Exploring cross-linguistic influence: Perception and production of L1, L2 and L3 bilabial stops by Mandarin Chinese speakers

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Table of Contents

Abstract

English, Spanish and Mandarin possess different stop patterns and VOT has been used as an important cue to contrast stops. The present study was designed to examine the perception and production of labial stops by Mandarin learners of English and to gain an insight of the interaction between these languages. Twenty Mandarin learners of English as an L2 took part in this study: ten L1 Mandarin, L2 English speakers (Group A), and ten L1 Mandarin, L2 English and L3 Spanish speakers (Group B). The L2/L3 speakers participated in a series of identification tests in which listeners had to identify stimuli from a VOT continuum as either /p/ or /b/, in different languages. The participants' production of the labial stops in different languages was also elicited. The results indicated the following: 1) The fact of learning L3 may alter the L1 and L2 VOT patterns. Participants in Group B produced stops with significantly different VOT values from Group A. 2) The stops produced by Group B in Mandarin and English had longer VOT values than Group A's, which did not conform to the expectation that learning Spanish would result in shorter VOT values in English. 3) The perception results did not show significant differences between Group A and B, as the two groups perceived similarly in English and Mandarin. Nevertheless, their perception differed from that of the Mandarin and Spanish monolinguals, which may suggest a regressive transfer from L2 or L3. 4) No significant correlation was found between perception and production. This study is only an attempt to compare the VOT patterns of L2 and L3 learners. Future study may also examine other places of articulation or conduct a longitudinal study.

Key words: bilabial stop, VOT continuum, L3, perception, production

1. Introduction

The importance of stops has been stated by Ladefoged and Maddison (1996: 47), "[s]tops are the only kind of consonants that occur in all languages". In fact, there is an extensive body of studies on stops (Lisker and Abramson, 1964; Lisker and Abramson, 1970; Flege and Hammond, 1982; Flege, 1991; Thornburgh and Ryalls, 1998; Cho and Ladefoged, 1999; Chao and Chen, 2008; Klein, 2008; Linpiska, 2015; Wrembel, 2015). VOT is employed to contrast stops in many languages (Lisker and Abramson, 1970). For instance, English, Spanish and Mandarin are languages with two phonological stop categories per place of articulation but a different implementation of contrast in terms of VOT. Generally, it could be stated that in word initial position, Mandarin has the longest VOT values for fortis stops, followed by English, whereas Spanish presents the shortest values (Lisker and Abramson, 1964; Chao and Chen, 2008). Therefore, it may be expected that learners with different linguistic background will perform in a different way.

There is a large volume of research on L2 speech acquisition, focusing on age of leaning (Flege, 1991; MacKay, Flege, Piske and Schirru, 2001; Jia, Strange, Collado and Guan, 2006), language experience (Abramson and Lisker, 1970; Flege and Eefting, 1988; Klein, 2008; Holliday, 2015), among other factors. Cross-linguistic influence also plays an important role in foreign language learning and knowing the interaction between different languages is crucial to gain a better understanding of L2 speech learning, particularly in multi-lingual contexts. Recently, focus has been moved to L3/Ln learning (Bannert, 2005; Llama, Cardoso and Collins, 2010; Wunder, 2011; Wrembel, 2011, 2012; Lipínska, 2015). However, within the nascent field of L3 acquisition, in contrast with the numerous numbers of investigations on syntax and lexicology, few studies attempt at investigating phonological acquisition. In the same way that L1 and L2 may facilitate or hinder the Ln acquisition, this effect could also be in the opposite direction and thus exert a negative transfer from the L2/L3 onto the already existing phonetic system of learners, as mentioned for instance in the Merger Hypothesis (MH) postulated by Flege (1987).

The aim of the study is twofold. First of all, to date, despite the abundance of studies on cross linguistic research, few studies have centered on comparing Spanish, English and Mandarin VOT patterns with empirical data. Hence, this study aims at presenting a comparison between the production and perception of bilabial stops in these three languages. Since the present study focuses on the different VOT patterns of word initial stops, stops in medial or final position will not be discussed any further.

Another main purpose of this study is to examine the regressive transfer of L3 on L1 and L2. To be more specific, whether learning an L3 affects the categorization of L2 sounds. It is also intended to examine the extent to which the transfer occurs. Following Flege's (1995) Speech Learning Model, there may be a relationship between production and perception. Thus, the effect of L3 regressive transfer in present study will be examined from two aspects.

Chapter 2 presents a review of the phonetic difference and VOT patterns of Mandarin Chinese, English and Spanish. The detailed description of experiment methodology, including the creation of stimuli for the perception tests and the characteristics of the production test, is presented in Chapter 3. Chapter 4 presents the analysis and discussion based on the experiments' results and Chapter 5 provides the final conclusions.

2. Literature review

2.1 Stops and VOT patterns

As aforementioned, stops are important in cross-linguistic research since they are shared by many languages. English, Spanish and Mandarin have similar stops phonemically, thus, in all three languages there are six stops: /b/, /p/, /d/, /t/, /g/ and /k/. According to place of articulation, English, Spanish and Mandarin fall into three categories but there are subtle differences. English /b/ and /p/ are bilabial stops; /d/ and /t/ are alveolar stops; /g/ and /k/ are velar stops. Spanish stops /b/ and /p/ are bilabial while /g/ and /k/ are velar, like in English. However, /d/ and /t/ are dental. Mandarin stops are similar to English stops in that /b/ and /p/ are bilabial and /g/ and /k/ are velar. Nevertheless, the classification of /d/ and /t/ is still in debate. Lin and Wang (1992) report them as alveolo-dental. Duanmu (2000: 27) concludes that "[t]he place of constriction in Standard Mandarin Chinese dentals is generally more forward than that in the corresponding American English sounds" and he calls them dentals, as the tongue tip in these sounds is generally found on the upper teeth. Lin (2007: 41) argues that Mandarin [t] and [t^h] could be dental or alveolar depending on the speaker. In the same vein, Chin (2008: 50) classifies them as dental.

Voice onset time (VOT) is the "[i]nterval between the release burst and the onset of laryngeal pulsing" (Lisker and Abramson: 1964). In consonance with

Keating (1984: 295), VOT is “the time interval between the release of a stop consonant occlusion and the onset of vocal-fold vibration”. Throughout this paper, the term VOT will refer to voice onset time. The importance of such cue in cross linguistic study has been stated by Lisker and Abramson (1970: 569), “many languages use VOT, in similar but not identical ways, to distinguish either two or three stop categories” and VOT is an important cue to contrast stops (Abramson and Lisker, 1970; Chao and Chen, 2008).

VOT is affected by place of articulation and vowel context (Chen, Chao and Peng, 2007) both in production and in perception (Rochet and Fei, 1991). It is generally stated that VOT tends to be longer when the stops are followed by a high vowel than by a low vowel (Chen, Chao and Peng, 2007). It is also commonly argued that the further back the place of articulation, the longer the VOT (Rochet and Fei, 1991; Chao and Chen, 2008). Some other factors which may influence VOT are age (Flege and Eefting, 1988; Flege, 1991; Deuchar and Clark, 1996; Thornburgh and Ryalls,1998), gender (Thornburgh and Ryalls, 1998), code switching (Olson, 2013) and language experience (Abramson and Lisker, 1970; Flege and Eefting,1988; Klein, 2008; Holliday, 2015).

Even though Mandarin, English and Spanish are all languages with two categories, namely a two-way stop contrast, they illustrate three kinds of VOT conditions concerning the relationship between voicing and stop release: 1) voiced and unaspirated: voicing begins before release, i. e. voice lead VOT; 2) voiceless and unaspirated: voicing starts just after the release, i. e. short lag VOT; 3) voiceless and aspirated: voicing lags behind the release, i. e. long lag VOT (Lisker and Abramson, 1964: 389).

In Mandarin, stops can only occupy the initial position and they are all voiceless. Thus, aspiration serves as a distinctive feature. /p t k/ are voiceless unaspirated stops and /p^h t^h k^h/ are voiceless aspirated stops. They are closer to English than to Spanish (Chen, 2007). However, there is some debate regarding the existence of voiced allophones. In keeping with Duanmu (2000: 27), the Mandarin unaspirated voiceless stops /p t k/ could become voiced [b], [d], [g] in an unstressed syllable. This description contrasts with that of Chin's (2008: 39) who states that "[t]here are no voiced stops in Chinese". There may be no voiced stops as phoneme, but there are voiced stops as allophones. Table 1 presents the VOT values reported in the literature for Mandarin stops.

Table 1. Mandarin VOT value reported (msec)

		p^h	t^h	k^h	p	t	k
Chao, Chen and Peng (1999)	Mean	77.8	75.5	85.7	13.9	15.3	27.4
	Range	63-90	65-87	74-98	10-18	12-18	20-33
	SD	23.7	18.4	19.4	6.6	5.7	9.6
Chao and Chen (2008: 223)	Mean	82	81	92	14	16	27
	Range	35-147	45-123	50-138	7-65	7-33	15-65

In English, voiceless stops present aspiration in word initial position and thus, have a long lag VOT value. Voiced stops in the same position, however, have either short lag or voice lead VOT value. Stops also contrast at word medial and final positions in English. However, non-initial stops are not the focus of this study. Table 2 illustrates the VOT values for English stops provided by Lisker and Abramson (1964: 395).

Table 2. English VOT value reported by Lisker and Abramson (1964)

		b	d	g	p	t	k
Lisker and Abramson (1964: 392)	Mean	1/-101	5/-102	21/-88	58	70	80
	Range	0:5/-130: -20	0:25/ -155: -40	0:35/ -150: -60	20: 120	30: 105	50: 135

In Spanish, stops are divided into fully voiced /b d g/ and voiceless /p t /k/. The voicing as a cue to distinguish /b/, /d/, /g/ from /p/, /t/, /k/ in Spanish only occurs in the initial position of the syllable (Fernández, 2007: 487). There is no stop voicing contrast in the final position. Table 3 shows the VOT values for Spanish stops (Lisker and Abramson, 1964: 395).

Table 3. Spanish VOT value reported (msec)

		b	d	g	p	t	k
Lisker and Abramson (1964: 392)	Mean	-138	-110	-108	4	9	29
	Range	-235: -60	-170: -75	-165: -45	0: 15	0: 15	15: 55

In summary, in word initial position, English has voiced and voiceless stops, which correspond to short lag VOT (or voice lead) and long lag VOT (Lisker and Abramson, 1970). Spanish /b d g/ display voicing lead and Spanish /p t k/ present short lag VOT (Abramson and Lisker, 1964; Flege and Hammond, 1982). Mandarin unaspirated and aspirated stops are featured respectively by short and long lag VOT, which is similar to English (Lisker and Abramson, 1964). However, as claimed by Klein (2008), English's long lag VOT may be shorter than that of Mandarin, and its short lag VOT is also shorter than that of Mandarin.

Table 4 below shows a classification of stops in terms of VOT in these three languages in line with Abramson and Lisker's (1964). Stops can also be described in terms of articulatory force, although it is hard to define and measure (Roach, 1983). For the sake of clarity, English and Spanish voiceless stops and Mandarin aspirated stops will be referred to as fortis whereas English and Spanish voiced stops and Mandarin unaspirated stops will be referred to as lenis throughout this paper. Thus, in Table 4, cells on the left region in black contain lenis stops where those on the right part are fortis stops.

Table 4. Classification of VOT according to three-category

	voicing lead	**short lag**	**long lag**
Spanish	/ b/, /d/, /g /	/p/, /t/, /k/	
English	/ b/, /d/, /g /	—	/p/, /t/, /k/
Mandarin		/p/, /t/, /k/	/pʰ/, /tʰ/, /kʰ/
VOT value	- negative	…	+positive

2.2. L2 and L3 acquisition

In the last few decades, L2 acquisition, especially of English phonology, has been widely studied. The studies centered mainly in the factors which influence L2 acquisition such as age of learning (Flege, MacKay and Meador, 1999; Flege, Schirru and MacKay, 2003) and effect of training (Bradlow et al. 1999; Rvachew, 1994; Hazan et al., 2005; Aliaga-García and Mora, 2009), among others. In the same vein as the L1 could affect L2 acquisition, there is also a possible effect of the L2 on the L1. In fact, some studies have found a regressive transfer from the L2 to L1 (Flege, 1987).

