												
Home	80%	10%	10%	38%	38%	24%	83%	17%	0%	93%	0%	7%
School	15%	70%	15%	0%	88%	12%	50%	17%	33%	71%	7%	22%
Work	6%	59%	35%	0%	86%	14%	25%	50%	25%	100%	0%	0%
Social situations	30%	30%	40%	0%	100%	0%	80%	0%	20%	85%	0%	15%
	SPAN	ENG	BOTH	SPAN	ENG	BOTH	SPAN	ENG	BOTH	SPAN	ENG	BOTH
More comfortable language	15%	15%	70%	0%	63%	38%	80%	0%	20%	93%	0%	7%

The acoustic parameters analyzed were Voice Onset Time (VOT) and Percentage Voicing (%V). The results are summarized in Table 3.

Table 3. Summary of the acoustic analysis of voiced and voiceless stops used in the perception stimuli

	/p/	/t/	/k/	/b/	/d/	/g/
VOT (ms) word initial	10.49	15.57	21.95	–55.72	–85.70	–63.36
VOT (ms) word medial	7.01	16.26	37.59	–	–16.79[5]	–7.89
%V word initial	24.92	20.02	12.83	96.58	98.78	78.83
%V word medial	4.67	3.06	2.51	90.26	72.62	93.25

These results show that the stimuli used for our perception experiment displayed a clear difference between voiced and voiceless stops at each place of articulation. As in previous studies, voiced stops are fully voiced and have a long negative VOT. Voiceless stops have a short positive VOT (Abramson and Lisker 1973). The values for voiceless stops in initial position are similar to those reported for Castilian Spanish (Rosner et al. 2000), but our voiced stops in initial position had shorter voicing lead than in Castilian Spanish (/b/ –91.5, /d/ –91.6, /g/ –73.7). Yet, as stated by Williams (1977a) and confirmed by the results reported by Rosner et al. (2000), Spanish VOT values seem to vary across dialects. The values for stops in intervocalic position are also consistent with results previously reported for other Spanish dialects (Lewis 2000). In particular, these results are similar to those obtained by Lewis for the Colombian speakers in his study (VOT: /p/ 12.77; /t/ 18.72; /k/ 30.4), although the values for percentage voicing obtained here are slightly higher than Lewis' (/p/ 14%; /t/ 15%; /k/ 6.8%). Finally, although dorsals do not show the smallest difference in VOT in our corpus, the values obtained for percentage voicing motivate our hypothesis. In summary, as stated earlier, the values presented in Table 3 show clear voicing contrasts between voiced and voiceless stops.

The F1 and F2 of the vowels used to test the discrimination of /e/ vs. /i/ and /o/ vs. /u/ were measured in Bark. The average values for the vowels in stressed (S) and unstressed (U) positions are listed in Table 4:

5. VOT in medial position was measured when relevant (i.e. with stops in absolute initial position). In the variety under investigation this included the realization of /d/ in *ardo* 'burn' and /g/ in *rasgo* 'tear', which are realized as stops, as opposed to the most frequent approximant realization observed in other dialects. All cases of /b/ in medial position were realized as approximants; thus VOT was not measured.

Table 4. Mean F1-F2 values (in Bark) for the vowels [e, i, o, u] in the perception stimuli

	[e]		[i]		[o]		[u]	
	S	U	S	U	S	U	S	U
F1	5.5±0.15	5.3±0.21	3.7±0.30	3.4±0.22	5.6±0.23	5.4±0.18	3.7±0.70	4.5±0.26
F2	13.2±0.41	13.2±0.47	14±0.26	14.2±0.26	8.4±0.21	8.7±0.45	7.3±0.74	7.6±0.94

The F1-F2 values displayed in Table 4 are very close to those reported by Morrison and Escudero (2007) for Peruvian Spanish, yet our F1 for [i] and [u] are slightly lower (Peruvian [i] and [u] are 4.2). Table 4 shows that the vowels used in our perceptual experiment were distinctively produced and that the differences in formant values were slightly lower in post-tonic than in tonic positions.[6]

4.3 Procedure

An AX discrimination task was used to test our hypotheses, where 'X' was either different or similar to 'A'.[7] Members of the pair were separated by a 4s ISI (inter-stimulus interval). After hearing the second item, the participant had to decide whether the two items were the same or different by pressing either a red or a green button on a response pad connected to the computer running Superlab Pro 4.1. After selecting a response, a one second pause was inserted, and the next pair was presented.