The Speech Learning Model (SLM) proposed by Flege (1995) argues, based on the equivalence classification hypothesis, that new L2 sounds which are not found in L1 are eventually more likely to be acquired, whereas similar L2 phones will be assimilated to the already existing L1 system. Hence, based on the equivalence classification and comparison of L1 and L2, three kinds of phones are distinguished: new, similar and identical phones. New phones "have no counterpart in the L1 and so, by definition, differ acoustically from phones found in L1" (1987: 48). Therefore, it is easier for L2 learners to establish a new category for them. Identical phones are those which are perceived and produced in the same way in L1 and L2. Similar phones are those with an equivalence in the L1 but differing slightly from L1 counterpart. Examples given by Flege (1987) are the /t/ in French and English (short-lag dental in French and long-lag alveolar stop in English). Another example can be the /u/ in French and English, which has a higher and more variable F2 in English. Flege also assumes that there is a relation between perception and production. As claimed, "[w]ithout accurate perceptual "targets" to guide the sensorimotor learning of L2 sounds, production of the L2 sounds will be inaccurate" and in many cases the failure of production is a cause of failure in perception but not always (1995: 238). The regressive influence of L2 on L1 is mentioned in the Merger Hypothesis (MH) postulated by Flege (1987). The MH hypothesized that L2 learners may create a compromise value by merging L1 and L2 similar phones. For example, Flege (1987) found that L1 French speakers living in Chicago who were proficient learners of English produced both English /t/ and French /t/ with comparable values that were intermediate between French and English /t/.

Following Flege's study, Lord (2008) compared the production of English and Spanish word initial stops focusing on the effect of L2 on L1. English native speakers with high level of Spanish were compared to English and Spanish monolinguals. English production was compared between English monolinguals and bilinguals whereas Spanish production was compared between Spanish monolinguals and bilinguals. The mean value of the bilinguals' English production (70 ms for /p/, 71 for /t/ and 79 ms for /k/) was shorter than that of English monolinguals (84 ms for /p/, 91 for /t/ and 100 ms for /k/). However, only the difference found with velars reached significance. The mean value of the bilinguals' Spanish production (25 for /p/, 29 for /t/ and 50 for /k/) tended to be slightly longer than that of Spanish monolinguals' (21 for /p/, 25 for /t/ and 34 for /k/). However, the difference was found to be non-significant in all places of articulation, showing a possible tendency but no actual effect of the L2 on the L1. Even though the statistical results did not support the hypothesis that the L2 had an effect on the L1, based on this tendency, Lord concluded that there is "a definite trend toward the hypothesized outcomes" (2008: 189).

Recently, there seems to be a growing number of studies within the field of L3 acquisition. In a multilingual context, L3 learning is increasingly common. As suggested by Wunder (2011: 106), L3 learners differ from L2 learners in terms of language capacity and the knowledge they possess. Amaro (2012:33) also pointed out the difference by stating that L3 learners "possess a lager repertoire of linguistic and metalinguistic knowledge". However, the majority of these studies belong to the fields of lexicology and syntax. The lack of studies on L3 phonology was explained by Wunder (2011: 107) by the methodologically highly difficult task of differentiating among the potential influence of different source languages.

Cross linguistic influence, as reported by Llama, Cardoso and Collins (2010: 39), is "[t]he effects that previously learnt languages can have on the learning of a new language". Two points are worth noting. First of all, the cross-linguistic influence could be bi-directional, namely forward or backward. The latter is what Amaro (2012: 42) refers to as regressive transfer. In the same way as the L1 and L2 may hinder or facilitate L3 acquisition, the L3 could also influence the previously learnt languages. Also, transfer could be negative or positive, as stated by Wunder (2011: 107).

Several studies reported evidence of the negative transfer. Bentahila (1975) examined the effect of the L2 on L3 in three levels, namely phonological, lexical and grammatical. Moroccan and Algerian learners of English (L1 Arabic L2 French) were compared to Iraqis and Kuwaitis who did not speak French. English is more closely related to French than to Arabic, for instance in terms of alphabet and lexis (1975: 14). Influence of L2 French was found at the phonological level. Moroccan and Algerian participants substituted the English voiceless bilabial stop by taking out aspiration from a French-like voiceless bilabial stop whereas the Iraqis and Kuwaitis replaced it by an Arabic-like voiced one. In the case of the English voiced labiodental fricative /v/, Moroccans and Algerians could produce it accurately, as /v/ is part of the French inventory, whereas the other groups tended to substitute it by an Arabic voiceless fricative.

However, the transfer of L2 appeared to be negative in terms of the production of English affricates. Moroccan and Algerian Arabic speakers were unable to produce them presumably due to the influence of L2 French, while the Iraqis and Kuwaitis were more successful. In this case, there was a negative effect of L2 French orthography.

Turning to the factors contributing to cross-linguistic influence, in the field of phonology, several studies suggested a combined effect of languages. Wunder (2011) examined the VOT production of stressed syllable-initial voiceless stops by L1 German, L2 English and L3 Spanish speakers. All these languages possess a /b d g/ vs. /p t k /contrast. However, aspiration serves as a different cue. Whereas in German and English it is a characteristics of initial voiceless stops, in Spanish there is no aspiration. Eight participants with mostly beginner's proficiency of L3 Spanish participated in the experiment. They were asked to read a nonsense text in English and Spanish to elicit potential stops. The Spanish production seemed to be influenced more by their L1 German than by their L2 English. Nevertheless, many stops were produced with a hybrid VOT value. Wunder stated that "it cannot be determined wherever VOTs were influenced by L1 German or native-like Spanish" (2011: 116).

L2 status has also been investigated by scholars. It is defined by Hammarrberg (2001: 36–37) as "a desire to suppress L1 as being 'non-foreign' and to rely rather on an orientation towards a prior L2 as a strategy to approach the L3". Llama, Cardoso and Collins (2010) examined the VOT production in onset stressed position of L3 Spanish learners who differed in their L1 and L2, either French or English. In terms of VOT values, French and Spanish are typologically closer than English. All the participants were found to have a higher proficiency in their L2 than L3 by a vocabulary test. The data for L3 production did not corroborate the positive effect of L2 status. The comparison of L2 and L3 production suggests a combined effect of L1 and L2, which has also been claimed by Lipínska (2015: 80). However, it seems that L2 status plays a more than significant role than the language distance does in the L3 acquisition. Wrembel (2011) examined the production of stops in onset stressed position produced by 32 Polish participants (L2 English and L3 French). English /p t k/ have longer VOT value than both Polish and French. The results showed that the participants produced English stops with long lag VOT. Their French stops had longer VOT than the French and Polish monolinguals' stops, but shorter than the English monolinguals'. Thus, influence of L2 on L3 was found. However, there also seemed to be a regressive transfer onto L1 Polish, as the participants produced slightly longer VOT in /t/ and /k/ than the Polish monolinguals. Moreover, the hypothesis that the L2 influences the L3 had been corroborated.

The L3 acquisition literature suggests some other relevant factors. Proficiency was claimed as one possible factor affecting L3 acquisition. Wrembel (2011) in her study showed no effect of L2 proficiency on VOT production since two groups with different L2 proficiency level produced L3 in a similar way. In contrast to Wrembel, Garcia (2013) examined the effect of L2 (Spanish) proficiency on L3 Portuguese production by L1 English learners focusing on the vibrant /r/, which has different phonemic realizations in these three languages. The results failed to support the positive effect on L2 proficiency on L3 acquisition due to the fact that participants with low L2 proficiency level produced more target like sounds in L3 than the participants with L2 intermediate level. Wrembel (2012), however, suggested in another study that L1 Polish has a stronger effect on L3 English than L2 French does by a foreign accent rating task.

To sum up, the L3 phonological acquisition seems to be a quite complex and it is influenced by many different factors. The interaction between learnt languages is multiple, which can sometimes produce negative or positive transfer between them. Since regressive transfer from L2 to L1 had been observed (Wrembel, 2011), similar transfer may also be found from L3 to L2, even to L1. To the best of our knowledge, few previous studies have examined the interaction between English, Mandarin and Spanish, especially in terms of the regressive effect of L3 Mandarin on English and Spanish.

2.3 Research questions

Following the issues reviewed in the previous sections, the general research questions addressed in this study are:

1. Do L2 and L3 learners differ from native speakers in terms of their perception of the stop voicing contrast? In other words, do Mandarin speakers who speak an L2/L3 perceive Mandarin stimuli differently from Mandarin monolinguals? As Flege (1995) stated, the fact of learning a second language may affect their L1 system.
2. Does acquiring a third language have an effect on the production and perception of their L2 (as well as on their L1)? Do participants in Group A

and B perform in the same way in both English and Mandarin? If L3 acquisition does not exert a regressive transfer, it would be expected that Group A and B behave in a similar way.

3. Do Mandarin speakers of L2 English and L3 Spanish have the same system for all languages or a separate one for each? How about Mandarin speakers of L2 English? Following Flege's Merger Hypothesis, it is possible that L2 learners develop an intermediate value for similar phones. Since bilabial stops are similar in English, Spanish and Mandarin, it is possible to observe a merged system of the L2 and L3.
4. Is there a relationship between perception and production? According to the SLM, difficulty in perception may be linked to inaccurate production (Flege, 1995). If so, if learners modify their perceptual categories in their L2 and L3, their production of stops may also change.

3. Methodology

3.1 Participants

The main participants in this research project included 20 Chinese learners of English. At the time of recruiting, they were either PhD, masters or exchange students at the Universitat Autònoma de Barcelona, Spain. Their mean age was 26, ranging from 22-30 years old. Participants were native speakers of Mandarin Chinese and none of them had a marked regional accent. All participants consented to take part in the perceptual experiment and to be recorded.

Participants were asked to fill out a Language Background Questionnaire (See Appendix B). Based on their linguistic background, they were divided into two groups according to whether they had learned L3 Spanish or not. Importantly, the average length of English learning for both groups was comparable, about 12.5 years. Participants in both groups had obtained the certificate CET 6 (College English Test Band 6) or equivalent IELTS certificate (Overall band score of 6.5-7 out of 9), which implies an intermediate-advanced level. Group A contained 10 participants with L2 English while Group B contained 10 participants with L2 English and L3 Spanish. Participants in Group B had learned Spanish in college for about 5.5 (3-10) years and they had a level of approximately a B2/C1 in the Common European Framework of Reference for Languages: Learning, Teaching, Assessment (CEFRL, Council of Europe, 2001). None of participants in both groups had lived in an English speaking country at the time of experiment and all of them they had spent 1.2/1.8 years in a Spanish speaking country. Participants in Group A reported to use English on a daily basis whereas participants in Group B reported daily use of Spanish. Table 5 presents the characteristics of both groups.

Table 5. Background information of Group A and B

	Group A	**Group B**
Number of participant	**10**	**10**
Age (mean)	28.3	23.6
Age (range)	27:30	22:26
Time of English learning (mean)	12.9	12.5
Time of English learning (range)	10:17	10:14
Time of Spanish learning (mean)	__	5.5
Time of Spanish learning (range)	__	3:10

	Group A	Group B
Number of participant	**10**	**10**
Time spent in English speaking country	0	0
Time spent in Spanish speaking country	1.8	1.2

Two English monolinguals (Group E), two Spanish monolinguals (Group S) and four Mandarin monolinguals (Group M) served as control group and participated in the perception test. They had reported little knowledge of other languages and almost no experience in other foreign countries. The description of all groups that participated in this study is summarized in Table 6; groups will be referred to by the label indicated on this Table for the remaining of this paper (Group A, Group B, Group M, Group E and Group S).

Table 6. Language backgrounds of participants

Group	n	L1	L2	L3
A	10	Mandarin	English	——
B	10	Mandarin	English	Spanish
M	4	Mandarin	——	——
E	2	English	——	——
S	2	Spanish	——	——

3.2 Stimuli

3.2.1 Perception stimuli

The stimuli of the perception task were created based on natural production rather on synthesized stimuli. Since the purpose of this study is to examine the perception of VOT in different languages, it was considered more appropriate to use the same continuum for all languages. Firstly, the production of /b p/ in word initial position followed by a long high vowel /i/ was produced by a male speaker of Spanish and English who was an experienced phonetician and who produced [bi], [pi] and [p^hi] syllables in isolation.

A total of 36 tokens were elicited, which varied from negative to positive VOT (from 117ms to -155ms). In order to select the most ambiguous token to create the VOT continuum, the 36 productions were analyzed. The release burst duration, burst intensity and VOT length were measured for each token. Detailed information about each token is provided in Appendix C. The importance of burst intensity on VOT perception has been claimed by Delvaux, Huet, Piccaluga and Harmegnies (2008). Table 7 and 8 present the characteristics of the tokens examined. Mean burst duration and intensity were calculated as 6 ms and 61dB, which were used as criteria for selecting an ambiguous burst. Since the burst is also a cue for perception, according to the average and median of all burst duration and intensity, an ambiguous burst were cut from token 27 (burst duration, 6ms; burst intensity, 64 dB). Both tokens were modified to the default intensity (scale peak, 0.99; scale intensity, 75dB) so that perceptually, they were perceived with the same loudness.

Table 7 . Acoustic characteristics of voiced stops

	Burst duration (msec)	**VOT (msec)**	**Bust intensity (dB)**
Average	6.2	-98	67.5
Median	6.5	-99	68
Maximum	8	-12	80
Minumum	4	-155	40

Table 8 . Acoustic characteristics of voiceless stops

	Burst duration (msec)	VOT (msec)	Bust intensity (dB)
Average	6	50	56
Median	6	37.5	56.5
Maximum	8	117	69
Minumum	2	0	43

In order to create the steps in the VOT continuum that involved prevoicing, the burst of token 12 (6ms) was substituted by the ambiguous burst and a small portion of 5 ms of prevoicing which contained low energy was cut off. The duration of prevoicing of token 12 now was -99 ms. The intention was to create 9 ms steps from -99ms to +135ms, but steps near 0 ms were shorter, as explained below. The process to create the stimuli with negative VOT values followed Schuttenhelm (2013). Steps were created by extracting cycles of about 9 ms from the middle of the prevoicing period from the selected token (token 12). Extractions of portions of the sound wave always occurred at zero crossings. The following figures present that spectrogram of the burst, a voiced stop and a voiceless stop with the ambiguous burst.

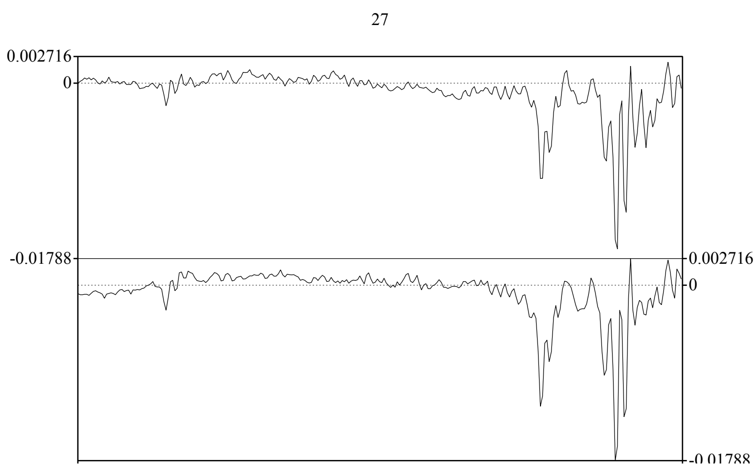

Figure 1. Ambiguous burst extracted from token 27

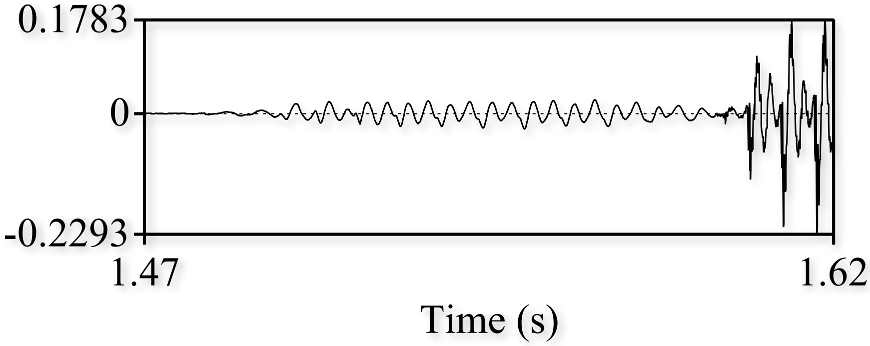

Figure 2. Voiced stop with ambiguous burst

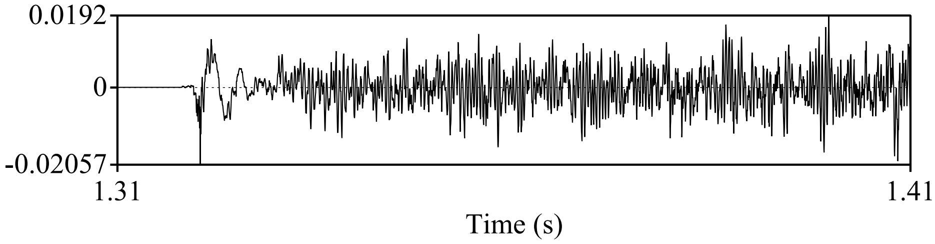

Figure 3. Voiceless stop with ambiguous burst

In order to create sounds with positive VOT value, a Praat script was used. Token 12 was selected as the voiced sound and token 24 (115 ms) was chosen as the voiceless one. With the script, aspiration was extracted from token 24 and was inserted after the ambiguous burst in steps of 9 ms, starting from 9ms to 135ms. 15 voiceless stimuli were created.

Nevertheless, in a pilot test, it seemed that 9 ms steps were too wide since Mandarin, Spanish and English monolinguals all fell into the same range of responses between 9 to 27ms. Therefore, 4.5 ms steps were created between -34ms to 27ms. From -34 to 27ms, cycles of approximately 4.5 ms were cut off manually, which yielded a total number of 18 stimuli for the voiceless stimuli and 15 for the voiced part. The same vowel was used for both voiced and voiceless stops since the creation of voiceless stops was adding aspiration onto the originally voiced token.

In summary, the whole continuum ranged from -105ms to +135ms. It varied in steps of near 4.5 milliseconds between -34ms to +27ms and in steps of 9 ms for the rest, resulting in a total of 33 stimuli. The range covers possible VOT models in the three languages under study, namely voicing lead, short lag and long lag. The following Table 9 and 10 present the actual VOT value for voiced and voiceless stops.

Table 9. Actual VOT value for voiceless stops

stimulus	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
aspiration	4.5	9	13.2	18	22	27	36	45	54	63	72	81	90	99	108	117	126	135
cut off aspiration	4.5		4.8		5		9		9		9		9		9		9	
		4.2		4		9		9		9		9		9		9		

Table 10. Actual VOT value for voiced stops

stimulus	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
prevoicing	-99	-91	-82	-73	-64	-55	-46	-37	-28	-24	-18	-13	-9	-4	0
cut off prevoicing	8		9		8.9		9.2		4		5		5		
		9		9.2		9		8.9		6		4		4	

3.2.2. Identification task

The perception experiment involved an identification task created with Praat (Boersma and Weenink, 2016). The task was a two-alternative forced-choice task. Each stimulus was set to play three times randomly with a break after every 30 stimuli. In total there were 99 stimuli for identification; the same test was performed in each of the three languages.

After a pilot test, it was decided that inserting these stimuli in carrier sentences may activate better the language mode. The same speaker who produced the original tokens was recorded in Spanish and English saying “Ahora digo” and “Now I say”. The Mandarin sentence “wu̯ɔ^{3} ʂu̯ɔ^{1} (I say)” was also elicited from the same speaker after being instructed by a native Mandarin speaker and once this sentence was reported as “well understood as Chinese” by Mandarin speakers. The stimuli from the continuum then were inserted approximately 100 ms after the end of vowel in each carrier sentence. The scale intensity and peak were modified to default value (peak, 0.99; intensity, 70dB) for all stimuli to normalize the intensity. In this fashion, three identification tasks were created, with stimuli from the same continuum presented in each of the three languages tested, that is, one for Spanish, one for English and one for Mandarin Chinese. The procedure of the perception experiment is described in section 3.3 below.

3.2.3 Production task

In order to elicit production, words containing bilabial stops were produced in carrier sentences in each language. Firstly, three similar vowels, a high vowel /i/, a middle vowel /e/ and a low vowel /a/ were chosen for all three languages so that the vowel context would not be a confounding variable. Attempts were made to find minimal pairs in each language. It was intended to create disyllabic words in all languages[1]. However, it has been difficult to find

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[1] As Chao and Chen (2008: 220) and Chen, Chao and Peng (2007) stated, due to the fact that all Chinese sounds are monosyllabic, it is easier for the participants if disyllabic words or words with more two characters are presented as stimuli. Therefore, the choice of stimuli also alters the VOT value and using disyllabic words would lead to a shorter VOT than using a monosyllabic one.

minimal pairs in English with two syllables. 14 distracters were used in each language so that the target sounds would not be predictable for all participants. All stimuli were real words and they were placed at the beginning of a carrier sentence in each language. In English, “XXX is the next word”; In Spanish, “XXX es la siguiente palabra”; In Mandarin, “XXX shi xia yi ge ci yu”. The list of sentences was randomized. The target words used for each language were the following:

English:	pace/base	perry/berry	peach/beach
Spanish:	peca/beca	pata/bata	pita/bita
Mandarin:	胚胎 / 背着	趴下 / 巴结	批评 / 逼迫
	[p^{h}eɪ̯^{1}t^{h}aɪ̯^{1}]/	[p^{h}ɑ^{1}ɕi̯ɑ^4]/	[p^{h}i^{1}p^{h}iŋ^2]/
	[peɪ̯^{1}tʂə^5]	[pɑ^{1}tɕi̯ɛ^5]	[pi^{1}p^{h}u̯ɔ^4]

3.3 Procedure

Data was collected in several sessions. In order to ensure that participants would not be aware of the study purpose, production was collected before perception. As suggested by Llama, Cardoso and Collins (2010: 45), “it was important to promote the activation of all three languages so they would all have an equal chance of becoming a potential source of CLI”. Attempts had been made to activate the language mode for each task.

3.3.1. Production experiment

For the elicitation of production, participants were asked firstly to read a list of disyllabic real English words. They were introduced in English the task they were going to carry out at a normal speech rate. Before the task, they were instructed to read the consent form in English. Afterwards, they were told to read the English list of words. After finishing this, they were asked to produce a list of Chinese words in a carrier sentence and in this case the instructions were given in Mandarin to insure the activation of language mode. Finally, participants who had learned Spanish as L3 were shown a short story in Spanish on a computer. Afterwards, a list of Spanish words was produced in carrier sentences. Instructions were given in the language of stimuli, for example, Spanish for the Spanish words, English for the English words. Two examples were included for practice.

The recording took place in a sound-attenuated room at the Speech Laboratory at University Autònoma de Barcelona. Participants were asked to read out the list in a normal speed when they were ready. Due to some limitations, half of the participants were recorded using a SONY PCM-D50 high quality recorder in the lab and the other half were recorded using the recording equipment in the same lab. Only participants of Group A and B had performed this test. Each sentence was repeated twice. 800 words (10 participants x two groups x 20 stimuli x 2 repetitions) were elicited each for Mandarin and English. 400 words (10 participants x 20 stimuli x 2 repetitions) were elicited for Spanish. Taking out the fillers, 594 tokens were elicited for all languages[2]. The Following Table 11 shows the number of elicited production.

[2] The Spanish lenis tokens of participant B06 were discarded since he produced /b/ as approximant even in word initial position, which was not comparable.

Table 11. Production elicitation

	Mandarin	English	Spanish
A	10x2x20	10x2x20	——
B	10x2x20	10x2x20	10x2x20

3.3.2. Perception experiment

The perception test consisted of three two-alternative forced-choice tasks. Participants were provided with randomized stimuli through a good quality headphone and they were asked to choose the corresponding word in each language on the screen. For example, English words “beach” (/bitʃ/) “peach” (/pitʃ/) were given in an English identification task and the participants were supposed to select the word according to what they hear. In the same vein, Mandarin words “鼻(/pi/)” “皮(/pʰi/)” and Spanish words “pita (/pita/)” “bita (/bita/)” were used respectively in the Mandarin and Spanish identification tasks.

Participants conducted firstly the Mandarin test and before that, they were instructed in Mandarin what they were going to do. Before moving on to the English identification test, they were shown a three-minute short video in English, namely “the North wind and the sun”, to activate the English mode. Another Spanish two-minute video was shown to participants before doing the Spanish identification test. A practice test was given before each test to familiarize the participants with the process. Instructions were given in the language of each test.