The experiment was conducted in two sessions (one for consonants and the other one for vowels); participants sat in a quiet room, wearing headphones. Both sessions were conducted completely in Spanish. The first session had a total of 129 pairs. There was a break after 45 trials, for a total of 2 breaks. The second session included a total of 108 pairs. A break was provided after 40 trials, for a total of 2 breaks.

For every pair of stimuli the following information was recorded by Superlab: Contrast (either /b, p/, /g, k/, /d, t/, /e, i/, /o, u/), the actual words used in each item of the pair (this was used later to retrieve the position, stress and context), whether the words were the same or different, the participant's response, and the response time of the participant (from the end of the second item in the pair to the moment the participant pressed a key).

6. The authors reported formant values in Hz, so we converted their values to Bark in order to compare them with our data.

7. The number of stimuli where X was different from A was 79 and where X was similar to A was 162.

5. Results

This section presents the results for each of the hypotheses tested. First, we analyze group performance; second, we discuss the results for consonants according to place of articulation and position; and third, we present the results for vowels according to stress and their position on the front-back axis.

5.1 Differences between groups

Performances between groups were compared based on overall errors and then further investigated for influence of linguistic variables included in the present study. First, a one-way ANOVA was conducted to compare performance per group, where vowels and consonants were collapsed in a single error score per speaker. Overall, controls had the lowest percentage of errors (6.75%) followed by intermediate HSs (9.8%), Advanced HSs (10.2%), and LTIs (13.6%).[8] Results showed a significant difference between groups (F (32, 41) = 4.01, p=0.014). A Tukey post-hoc test showed that the control group was significantly different from the LTIs. There were no significant differences in error scores between HSs and LTIs. The similarity between the bilingual groups suggests that contact with English may have an impact on their perception of segmental contrasts.

We investigated these results further by analyzing the performance of groups in each linguistic context. In every case we performed a one-way ANOVA, and when a significant difference was found, a Tukey post-hoc test was performed. For the discrimination of consonants (see Appendix B), there was a significant difference (F (3, 41) = 4.58, p=0.007) between controls (7.09%) and LTIs (16.9%), with the performance of HSs somewhere in between, but not significantly different from the other two groups. These results match the ones obtained for overall performance. For the discrimination of vowels, no significant differences were found between groups (F (3, 41) = 1.07, p=.37), although the pattern is similar to the one observed in consonants (see Appendix B).

Two further analyses were performed in order to determine whether there were further differences between groups. First, we analyzed the reaction times to explore whether the relative differences in accuracy between groups were due to differences in speed. Thus, we conducted a one-way ANOVA on the logarithms of the response time[9]

8. We also tested other groupings of the subjects based on DELE scores, most comfortable language and percentage of language use. In none of those cases significant differences between the groups were found.

9. We used the natural log of the response time measured in ms., because the distribution of the logarithms is closer to a Gaussian (normal) distribution than the actual response times.

to compare the performance between groups (Table 5). The only significant difference was found in the performance of the intermediate HS group, which had the slowest response time (F (3, 10402) = 22.66, $p < 0.001$).

Table 5. Logarithm of response time per group

Group	N	Mean	SD	Equivalent Resp. Time (ms.)
Advanced HSs	4401	6.38	0.82	590 ms
LTIs	1374	6.39	0.81	593 ms
Controls	3229	6.40	0.81	603 ms
Intermediate HSs	1402	6.58	0.74	719 ms

The second type of analysis was a comparison of the directionality of errors per group in order to determine whether participants presented more errors in similar pairs, suggesting some kind of task-effects, or in different pairs. Thus, a one-way ANOVA was conducted to explore the type of error by group, that is, whether similar stimuli were perceived as different (= false alarm) or whether different stimuli were perceived as the same (= miss). A score of error directionality was calculated per speaker as the difference between the 'miss' and 'false alarm' rates. The differences between groups were not significant (F (3, 41) = 0.25, p = 0.86). Table 6 shows the averages per group.

Table 6. Score of error directionality per group

Group	N	False Alarm	Miss	Difference[10]	St.Dev.
Advanced HSs	19	10.6%	9.4%	−1.22%	7.79%
Controls	14	7.4%	5.4%	−1.99%	2.56%
Intermediate HSs	6	9.9%	9.7%	−0.20%	4.40%
LTIs	6	13.4%	13.9%	0.55%	10.06%

We noticed that both heritage groups had a higher rate of false alarms than misses, which mirrors the performance of the control group. HSs also had a lower rate of discrimination errors than LTIs.