Due to the difficulty of finding monolingual participants, the collection of such data by groups M, S and E took place in other circumstances. The collection of Spanish and English monolinguals' data took place at the participants' home. Regarding the Mandarin monolinguals, the test material and a carefully written guideline were sent to Mandarin monolinguals who were acquaintances of the researcher in China. They were guided to install the software Praat and they conducted the test in a quiet room.

4. Analysis and results

The results of the production experiment are presented first, followed by the results of the perception experiment.

4.1 Production

The elicited production was analyzed with the program Praat. VOT was measured from the release burst to the start of voicing of vowel for the fortis stops and from the start of prevoicing to the burst release for the lenis stops. All tokens were measured twice carefully (See Appendix D for detailed production results).

The mean VOTs of stops and detailed measurements including mean, standard deviation, maximum and minimum produced by participants in Group A and B are shown in Table 12.

Table 12. Detailed information of production

	Language	Sound	Mean	St. Deviation	Minumum	Maximum
Group A	Mandarin	Fortis	66	17	31	101
		Lenis	12	4	4	24
	English	Fortis	50	12	28	89
		Lenis	-10	48	-145	29

	Language	Sound	Mean	St. Deviation	Minumum	Maximum
Group B	Mandarin	Fortis	72	26	29	142
		Lenis	10	6	-16	20
	English	Fortis	60	18	24	97
		Lenis	5	32	-132	25
	Spanish	Fortis	12	6	1	29
		Lenis	-11	43	-135	26

Results are presented separately for fortis and lenis stops in Figures 4 and 5. Examining fortis stops from Figure 4, it looks like group B produced slightly longer VOT values than group A in both Mandarin and English. However, the standard deviation observed in all these cases suggest that there is more variation in group B than in group A (26 ms vs. 17ms for Mandarin, respectively; 18ms vs. 12ms for English). Turning to the lenis stops, from Figure 5 it can be observed that in Mandarin Group B produced slightly shorter VOT values than Group A. Nevertheless, surprisingly Group B produced longer VOT in English and the mean VOT values of Group B even presented to be negative. What can be observed is that in both cases, the groups display a general declining tendency from Mandarin to English to Spanish, which conforms to the expected tendency.

Figure 4. Mean VOTs for fortis stops

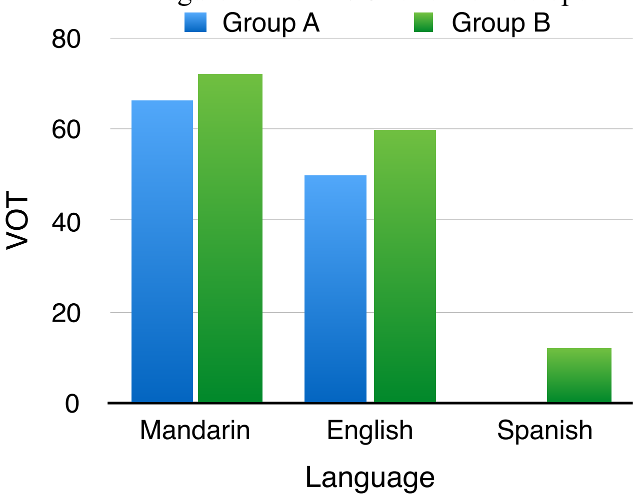
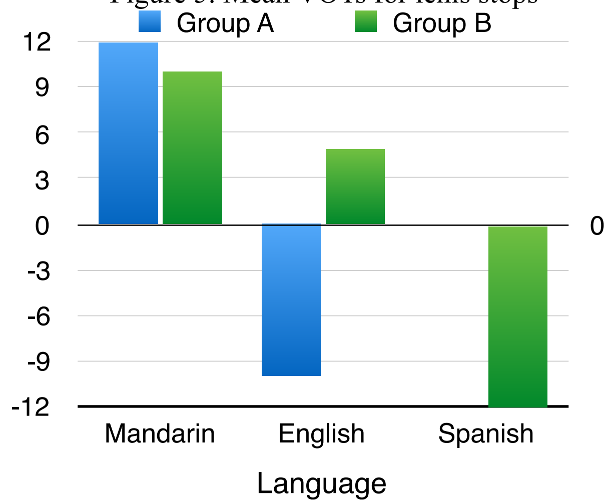


Figure 5. Mean VOTs for lenis stops



The data gathered were submitted to a statistical analyses using SPSS software. In order to compare the results for different groups in different languages, a statistical test was conducted on the actual VOT production using t-tests (dependent variable = VOT in ms).

The between groups independent samples t-tests (Group A and Group B, language as between group factor) indicate that the two groups differed significantly in the production of the Mandarin lenis stops ($t_{(118)} = 2.108$, $p < .05$) but not in fortis stops ($t_{(118)} = -1,477$, $p > .05$). As a matter of fact, the difference seems to be small numerically in both cases (66ms vs. 72ms for fortis stops and 12ms vs. 10ms for lenis stop). The reason why such a small difference could be significant in the case of the lenis stops may due to differences in variability between the two groups (Group A's range: 4 to 24 ms vs, Group B's range: -16 to 20 ms).

The results turned out to be significant for both fortis ($t_{(118)} = -3.703$, $p < .05$) and lenis stop ($t_{(116)} = -2.029$, $p < .05$) in English. Even though the results were significant in both cases, the difference within each language tended to be small (50ms vs. 60ms for fortis stops and -10ms vs. 5ms for lenis stop). However, it also seems that Group B produced English fortis and lenis stops with longer VOT than Group A. Nevertheless, fortis stops produced by both groups had long lag VOT.

With the view to compare the production within group, a paired samples t-test and one-way ANOVA were conducted respectively for Group A and B. The Mandarin and English production of Group A differed significantly both for fortis ($t_{(118)} = -3.571$, $p < .05$) and lenis stops ($t_{(118)} = 6.054$, $p < .05$). Even though the results were significant in both cases, the difference seemed to be small numerically for fortis stops (66ms vs. 50ms) and for lenis stops (12ms vs. -10ms). As expected, Mandarin stops produced by Group A had longer VOT than English ones.

Table 13. Pairwise comparison results of Group B

	Fortis		Lenis	
	English	Mandarin	English	Mandarin
Mandarin	p < .01	—	p > .05	—
Spanish	p < .01	p < .01	p < .01	p < .01

The results of the one-way ANOVA investigating the production of stops in all three languages by Group B yielded a significant main effect of language for both fortis stops [F (2, 89) = 336.28, p < .01] and lenis stops [F (2, 77) = 7.71, p < .01]. Mandarin has the longest VOT for both fortis and lenis stops followed by English and, as expected, Spanish had the shortest VOT values. In order to locate the significant differences, pairwise comparisons were used with Bonferroni correction. As for the fortis stops, English and Mandarin differed significantly and a significant difference was also found between English and Spanish. Both English and Mandarin fortis stops had long lag VOT whereas Spanish fortis stops had a short lag VOT. In terms of the lenis stops, Mandarin and English did not turn out to be different at a significant level but Spanish differed from both English and Mandarin significantly. The Spanish lenis stops were produced with voice lead VOT value and the English and Mandarin stops had short lag VOT. Table 13 illustrates the results of pairwise comparison.

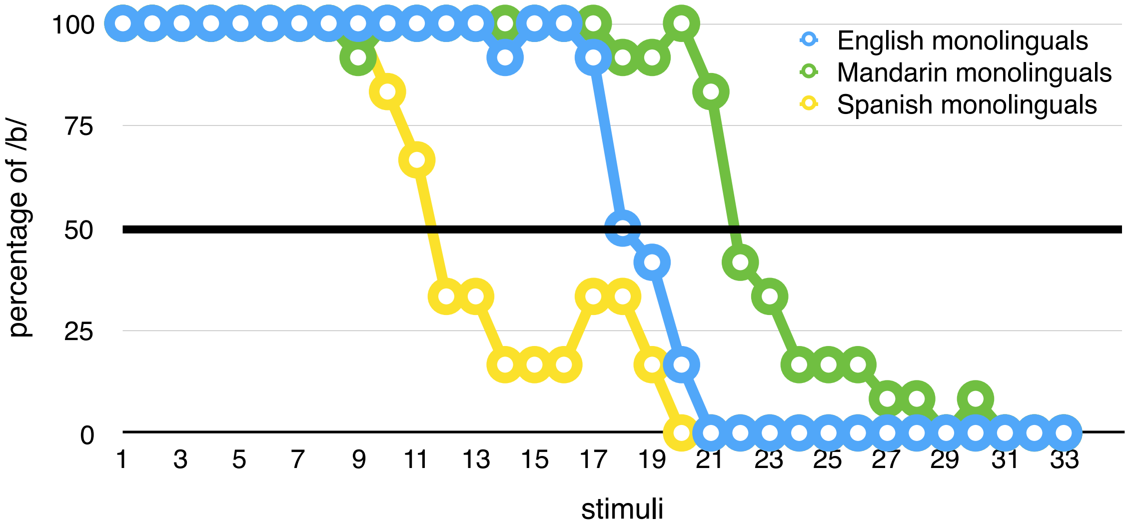
In summary, Group A and B differed significantly in their production of lenis stops in English and in Mandarin. However, in the case of the fortis stops the two groups only differed significantly in English. Nevertheless, it is worth noting that all fortis stops were produced with long lag VOT and the difference within groups and languages were small numerically. Group A's English and Mandarin turned to be different significantly, for both lenis and fortis stops. Group B's fortis stops showed significant difference between English, Mandarin and Spanish, Nevertheless, their English and Mandarin lenis stops were similar, but differed from their Spanish production. In general, thus, the two groups produced stops with values that would be expected for each language, i.e., long lag VOT for English and Mandarin fortis stops, short lag VOT for Spanish fortis stops and Mandarin lenis stops, short lag VOT or voice lead for English lenis stops, and voice lead for Spanish lenis stops.

4.2 Perception

The percentage of /b/ responses[3] were calculated for all languages and groups. The results of the monolingual speakers are presented first followed by the results obtained by Group A and Group B in each language.

Figure 6 presents the perceptual curves of the monolingual speakers of each of the three languages that provided the control data. In this and the following figures, the X axis indicates the 33 steps in the VOT continuum from negative to positive values. The Y axis presents the percentage of perception of each stimulus as lenis stop (Spanish and English /b/, Mandarin voiceless unaspirated stops[4]). Generally, it can be clearly observed that Spanish monolinguals seem to have the lowest /p/-/b/ boundary of about -18ms (at stimulus 11). English monolinguals exhibited a slightly higher boundary (at stimulus 18, around 13.2ms) whereas the Mandarin monolinguals illustrated the highest perceptual boundary (at stimulus 22, around 36ms).

Figure 6. Perceptual curves of monolinguals



[3] The /b/ responses here stand for the lenis stops in all three languages.

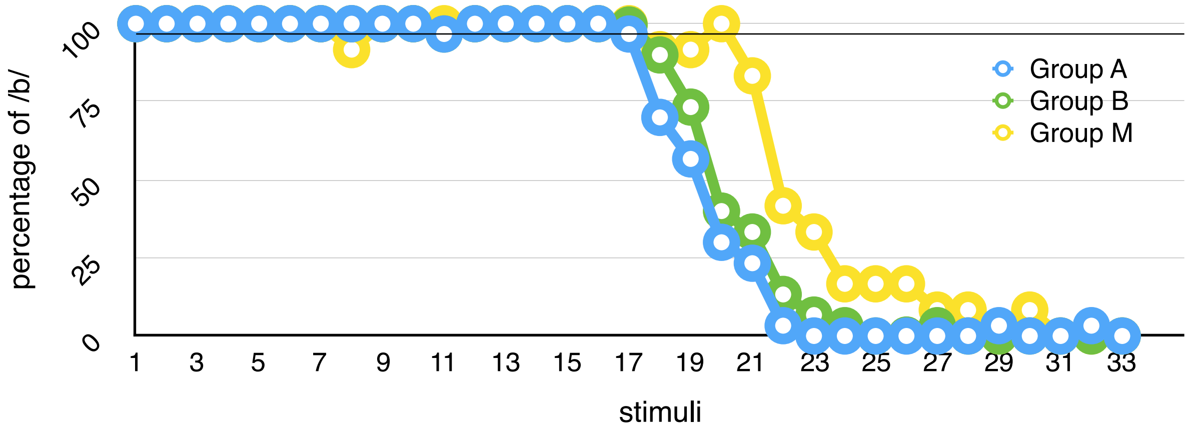
[4] See Tables 9 and 10 in section 3 above for the actual VOT values represented by each step in the continuum.

Chi-square tests were conducted firstly comparing the performance of the different groups in each identification test. Separate Chi-square tests were performed at each stimulus where the percentage of /b/ responses were near 50%. The results for each identification task, so for the perception in each language, are presented in the next subsections (See Appendix E for detailed results).

4.2.1 Mandarin perception

Figure 7 presents the perceptual curves corresponding to the identification of the lenis labial stops in Mandarin. The overall trend of Mandarin perception seems to suggest that Group A had the lowest perceptual boundary and Group M had the highest. Group A and B however, seem to share a similar curve.

Figure 7. Perception of Mandarin stops by Group A B M



Recall that groups were compared in terms of their results for stimuli near a 50% value, namely stimuli 19 (18 ms), 20 (22 ms) and 21 (27 ms) in this case. The percent identification of stimulus 19 as /b/ was 56.7% for Group A, 73.3% for Group B and 91.7% for the control group. It looks like at 18ms, participants in three groups generally perceive a lenis stop in Mandarin. The percentage at stimulus 20 was 30% for Group A, 40% or Group B and 100% for the control group. It is likely that monolinguals have a higher VOT perceptual boundary than participants in Group A and B. The percentage at stimulus 21 was 23.3% for Group A, 33.3% for Group B and 83.3% for Group M.

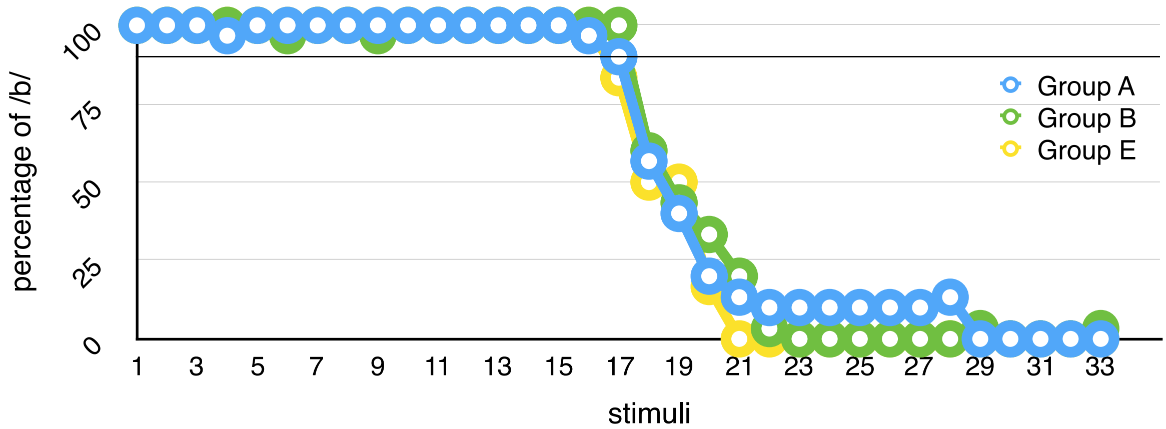
From the Chi-square test, no significant group difference was found at stimulus 19 (χ^2 (2, N=72) = 5.899, $p > .05$). However, a significant result was obtained at stimulus 20 (χ^2(2, N=72) =17.622, $p < .05$) and stimulus 21 (χ^2(2, N = 72) =13.547, $p < .05$). At all these stimuli, further tests were conducted between every pair of groups. At stimulus 20 there was a significant difference between the Mandarin monolinguals and Group A (χ^2(2, N=42) =16.8, $p < .05$) and between the monolinguals and Group B (χ^2(2, N=42) = 12.6, $p < .05$), but not between group A and B (χ^2(2, N=60) = 0.659, p > .05). At stimulus 21, similar results were obtained: no significant difference between Group A and Group B (χ^2(2, N=60) = 0.742, $p > .05$) but a significant difference between the monolinguals and Group A (χ^2(2, N=42) = 13.3, $p < .05$) and Group B (χ^2(2, N=42) = 9.125, $p < .05$). When participants in Group A and B perceived the stimulus 20 and 21 as fortis stops, Group M perceived it as a lenis stop, which may suggest Group A and B have a lower boundary than Group M.

In general, the results are in line with the general expectation that Mandarin fortis stop has a long lag VOT value. In general, participants in Group A and B performed in a similar way, but their perception differed from the Mandarin monolinguals' in the sense that their perceptual boundary is lower than the monolinguals'. The difference observed in the performance of Group A and B from Group M can be interpreted as a possible regressive effect of L2 on L1. It may be led by the fact of having learnt English. Since no significant difference was found between Group A and B, the regressive transfer of L3 on L2 could not be claimed.

4.2.2 English perception

Figure 8 presents the identification functions obtained by the three groups of participants. In this case, the three perceptual curves tend to overlap.

Figure 8. Perception of English stops by Group A B E



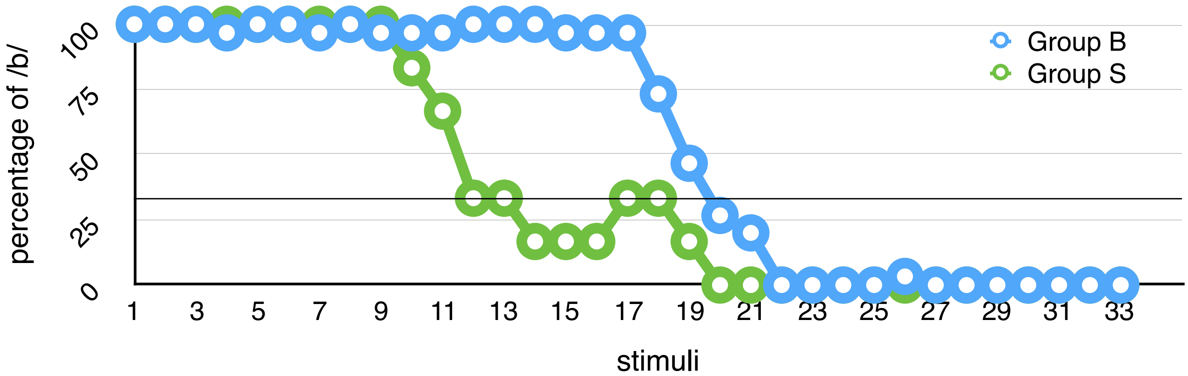
At stimulus18 (13.2ms), the percentage of perception as /b/ was 56.7% for Group A, 60% for Group B and 50% for Group E. At stimulus 19 (18ms), the percentage of perception as /b/ was 40% for Group A, 43.3% for Group B and 50% for the control group. It appears that starting from 18 ms, more participants from Group A and B perceived the stimulus as /p/. However, the perception by the control group seemed to remain still the same and with 50% it is hard to claim the perception as either /b/ or /p/. Therefore, it is necessary to examine the stimulus 20 (22ms). The percentage of perception as /b/ was 20% for Group A, 33.3% for Group B and 16.7% for the control group.

The Chi-square tests were conducted at stimulus 18, 19 and 20 and showed no significant differences among the groups (χ^2 (2, N=66) = 0.222, p > .05, χ^2 (2, N=66) =0.222, p > .05, and χ^2 (2, N=66) =1.685, p > .05, respectively), which suggests that all groups perceived English stops basically in the same way. The statistical results seemed to be in accordance with what is observed in the Figure above, in which all three curves overlap. It seems that participants in all three groups performed in a similar way and, hence, the Mandarin speakers of English as an L2 seemed to have an English-like perception in terms of English stimuli. This may be explained by the language experience, since all participants had learned English for about 12 years, it is more likely that they had developed a native like system for their English stops.

4.2.3 Spanish perception

Regarding the Spanish stimuli, Figure 9 shows the identification functions for the Spanish monolinguals and Group B. It can be observed that the perceptual boundary of Group S occurs notably earlier than Group B.

Figure 9. Spanish perception by Group B S



Group B and S performed differently in a great number of steps, including stimulus 11 to 20. Chi-squares were conducted at each of these stimuli (See Appendix E Table A.6. for more detailed percentages). Statistical results for each stimulus suggest that at stimulus 11 ($\chi2(1, N = 36) = 4.245$, $p < .01$), stimulus 12 ($\chi2(1, N = 36) = 17.478$, $p < .01$, stimulus 13 ($\chi2(1, N = 36) = 17.478$, $p < .01$), stimulus 14 ($\chi2(1, N = 36) = 22.483$, $p < .01$), stimulus 15 ($\chi2(1, N = 36) = 18.265$, $p < .01$), stimulus 16 ($\chi2(1, N = 36) = 18.265$, $p < .01$), stimulus 17 ($\chi2(1, N = 36) = 1.605$, $p < .01$), the L3 Spanish learners differed from the native Spanish speakers. Therefore, the performance is affected by the groups' L1. However, according to the statistical test, results at stimulus 18 ($\chi 2(1, N = 36) = 3.396$, $p > .05$), stimulus 19 ($\chi 2(1, N = 36) = 2.04$, $p > .05$) and stimulus 20 ($\chi 2(1, N = 36) = 3.344$, $p > .05$) were not significant.

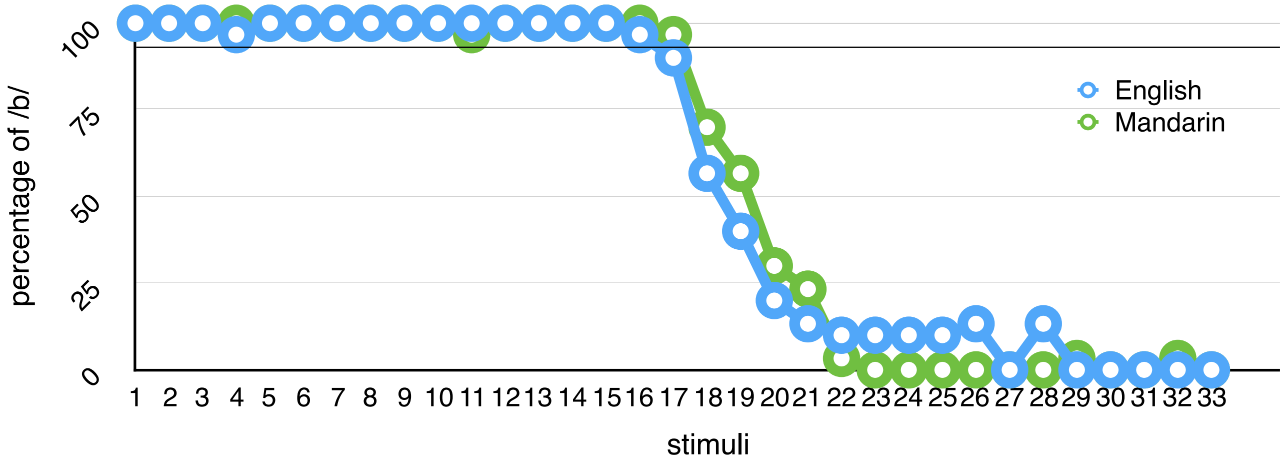
The statistical results and perceptual curves thus generally support the analysis that the perception of Spanish stops by Group B differed from that of the monolinguals. Since Spanish has short lag VOT, Group S perceived the fortis stops with shorter VOT than Group B did. In other words, Group B did not seem to perceive the Spanish /p/-/b/ contrast in a native-like manner. The performance of each group in the different languages tested is analyzed next.

4.2.4 Group A and B: Within group, between language comparisons

The same procedure was applied to examine the performance of Group A and B in different languages (See Appendix E Table A.7. for Group A's perception of English and Mandarin stops and Appendix E Table A.8. for Group B's perception of English, Mandarin and Spanish stops).

Starting with Group A, Figure 10 shows the perceptual results in the two languages tested. The percentage of /b/ responses at stimulus 18 were 56.7% for English, 70% or Mandarin. At this point, participants perceived more voicing for both languages. At stimulus 19, this percentage changed to 40% for English and 56.7% for Mandarin. The percentage for Mandarin /p/ responses exceeded /b/ at stimulus 19 (18ms), whereas this did not occur in English until stimulus 20 (30% vs. 70%). Observing from the figure, on the whole the perception of Mandarin and English by Group A generally overlapped.