10. A negative number indicates a higher proportion of false alarms (same stimuli detected as different) and a positive number indicates a higher proportion of misses (different stimuli detected as same).

5.2 Differences between groups: Consonants vs. vowels

Performance between groups varied depending on consonant place of articulation. There was significant difference (F (3, 41) = 6.32, p=.001) between groups in the discrimination of labials, with advanced HSs (5.51%) and controls (4.25%) having a better performance than LTIs (16.41%). Also, a significant difference (F (3, 41) = 3.95, p=0.015) was found in the discrimination of dorsals, with controls (10.71%) performing better than advanced HSs (18.63%) and LTIs (20.35%). No significant differences were found between groups for coronals (F (3, 41) = 2.28, p=0.04). See table in Appendix C.

With regard to the discrimination of vowels by the different groups, no significant differences were found either for front vowels (/e, i/) (F(3, 41) = 1.05, p=0.38) or back vowels (/o, u/) (F (3, 41) = 0.62, p=0.6). Although differences were not significant, again controls had the lowest error rates and LTIs the highest. See table in Appendix D.

5.3 Stop consonants by position and place of articulation

For this part of the analysis all bilingual groups were collapsed. A total of 6 error scores per speaker were calculated (3 places of articulation x 2 positions). The mean and SD values are shown in Table 7. The high values of SD are due to high inter-speaker differences. To analyze the significance of the differences due to consonants' position and place of articulation, a repeated measures ANOVA was conducted to mitigate the effect of the high inter speaker variation.

Results support our hypotheses for consonants. There were more discrimination errors in word-initial than in word-medial position. Consonants in initial position had a mean error score of 17.8%, compared to 8% in medial position (F (1, 149) = 48.0, p<0.001). With regard to place of articulation, there were more discrimination errors with dorsals (19.70%) than with coronals and labials (11.5% and 7.6%, respectively) (F (2, 148) = 25.31, p<0.001). A Tukey post-hoc test revealed significant difference between dorsals and the other two types of consonants.

Table 7. Consonants by position and stress

Consonant by position				**Consonant by place of articulation**			
Position	**N**	**Mean**	**St.Dev.**	**Contrast**	**N**	**Mean**	**St.Dev.**
Initial	90	17.87%	12.80%	/b/ vs. /p/	60	7.60%	9.10%
Medial	90	8.01%	8.09%	/d/ vs. /t/	60	11.51%	10.25%
				/g/ vs. /k/	60	19.70%	12.43%

5.4 Vowel by front-back dimension and stress

An ANOVA was conducted to compare vowels according to stress and their position in the front-back axis. Front vowels were not more difficult to discriminate than back vowels. In fact, front vowels had a lower mean error score than back vowels (8.5% and 9.1%, respectively), but these differences were not significant (F (1, 89) = 0.30, p=0.585). As predicted, unstressed vowels were significantly more difficult to discriminate than stressed vowels (10.4% and 7.1%, respectively) (F (1, 89) = 12.22, p=0.001).

Table 8. Vowels by stress and type (front vs. back)

Vowel by stress				Front vs. back vowels			
Stress	**N**	**Mean**	**St.Dev.**	**Contrast**	**N**	**Mean**	**St.Dev.**
Stressed	60	7.12%	4.87%	/e/ vs. /i/	60	8.50%	7.38%
Unstressed	60	10.40%	8.00%	/o/vs. /u/	60	9.06%	6.31%

6. Discussion and conclusions

6.1 Research questions and hypotheses

Controls significantly differed from LTIs in their discrimination performance, yet there were no significant differences in the overall performance of advanced HSs and LTI. This includes the number and directionality of errors and the response time. Some differences were found for consonants, with advanced HSs patterning with controls in the perception of labial contrasts and with LTIs in the perception of dorsals. Taken together, these results are consistent with maturational approaches to language acquisition, since they suggest that being exposed to Spanish at an early age allows bilinguals to discriminate native contrasts.

As stated earlier, the fact that LTIs patterned significantly differently from controls is intriguing and it needs further investigation before we can draw any conclusions, especially because the LTI group was smaller than the other groups (see our discussion in §6.2). Keeping this in mind, we suggest that these results could be an indication that exposure to an L2 later in life affects native speech perception (Flege 1995). Language acquisition studies suggest that the L1 phonological system acts as a filter that accommodates new linguistic input to its structure (Trubetzkoy 1969; Wode 1978). Adult L2 learners already have a phonological system in place when they incorporate new speech categories from the L2. Thus, the native phonological system may be affected as new sounds are integrated into an already established system (Flege 1995). As opposed to LTIs, HSs are exposed to both languages since early childhood; thus, their native phonological system could still be developing when the L2 is being acquired. Since speech categories from both languages are acquired almost simultaneously, there is no phonological system formed a priori to which new categories will be added (Antoniou et al. 2012).