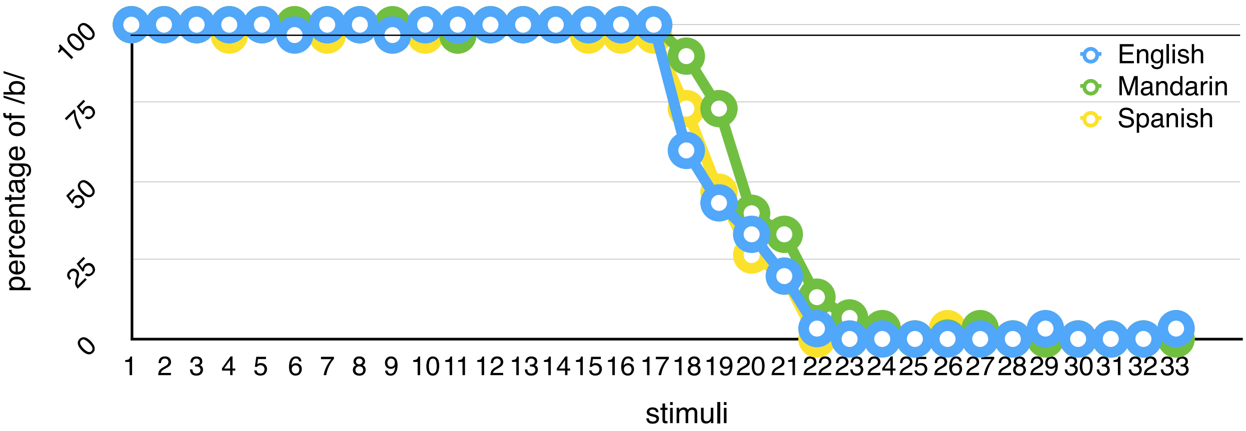
Figure 10. English and Spanish perception by Group A



These perceptual difference between English and Mandarin turned to be non-significant at stimulus 18 (χ^2 (4, N = 60) = 1.148, *p* > .05), stimulus 19 (χ^2 (4, N = 60) =1.669, *p* > .05) and stimulus 20 (χ^2 (4, N = 60) = 0.8, *p* > .05). At all these stimuli, English seemed to have a lower percentage in perceiving the stimulus as lenis and it may be that they have a lower VOT boundary than the Mandarin one. Nevertheless, the differences were not significant.

Similarly, as illustrated in Figure 11 below, the perception of stimuli as /b/ by Group B in the three languages differed mainly at stimulus 18 (60% for English, 90% for Mandarin, 73.3% for Spanish), 19 (43.3% for English, 73.3% for Mandarin, 46.7% for Spanish) and 20 (33.3% or English, 40% for Mandarin, 26.7% for Spanish) as well. At 18 ms the stimuli are perceived as fortis in Spanish and English, whereas in Mandarin it is still perceived as a lenis stop. The perception of Mandarin did not show a tendency towards /p/ until VOT was 22 ms.

Figure 11. English, Mandarin and Spanish perception by Group B



These differences between languages were significant at stimulus 18 (χ^2 (2, N = 90) = 7.125, p < .05) and 19 (χ^2 (2, N = 90) = 6.541, p < .05) but not at 20 (χ^2 (2, N = 90) = 0.097, p >.05) for Group B. Further tests were conducted between each pair of languages at stimulus 18 and 19. At stimulus 18, English (60%) and Mandarin (90%) were found to be significantly different (χ^2 (1, N = 60) = 7.2, p < .05), while Spanish (73.3%) and Mandarin did not show a significant difference (χ^2 (1, N = 60) = 2.783, p > .05), and English and Spanish also turned out to be similar (χ^2 (1, N = 60) = 1.2, p > .05). At stimulus 19, English (43.3%) and Mandarin (73.3%) were found to be significantly different (χ^2 (1, N = 60) = 5.554, p < .05), Spanish (46.7%) and Mandarin also showed a significant difference (χ^2 (1, N = 60) = 4.44, p < .05). However, English and Spanish also turned out to be similar (χ^2 (1, N = 60) = 0.067, p > .05). Therefore, at stimulus 18, Mandarin had the highest percentage of perceiving /b/ and this runs in line with the fact that Mandarin has a higher VOT boundary. At stimulus 19, English and Spanish seemed to overlap and they differed significantly from Mandarin. As in the case of stimulus 18, here Mandarin also showed a high VOT perceptual boundary.

From these results, it could be observed that participants in Group B exhibit highest VOT boundary for Mandarin, followed by Spanish and they had the lowest boundary for English. The difference between Mandarin and English reached significance whereas English and Spanish seem to have a similar boundary but this is not always the case. It may be that L3 leaners have developed a separate English perceptual system but not in the case of Spanish. The fact that their L3 resembles their L2 could be interpreted as related to a short period of learning, noting that their average time of English learning was 12.5 years and their average time of Spanish learning was 5.5 years.

Table 14. Perceptual boundary and production results

Group	Participant	English Production	English Perception	Mandarin Production	Mandarin Perception	Spanish Production	Spanish Perception
A	1	67.5	27	80	27	—	—
A	2	40	18	39.5	36	—	—
A	3	63.75	27	79.25	45	—	—
A	4	53.25	18	59.25	13.2	—	—
A	5	36.5	18	50.5	27	—	—
A	6	39.5	36	57	36	—	—
A	7	45.75	18	56.25	18	—	—
A	8	55.75	13.2	80.25	36	—	—
A	9	54.25	22	63.75	27	—	—
A	10	44.25	13.2	69.5	18	—	—
B	1	41.75	36	65.5	27	8.75	27
B	2	50	18	52	36	13.5	13.2
B	3	69	36	80	45	22	36
B	4	71.25	22	61.5	36	9.75	22
B	5	50	22	65	27	16	18
B	6	70.75	18	120	22	21.75	22
B	7	34.75	36	63	45	4	36
B	8	85.75	27	98	22	9.75	18
B	9	57.5	27	39.25	36	13.25	13.2
B	10	69.5	13.2	60	27	8.75	22

4.3 Perception and Production

In order to examine the relationship between perception and production, a value corresponding to the perceptual boundary for each participant in each different language was examined. This perceptual measure was the VOT of the first stimulus that was perceived 100% (3 out of 3 tokens) as a fortis stop. In some cases, participants did not perform consistently and thus some fluctuation could be observed in their choice. However, this was not common. This perceptual measure was contrasted to the average VOT in ms for each participant's production of /p/. Table 14 shows the perceptual boundary and production of fortis stop by each participant in each language. The results were submitted to a bivariable analysis of correlation.

Starting from group A, no correlation between production and perception was observed (r = 0.16, N = 10, $p > .05$) and no correlation was found between Mandarin production and perception (r = 0.185, N = 10, $p > .05$). The Pearson correlation test results for Group B revealed no significant correlation. The results for Mandarin perception and production (r = -.485, N = 10, $p > .05$), for English perception and production (r = -.383, N = 10, $p > .05$) and for Spanish perception and production (r =-.059, N = 10, $p > .05$) did not show significant difference. Data examined in this paper there does not seem to support any evidence on the relation between perceptual ability and production ability.

5. Discussion

The purpose of the present study was to examine the perception and production of labial stops by Mandarin learners of English and to gain an insight of the interaction between these languages.

Turning to the main research questions of this study, the first question addressed whether L2 and L3 learners differ from native speakers in each language in terms of perception. Starting from Mandarin, participants in both groups differed significantly from the monolinguals. The perceptual VOT boundary of Group A and B tended to be lower than that of Group M. Since Mandarin fortis stops have long lag VOT and their values are the longest among all the three languages examined, it is possible that learning a second or a third language with a lower VOT value may have affected the L2/ L3 learners' perceptual boundary by shifting it towards the left side of VOT continuum. This finding seems to be consistent with Lord (2008), who showed that Spanish and English bilinguals produced Spanish stops with longer VOT than the Spanish monolinguals and they produced English stops with shorter VOT value than the English monolinguals.

In terms of English perception, Group A and B perceived the English stimuli as the English native speakers did. It seems that participants in all three groups performed in a similar way and, hence, the Mandarin speakers of English as an L2 seemed to have an English-like perception in terms of English stimuli. In this case, no regressive transfer of L3 on L2 was apparent. This may be explained by the language experience, since all participants had learned English for about 12 years, it is more likely that they had developed a native like system for their English stops.

Regarding Spanish perception, participants in Group B differed from the monolinguals and they displayed a higher VOT boundary than Group S. There seems to be an effect of L1 or L2 on L3, which implies that Mandarin or English, languages with long lag VOT stops, lengthen their L3 Spanish perceptual boundary. It may also suggest that L3 learners have not acquired the perceptual pattern of L3 yet. To sum up, transfer had been found in L1 Mandarin and L3 Spanish, but not in L2 English.

The second research question investigated the extent to which learning an L3 affected the learners' previously learned languages. The findings provide partial support for the regressive transfer: in production, transfer from L3 to L2 was found and in perception, regressive transfer of L2/L3 on L1 was found. Regarding production, in English, Group B produced lenis and fortis stops with higher VOT values than Group A. In Mandarin, Group B produced longer VOT for fortis stops but not the lenis ones. All these difference were significant except for the Mandarin fortis stops The reason why Mandarin fortis production did not differ significantly may due to the similar VOT values produced (66ms vs. 72ms) and the similar standard deviation (17 vs. 26). As about perception, Group A and B showed no different in perceiving Mandarin and English stops. However, the perception of Mandarin stops by Group A and B differs significantly from the Mandarin monolinguals. Therefore, perceptually, no evidence was found to support the regressive transfer from L3 to L2 but the transfer from L2/L3 on L1 was found.

In general, in the case of Mandarin, it seems that L3 learning has effect only on lenis stops production and in the case of English, the effect of L3 learning applies to both L2 lenis and fortis production. It also seems that L2/L3 learning has a regressive transfer on L1 perception.

The next research question was whether the L2 and L3 speakers have separate categories for each language or use the same categories for all languages and the results need to be discussed separately. Comparisons within each group suggested that the English and Mandarin VOT patterns of Group A differ significantly, for both lenis and fortis stops, but only in production, not in terms of perception. However, it seems that English has a slightly lower VOT perceptual boundary than Mandarin. The English production (/p/, 50; /b/,-10) turned to be shorter than the Mandarin (/p/, 66; /b/,12), which abides by the general claim. However, it is interesting that even though the participants of Group A did not speak Spanish, the mean VOT of their English lenis stops was negative. This result may due to the fact that two participants of Group A produced highly prevoiced stops in English.

Group B exhibited a higher perceptual boundary for Mandarin, which differed at some steps from their English and Spanish boundaries. Their English and Spanish boundaries tended to be similar but at stimulus 19, they turned out to be different significantly. This may suggest that they possess different L1 and L2 perceptual patterns and the perceptual pattern may be similar to L1. Regarding production, all three languages differed in fortis stops: Mandarin had the longest VOT, followed by English and Spanish had the lowest. In terms of lenis stops, English and Mandarin showed no difference but they are significantly different from Spanish. Noting that the difference between English and Mandarin production was small (5ms vs. 10ms). However, Spanish lenis stops had negative VOT value while English and Mandarin had a short lag VOT.

To sum up, the reviewed data suggests that L2 leaners have two different production systems but only one perceptual system in their L1 and L2. L3 learners however, seem to have different VOT patterns both for their production and perception. This could be interpreted as the different language capacity that L3 learners possess and also, a metalinguistic awareness (Amaro, 2012). It is not enough only alluding to L2 learners in a multilingual context.

Regarding the last research question, the results did not seem to show a relationship between perception and production. No significant correlation was found between perception and production by any of the groups in any of the languages. According to Flege (1995), there is a relation between perception and production and without an accurate perception, the production is likely to be unsuccessful. These reviewed data provided negative evidence for this claim. For example, participants in Group B produced stops in three languages with significantly different VOT. However, according to their perceptual results, they were unable to establish two separate perceptual systems for at English and Spanish. This finding may relate to the methodological issue, as Amaro (2012: 51) stated, it is inadequate to compare the perception results and production results since they are elicited using different techniques. Moreover, it may also due to the small sample size.

6. Conclusions, limitations and lines for further research

The purpose of this study was to compare the VOT patterns in Mandarin, Spanish and English for word-initial bilabial stops and to gain an insight of the potential effect of learning an L3 on other previously learned languages.

Overall, the production and perception of Mandarin, English and Spanish stops examined follow the general expectation. Mandarin stops have the longest VOT values, followed by English stops and Spanish has the lowest. In perception Mandarin has the highest perceptual boundary. The English perceptual boundary is lower than Mandarin and Spanish has the lowest perceptual boundary. The use of continuum seemed be a good way to compare VOT boundaries in different languages.