With regard to the specific contrasts under study, the hypotheses for stop consonants involving position and place were supported. Stops in word-initial position were more difficult to discriminate than those in word-medial position. This was expected given the acoustic differences (VOT and percentage voicing) between voiced stops in initial and word-medial positions. In addition to these acoustic differences, /b, d, g/ are realized as approximants in word medial intervocalic position. This makes it easier to distinguish these consonants from voiceless stops in the same environment (e.g. 'ro[t]ar' *to rotate* vs. 'ro[ð]ar' *to roll*). Concerning the discrimination of consonants according to place of articulation, dorsal stops were more difficult to discriminate than coronals and labials. As explained earlier, this could be due to smaller differences in percentage voicing between voiced and voiceless dorsals.

Concerning vowels, we confirmed the hypothesis that unstressed vowels are more difficult to discriminate than stressed ones. Yet, the hypothesis about front vowels being more difficult to discriminate than back vowels was not supported. These results are consistent with Morrison's (2003) perceptual analysis of Spanish vowels by native Spanish and English speakers. In his study, Spanish listeners (L2 learners of English) had slightly higher misidentification rates for back vowels compared to front vowels (9% vs. 7%, respectively). English listeners (L2 learners of Spanish) showed the opposite pattern in their identification of Spanish vowels; they had higher rates of misidentification in front than in back vowels (16% vs. 9%, respectively). This would suggest that our subjects were using the Spanish mode of perception to discriminate relevant contrasts.

6.2 Experimental conditions and our bilingual groups

The difference in performance between the LTIs and the control group may be attributed to potential task-effects. Previous studies suggest that bilinguals do not behave similarly in discrimination vs. labelling tasks. For instance, in Antoniou et al.'s (2012) study, bilinguals behaved like monolinguals in discrimination tasks. Similarly, in Boomershine's (2013) study, Spanish heritage speakers patterned with Spanish monolinguals when judging the degree of similarity between the members of a minimal pair. However, Stevens, Liberman, Studdert-Kennedy and Ohman's (1969) study, which used two types of tests (labeling and discrimination), found that participants did not behave similarly. In the identification task with synthetic stimuli, American English and Swedish listeners behaved significantly different (i.e., the vowels identified were related to the vowel inventory of the listeners' L1); yet, in the ABX discrimination task, their performance was similar. Stevens et al. (1969) claim that these differences could be due to more universal auditory factors used by the participants in the discrimination task. Although in our study we used an AX discrimination task, we believe that similar tasks effects could have been at play, which made HSs behave like monolinguals in the discrimination test.

With regard to the testing condition, the experiments were conducted completely in Spanish by researchers who are native Spanish speakers. We predicted this would have a positive effect on our participants' discrimination of Spanish sounds. Consistent with Antoniou et al.'s (2012) finding, we would expect to find differences in bilinguals' performance if the language mode were shifted from Spanish to English. In the future, we would like to test our participants in English to determine whether their performance in one language can be correlated to their performance in the other.

It is also important to point out that bilinguals from El Paso have continuous exposure to both Spanish and English daily. This is the case in most environments: home, social, and work. Other bilinguals who live in more monolingual (English) environments may not have such intensive contact with both languages.

To summarize, the present study has offered a perceptual analysis of consonants and vowels in different populations of bilingual Spanish-English speakers: HSs and LTIs. The results do not provide evidence in support of the claim that there is phonological-perceptual attrition in HSs. On the contrary, HSs performed better than LTIs in the discrimination test. The results should be taken with caution given the low number of LTIs vis-à-vis HSs. We are currently supplementing this research with data from more speakers. In addition, we plan to incorporate other variables including language dominance to examine more closely the potential correlation between bilinguals' performance and their linguistic ability in both languages.