The cross-linguistic interaction is complex. As Amaro stated (2012), the transfer from one to another could be either forward or backward. L3 learning has effect on L1 (only lenis) and L2 (lenis and fortis) production and perception. Multilinguals have separate VOT patterns for their production in different languages: L2 learners have two production patterns in L1 and L2; L3 learners have three systems for fortis stops production and they have a same system for L1 and L2 lenis stops production but a different one for L3. As about their perception, L2 learners have the same perceptual system in L1 and L2 whereas L3 learners have more than one system. The data also suggests no relation between the perception and production.

This study has many limitations. The sample size was too small, especially in the control group, which may have affected the reliability of results. The testing condition was not exactly the same for all participants. The difficulty in recruiting monolingual participants hindered the collection of their production and made the data less comparable. Due to time limitation, the production of stops had not been analyzed in each vowel context even though data were collected. The way in which data were analyzed could also be in the debate.

More attention needs to be addressed on L3 acquisition, especially on phonetics. Future studies could be longitudinal and test the same participants before and after having learned an L3. Individual differences may have affected the outcomes. A further study could examine stops at other places of articulation.

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APPENDIX A

Production task

Mandarin:

波浪[pu̯ɔ^{1}lɑŋ^{4}]是下一个词语。(Wave is the next word.)
巴结[pɑ^{1}tɕi̯ɛ^{5}]是下一个词语。(Flatter the next word.)
鼻子[pi^{2}tsɨ^{5}]是下一个词语。(Nose is the next word.)
大学[tɑ^{4}ɕy̯œ^{2}]是下一个词语。(University is the next word.)
胚胎[pʰeɪ̯^{1}tʰaɪ̯^{1}]是下一个词语。(Embryo is the next word.)
逼迫[pi^{1}pʰu̯ɔ^{4}]是下一个词语。(Force is the next word.)
葡萄[pʰu^{2}tʰɑʊ̯^{5}]是下一个词语。(Grape is the next word.)
高考[kɑʊ̯^{1}kʰɑʊ̯^{3}]是下一个词语。(Exam is the next word.)
搭理[tɑ^{1}li^{5}]是下一个词语。(Respond is the next word.)
不要[pu^{2}ji̯ɑʊ̯^{4}]是下一个词语。(No is the next word.)
扑倒[pʰu^{1}tɑʊ̯^{3}]是下一个词语。(Fall down is the next word.)
趴下[pʰɑ^{1}ɕi̯ɑ^{4}]是下一个词语。(Prone is the next word.)
科学[kʰɰ̯ʌ^{1}ɕy̯œ^{2}]是下一个词语。(Science is the next word.)
开心[kʰaɪ̯^{1}ɕin^{1}]是下一个词语。(Happy is the next word.)
哥哥[kɰ̯ʌ^{1}kə^{5}]是下一个词语。(Brother is the next word.)
喝水[xɰ̯ʌ^{1}ʂu̯eɪ̯^{3}]是下一个词语。(Drink water is the next word.)
皮肤[pʰi^{2}fu^{1}]是下一个词语。(Skin is the next word.)
背着[peɪ̯^{1}tʂə^{5}]是下一个词语。(Carry is the next word.)
泼水[pʰu̯ɔ^{1}ʂu̯eɪ̯^{3}]是下一个词语。(Pour water is the next word.)
批评[pʰi^{1}pʰiŋ^{2}]是下一个词语。(Criticize is the next word.)

English:

Good is the next word.
Base is the next word.
Dutch is the next word.
Perry is the next word.
Game is the next word.
Bad is the next word.
Could is the next word.
Came is the next word.
Do is the next word.
God is the next word.
Touch is the next word.
Pace is the next word.
Pad is the next word.
Cod is the next word.
Berry is the next word.
Peach is the next word.
Too is the next word.
Beach is the next word.

Spanish:

Taza es la siguiente palabra.
Peca es la siguiente palabra.
Guiso es la siguiente palabra.
Cana es la siguiente palabra.
Cota es la siguiente palabra.
Bata es la siguiente palabra.
Gota es la siguiente palabra.
Pollo es la siguiente palabra.
Puna es la siguiente palabra.
Gana es la siguiente palabra.
Tapa es la siguiente palabra.
Casa es la siguiente palabra.
Bollo es la siguiente palabra.
Pita es la siguiente palabra.
Guapa es la siguiente palabra.
Quiso es la siguiente palabra.
Bita es la siguiente palabra.
Pata es la siguiente palabra.
Buna es la siguiente palabra.
Beca es la siguiente palabra.

APPENDIX B

Questionnaire and consent form

QUESTIONNAIRE

Statement of confidentiality:
Your name and other information gathered in this study will not be disclosed to any persons other than the investigator and his collaborators, and will only be used for statistical purposes without reference to individual particpants' personal information.

Participant Code (given on Consent form): ___________________________
Experiment date and time: ___________________________

Personal Information
1. Name: ___________________________ 2. Age___________
3. Degree and year ____
4. Place of birth ____
5. Place of residence____
6. Previous place(s) of residence (where you have lived for at least a few months; indicate when and for how long):

Language information
1. Parents' native language: ____
2. Mother tongue (L1, first language you learned, and you speak most fluently, your dominant language). ____
6. Other languages you speak. How fluently do you speak it/them? Indicate "very fluently", "quite fluently", "moderately fluently", "not very fluently".
Language Level of fluency Time of learning When do you speak it
L2: ____________ ______________ _____________ rarely sometimes often everyday
L3: ____________ ______________ ______________ rarely sometimes often everyday
L4: ____________ ______________ ______________ rarely sometimes often everyday
7. When and with whom do you speak English now? Circle the answer(s) that apply to you.

a) at home never rarely sometimes often
b) at university with my teachers never rarely sometimes often
c) with foreign friends (not native English speakers) never rarely sometimes often
d) with friends who are native English speakers never rarely sometimes often

8. How long have you been studying L2 (in number of years).
9. Have you spent time in a country where your L2 is spoken? If so when and for how long?
10. When and with whom do you speak L2 now? Circle the answer(s) that apply to you.

a) at home never rarely sometimes often
b) at university with my teachers never rarely sometimes often
c) with foreign friends (not native English speakers) never rarely sometimes often
d) with friends who are native English speakers never rarely sometimes often

11. How long have you been studying L3 (in number of years).
12. Have you spent time in a country where your L3 is spoken? If so when and for how long?
13. When and with whom do you speak L3 now? Circle the answer(s) that apply to you.

a) at home	never rarely sometimes often
b) at university with my teachers	never rarely sometimes often
c) with foreign friends (not native English speakers)	never rarely sometimes often
d) with friends who are native English speakers	never rarely sometimes often

<u>Consent form</u>

Participant's code: ____________

I, __________________________ agree to take part in a speech production and perception study.

I understand that the experiment will take about 20-30 minutes and will occur at a convenient time and place. I understand that the investigator will record my production. I understand that I may stop the recording at any time or withdraw from the study.

I understand that my name and my specific answers will remain confidential and that I will not be identified in any report or presentation which may arise from the study.

I understand that while I may not benefit directly from the study, the information gained may help achieve a better understanding of the process of language acquisition and may help improve methods of language learning.

I understand what this study involves and agree to participate.

Date Signature

APPENDIX C

Elicited tokens and acoustic information

	VOT (ms)	Burst duration	burst intensity
token 1	-155	5	70
token 2	-107	4	69
token 3	-83	6	67
token 4	-82	5	70
token 5	-12	4	68
token 6	-97	6	68
token 7	-54	7	68
token 8	-138	7	65
token 9	-129	5	72
token 10	-115	6	68
token 11	-78	5	68
token 12	-110	6	67
token 13	-60	7	67
token 14	-137	7	80
token 15	-143	8	75
token 16	-108	7	40
token 17	-88	8	67
token 18	-81	7	66
token 19	7	6	67
token 20	117	5	55
token 21	0	4	65
token 22	0	2	69
token 23	5	4	62
token 24	116	6	47
token 25	8	6	60
token 26	102	8	47
token 27	0	6	64
token 28	5	8	58
token 29	93	6	45
token 30	77	7	44
token 31	0	8	63
token 32	99	7	47
token 33	117	6	55
token 34	81	6	43
token 35	67	7	43
token 36	0	3	67
Average		6.055555556	61.55555556
Median		6	66

APPENDIX D Production results per group, language and word.

Table A.1. Production of Mandarin stops by Group A and Group B.

	pʰeɪ̯^{1}tʰaɪ̯^{1}	pʰɑ^{1}ɕi̯ɑ^{4}	pʰi^{2}fu^{1}	peɪ̯^{1}tʂə^{5}	pɑ^{1}tɕi̯ɛ^{5}	pi^{1}pʰu̯ɔ^{4}
A01_1	76	78	89	7	29	10
A01_2	65	57	90	8	10	12
A02_1	38	56	40	13	16	10
A02_2	31	66	49	15	15	12
A03_1	74	92	85	10	10	10
A03_2	59	77	99	11	9	12
A04_1	58	78	63	13	13	18
A04_2	48	64	68	18	13	17
A05_1	35	54	69	17	13	18
A05_2	32	44	66	12	11	17
A06_1	38	80	80	12	13	17
A06_2	47	61	63	8	13	16
A07_1	47	89	55	14	13	16
A07_2	42	76	81	13	12	24
A08_1	67	77	101	16	14	16
A08_2	69	81	84	17	16	13
A09_1	52	76	60	11	12	15
A09_2	57	61	86	8	10	12
A10_1	66	74	72	13	11	11
A10_2	73	76	67	15	8	11
B01_1	63	56	81	8	8	7
B01_2	41	66	77	9	8	6
B02_1	31	58	75	14	18	10
B02_2	43	49	59	10	20	10
B03_1	51	68	113	17	11	11
B03_2	65	55	91	18	16	10
B04_1	58	67	59	11	12	13
B04_2	62	88	67	12	15	9
B05_1	53	79	85	14	11	14
B05_2	51	66	71	12	12	18
B06_1	107	142	129	19	17	17
B06_2	117	105	127	20	13	16
B07_1	47	80	75	11	8	8
B07_2	62	94	68	12	10	9
B08_1	89	104	126	9	7	7
B08_2	85	86	92	10	8	5
B09_1	40	56	40	15	8	13
B09_2	44	29	33	13	11	14
B10_1	50	74	70	12	9	12
B10_2	47	70	73	13	11	13

Table A.2. Production of English stops by Group A and B.

	pace	perry	peach	base	berry	beach
A01_1	65	49	62	-108	-119	-126
A01_2	89	44	54	-116	-153	-151
A02_1	33	24	34	-91	-136	-145
A02_2	42	29	38	-85	-111	24
A03_1	62	77	63	14	16	-15
A03_2	57	69	73	15	11	-45
A04_1	58	64	55	12	18	10
A04_2	54	65	46	9	20	14
A05_1	38	42	38	10	17	12
A05_2	36	53	34	9	12	12
A06_1	39	41	54	16	19	13
A06_2	28	43	37	10	15	15
A07_1	48	32	49	16	20	18
A07_2	44	63	42	29	21	21
A08_1	44	71	57	9	15	12
A08_2	50	66	72	11	15	11
A09_1	46	75	58	9	25	9
A09_2	58	57	55	14	24	11
A10_1	36	11	57	10	7	9
A10_2	43	19	41	12	6	10
B01_1	43	59	47	9	13	13
B01_2	42	56	35	13	4	15
B02_1	26	53	77	14	20	21
B02_2	30	58	67	14	19	25
B03_1	64	78	61	-152	12	17
B03_2	73	83	78	17	10	18
B04_1	69	58	78	12	13	11
B04_2	63	55	75	10	11	17
B05_1	44	61	59	12	18	18
B05_2	48	50	49	11	21	15
B06_1	59	90	91	23	20	14
B06_2	51	77	82	22	19	15
B07_1	24	56	33	16	6	8
B07_2	55	78	27	11	6	7
B08_1	95	60	79	9	10	12
B08_2	97	65	72	10	11	14
B09_1	62	63	57	15	18	17
B09_2	60	74	51	16	13	13
B10_1	67	62	72	-88	-88	-82
B10_2	63	63	76	-115	15	15

Table A.3. Production of Spanish stops by Group B.

	peca	pata	pita	beca	bata	bita
B01_1	11	7	8	-111	9	4
B01_2	8	8	8	-99	7	6
B02_1	13	11	16	13	9	9
B02_2	15	13	10	15	9	10
B03_1	24	6	19	16	18	20
B03_2	29	8	16	10	17	15
B04_1	7	10	8	12	7	13
B04_2	14	11	10	11	7	13
B05_1	12	15	17	15	11	21
B05_2	14	14	21	14	14	26
B06_1	21	15	22	—	—	—
B06_2	23	12	21	—	—	—
B07_1	6	3	3	6	-49	8
B07_2	6	5	1	8	-36	-79
B08_1	11	6	9	-135	7	9
B08_2	10	9	9	13	8	-121
B09_1	13	8	14	-79	-75	14
B09_2	15	5	11	-70	-16	21
B10_1	4	6	12	-85	-63	-22
B10_2	6	8	13	-67	18	-24

APPENDIX E Perception results per group, language and word[1].
Table A.4. Perception of Mandarin stops by Groups A, B and M.