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Appendix A

Table A1. Stimuli used in the discrimination task

Consonants

Initial Tonic

/b/	/p/	/d/	/t/	/g/	/k/
Bata	Pata	Dales	Tales	Gana	Cana
Beso	Peso	Dejo	Tejo	Guiso	Quiso
Vino	Pino	Dilo	Tilo	Goce	Cose
Boca	Poca	Doce	Tose	Guste	Custe (last name)
Buzo	Puso	Duna	Tuna		

Initial Atonic

/b/	/p/	/d/	/t/	/g/	/k/
Bazar	Pasar	Dañó	Tañó	Garita	Carita
Becar	Pecar	Dejado	Tejado	Gordura	Cordura
Visar	Pisar	Diré	Tiré		
Volar	Polar	Domar	Tomar		

Medial Tonic

/b/	/p/	/d/	/t/	/g/	/k/
Subimos	Supimos	Rodar	Rotar	Pegar	Pecar
		Medí	Metí	Pegué	Pequé
		Cardón	Cartón	Seguía	Sequía
				Rasgó	Rascó
				Agudas	Acudas

Medial Atonic

/b/	/p/	/d/	/t/	/g/	/k/
Taba	Tapa	Falda	Falta	Vaga	Vaca
Sube	Supe	Arde	Arte	Pegue	Peque
Rubia[11]	Rupia	Ardo	Harto	Ego	Eco
Cabo	Capo				

Vowels

Initial Tonic

/e/	/i/	/o/	/u/
Peso	Piso	Poso	Puso
Tero	Tiro	Toco	Tuco
Queso	Quiso	Copo	Cupo
Ves	Bis	Modo	Mudo
Dejo	Dijo	Sopla	Supla
Zeta	Cita	Fondo	Fundo
Dele	Dile	Oso	Uso
Dejo	Dijo	Rombo	Rumbo
Mesa	Misa	Locas	Lucas
		Boda	Buda
		Dona	Duna

Initial Atonic

/e/	/i/	/o/	/u/
Pesar	Pisar	Acosado	Acusado
		Osaba	Usaba
		Sociedad	Suciedad
		Dorar	Durar

Medial Tonic

/e/	/i/	/o/	/u/
Senté	Sentí	Agosto	Agusto
Bebé	Bebí		
Medea	Media		

11. The contrast 'rubia ~ rupia' was later excluded from the analysis, because at this point we were only testing the influence of pure vowels on the discrimination of the sounds in question.

Medial Atonic

/e/	/i/	/o/	/u/
Pepe	Pepi	Hago	Agu[13]
Ante	Anti		
Roque	Rocky		
Cebe	Sebi[12]		
Ande	Andi		
Drogue	Drogui		

Appendix B

Table B1. Percentage of errors per group for consonants and vowels. A one-way ANOVA showed a significant difference in the discrimination of consonants but not vowels. A Tukey post-hoc test showed that the difference is significant between controls and LTIs (long term immigrants). IHS stands for 'intermediate heritage speakers' and AHS stands for 'advanced heritage speakers'

		Vowels		Consonants		
Group	**N**	**Mean**	**St.Dev.**	**Mean**	**St.Dev.**	**Tukey's Grouping**
LTI	6	9.72%	6.14%	16.87%	8.92%	A
IHS	6	6.96%	4.18%	12.27%	2.22%	AB
AHS	19	8.04%	4.14%	12.05%	6.54%	AB
CTRL	14	6.35%	3.06%	7.09%	3.42%	B

Appendix C

Table C1. Percentage of errors per group for labial, dorsal and coronal consonants. Significant differences were found in the discrimination of labials and dorsals.

		/b, p/			/t, d/		/g, k/		
Group	**N**	**Mean**	**St.Dev.**	**Tukey's Grouping**	**Mean**	**St.Dev.**	**Mean**	**St.Dev**	**Tukey's Grouping**
LTI	6	16.41%	11.56%	A	14.07%	10.86%	20.35%	7.45%	A
IHS	6	9.12%	3.50%	AB	11.11%	5.80%	16.67%	6.90%	AB
AHS	19	5.51%	6.15%	B	12.05%	7.85%	18.63%	8.72%	A
CTRL	14	4.25%	2.98%	B	6.35%	5.00%	10.71%	5.01%	B

12. Nickname for 'Sebastian'

13. Nickname for 'Agustina'

Appendix D

Table D1

Percentage of errors per group per vowel contrast. No significant differences were found.

		/e, i/		/o, u/	
Group	**N**	**Mean**	**St.Dev.**	**Mean**	**St.Dev.**
LTI	6	9.81%	5.82%	9.65%	7.43%
IHS	6	6.10%	5.13%	7.95%	4.59%
AHS	19	7.65%	5.06%	8.46%	4.34%
CTRL	14	5.89%	4.16%	6.86%	3.05%