	Group A				Group B				Group M			
	b		p		b		p		b		p	
	Count	%	Count	%	Count	%	Count	%	Count	%	Count	%
stimulus01-99ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	12	100.0%	0	0.0%
stimulus02-91ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	12	100.0%	0	0.0%
stimulus03-82ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	12	100.0%	0	0.0%
stimulus04-73ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	12	100.0%	0	0.0%
stimulus05-64ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	12	100.0%	0	0.0%
stimulus06-55ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	12	100.0%	0	0.0%
stimulus07-46ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	12	100.0%	0	0.0%
stimulus08-37ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	11	91.7%	1	8.3%
stimulus09-28ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	12	100.0%	0	0.0%
stimulus10-24ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	12	100.0%	0	0.0%
stimulus11-18ms	29	96.7%	1	3.3%	29	96.7%	1	3.3%	12	100.0%	0	0.0%
stimulus12-13ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	12	100.0%	0	0.0%
stimulus13-9ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	12	100.0%	0	0.0%
stimulus14-4ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	12	100.0%	0	0.0%
stimulus15-0ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	12	100.0%	0	0.0%
stimulus16+4.5ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	12	100.0%	0	0.0%
stimulus17+9ms	29	96.7%	1	3.3%	30	100.0%	0	0.0%	12	100.0%	0	0.0%
stimulus18+13.2ms	21	70.0%	9	30.0%	27	90.0%	3	10.0%	11	91.7%	1	8.3%
stimulus19+18ms	17	56.7%	13	43.3%	22	73.3%	8	26.7%	11	91.7%	1	8.3%
stimulus20+22ms	9	30.0%	21	70.0%	12	40.0%	18	60.0%	12	100.0%	0	0.0%
stimulus21+27ms	7	23.3%	23	76.7%	10	33.3%	20	66.7%	10	83.3%	2	16.7%
stimulus22+36ms	1	3.3%	29	96.7%	4	13.3%	26	86.7%	5	41.7%	7	58.3%
stimulus23+45ms	0	0.0%	30	100.0%	2	6.7%	28	93.3%	4	33.3%	8	66.7%
stimulus24+54ms	0	0.0%	30	100.0%	1	3.3%	29	96.7%	2	16.7%	10	83.3%
stimulus25+63ms	0	0.0%	30	100.0%	0	0.0%	30	100.0%	2	16.7%	10	83.3%
stimulus26+72ms	0	0.0%	30	100.0%	1	3.3%	29	96.7%	2	16.7%	10	83.3%
stimulus27+81ms	0	0.0%	30	100.0%	1	3.3%	29	96.7%	1	8.3%	11	91.7%
stimulus28+90ms	0	0.0%	30	100.0%	0	0.0%	30	100.0%	1	8.3%	11	91.7%
stimulus29+99ms	1	3.3%	29	96.7%	0	0.0%	30	100.0%	0	0.0%	12	100.0%
stimulus30+108ms	0	0.0%	30	100.0%	0	0.0%	30	100.0%	1	8.3%	11	91.7%
stimulus31+117ms	0	0.0%	30	100.0%	0	0.0%	30	100.0%	0	0.0%	12	100.0%
stimulus32+126ms	1	3.3%	29	96.7%	0	0.0%	30	100.0%	0	0.0%	12	100.0%
stimulus33+135ms	0	0.0%	30	100.0%	0	0.0%	30	100.0%	0	0.0%	12	100.0%

[1] The following tables were obtained from the chi-square tests and present the percentage of responses as the fortis and lenis stops for each stimulus sorted by group and language. The stimuli that were considered for the statistical analyses are highlighted in orange.

Table A.5. Perception of English stops by Groups A, B and E.

	Group A				Group B				Group E			
	b		p		b		p		b		p	
	Count	%	Count	%	Count	%	Count	%	Count	%	Count	%
stimulus01-99ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	6	100.0%	0	0.0%
stimulus02-91ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	6	100.0%	0	0.0%
stimulus03-82ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	6	100.0%	0	0.0%
stimulus04-73ms	29	96.7%	1	3.3%	30	100.0%	0	0.0%	6	100.0%	0	0.0%
stimulus05-64ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	6	100.0%	0	0.0%
stimulus06-55ms	30	100.0%	0	0.0%	29	96.7%	1	3.3%	6	100.0%	0	0.0%
stimulus07-46ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	6	100.0%	0	0.0%
stimulus08-37ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	6	100.0%	0	0.0%
stimulus09-28ms	30	100.0%	0	0.0%	29	96.7%	1	3.3%	6	100.0%	0	0.0%
stimulus10-24ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	6	100.0%	0	0.0%
stimulus11-18ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	6	100.0%	0	0.0%
stimulus12-13ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	6	100.0%	0	0.0%
stimulus13-9ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	6	100.0%	0	0.0%
stimulus14-4ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	6	100.0%	0	0.0%
stimulus15-0ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	6	100.0%	0	0.0%
stimulus16+4.5ms	29	96.7%	1	3.3%	30	100.0%	0	0.0%	6	100.0%	0	0.0%
stimulus17+9ms	27	90.0%	3	10.0%	30	100.0%	0	0.0%	5	83.3%	1	16.7%
stimulus18+13.2ms	17	56.7%	13	43.3%	18	60.0%	12	40.0%	3	50.0%	3	50.0%
stimulus19+18ms	12	40.0%	18	60.0%	13	43.3%	17	56.7%	3	50.0%	3	50.0%
stimulus20+22ms	6	20.0%	24	80.0%	10	33.3%	20	66.7%	1	16.7%	5	83.3%
stimulus21+27ms	4	13.3%	26	86.7%	6	20.0%	24	80.0%	0	0.0%	6	100.0%
stimulus22+36ms	3	10.0%	27	90.0%	1	3.3%	29	96.7%	0	0.0%	6	100.0%
stimulus23+45ms	3	10.0%	27	90.0%	0	0.0%	30	100.0%	0	0.0%	6	100.0%
stimulus24+54ms	3	10.0%	27	90.0%	0	0.0%	30	100.0%	0	0.0%	6	100.0%
stimulus25+63ms	3	10.0%	27	90.0%	0	0.0%	30	100.0%	0	0.0%	6	100.0%
stimulus26+72ms	3	10.0%	27	90.0%	0	0.0%	30	100.0%	0	0.0%	6	100.0%
stimulus27+81ms	3	10.0%	27	90.0%	0	0.0%	30	100.0%	0	0.0%	6	100.0%
stimulus28+90ms	4	13.3%	26	86.7%	0	0.0%	30	100.0%	0	0.0%	6	100.0%
stimulus29+99ms	0	0.0%	30	100.0%	1	3.3%	29	96.7%	0	0.0%	6	100.0%
stimulus30+108ms	0	0.0%	30	100.0%	0	0.0%	30	100.0%	0	0.0%	6	100.0%
stimulus31+117ms	0	0.0%	30	100.0%	0	0.0%	30	100.0%	0	0.0%	6	100.0%
stimulus32+126ms	0	0.0%	30	100.0%	0	0.0%	30	100.0%	0	0.0%	6	100.0%
stimulus33+135ms	0	0.0%	30	100.0%	1	3.3%	29	96.7%	0	0.0%	6	100.0%

Table A.6. Perception of Spanish stops by Groups B and S.

	Group B				Group S			
	b		p		b		p	
	Count	%	Count	%	Count	%	Count	%
stimulus01-99ms	30	100.0%	0	0.0%	6	100.0%	0	0.0%
stimulus02-91ms	30	100.0%	0	0.0%	6	100.0%	0	0.0%
stimulus03-82ms	30	100.0%	0	0.0%	6	100.0%	0	0.0%
stimulus04-73ms	29	96.7%	1	3.3%	6	100.0%	0	0.0%
stimulus05-64ms	30	100.0%	0	0.0%	6	100.0%	0	0.0%
stimulus06-55ms	30	100.0%	0	0.0%	6	100.0%	0	0.0%
stimulus07-46ms	29	96.7%	1	3.3%	6	100.0%	0	0.0%
stimulus08-37ms	30	100.0%	0	0.0%	6	100.0%	0	0.0%
stimulus09-28ms	29	96.7%	1	3.3%	6	100.0%	0	0.0%
stimulus10-24ms	29	96.7%	1	3.3%	5	83.3%	1	16.7%
stimulus11-18ms	29	96.7%	1	3.3%	4	66.7%	2	33.3%
stimulus12-13ms	30	100.0%	0	0.0%	2	33.3%	4	66.7%
stimulus13-9ms	30	100.0%	0	0.0%	2	33.3%	4	33.3%
stimulus14-4ms	30	100.0%	0	0.0%	1	16.7%	5	83.3%
stimulus15-0ms	29	96.7%	1	3.3%	1	16.7%	5	83.3%
stimulus16+4.5ms	29	96.7%	1	3.3%	1	16.7%	5	83.3%
stimulus17+9ms	29	96.7%	1	3.3%	2	33.3%	4	33.3%
stimulus18+13.2ms	22	73.3%	8	26.7%	2	33.3%	4	33.3%
stimulus19+18ms	14	46.7%	16	53.3%	1	16.7%	5	83.3%
stimulus20+22ms	8	26.7%	22	73.3%	0	0.0%	6	100.0%
stimulus21+27ms	6	20.0%	24	80.0%	0	0.0%	6	100.0%
stimulus22+36ms	0	0.0%	30	100.0%	0	0.0%	6	100.0%
stimulus23+45ms	0	0.0%	30	100.0%	0	0.0%	6	100.0%
stimulus24+54ms	0	0.0%	30	100.0%	0	0.0%	6	100.0%
stimulus25+63ms	0	0.0%	30	100.0%	0	0.0%	6	100.0%
stimulus26+72ms	1	3.3%	29	96.7%	0	0.0%	6	100.0%
stimulus27+81ms	0	0.0%	30	100.0%	0	0.0%	6	100.0%
stimulus28+90ms	0	0.0%	30	100.0%	0	0.0%	6	100.0%
stimulus29+99ms	0	0.0%	30	100.0%	0	0.0%	6	100.0%
stimulus30+108ms	0	0.0%	30	100.0%	0	0.0%	6	100.0%
stimulus31+117ms	0	0.0%	30	100.0%	0	0.0%	6	100.0%
stimulus32+126ms	0	0.0%	30	100.0%	0	0.0%	6	100.0%
stimulus33+135ms	0	0.0%	30	100.0%	0	0.0%	6	100.0%

Table A.7. Perception of Mandarin and English stops by Group A

	English				Mandarin			
	b		p		b		p	
	Count	%	Count	%	Count	%	Count	%
stimulus01-99ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%
stimulus02-91ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%
stimulus03-82ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%
stimulus04-73ms	29	96.7%	1	3.3%	30	100.0%	0	0.0%
stimulus05-64ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%
stimulus06-55ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%
stimulus07-46ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%
stimulus08-37ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%
stimulus09-28ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%
stimulus10-24ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%
stimulus11-18ms	30	100.0%	0	0.0%	29	96.7%	1	3.3%
stimulus12-13ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%
stimulus13-9ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%
stimulus14-4ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%
stimulus15-0ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%
stimulus16+4.5ms	29	96.7%	1	3.3%	30	100.0%	0	0.0%
stimulus17+9ms	27	90.0%	3	10.0%	29	96.7%	1	3.3%
stimulus18+13.2ms	17	56.7%	13	43.3%	21	70.0%	9	30.0%
stimulus19+18ms	12	40.0%	18	60.0%	17	56.7%	13	43.3%
stimulus20+22ms	6	20.0%	24	80.0%	9	30.0%	21	70.0%
stimulus21+27ms	4	13.3%	26	86.7%	7	23.3%	23	76.7%
stimulus22+36ms	3	10.0%	27	90.0%	1	3.3%	29	96.7%
stimulus23+45ms	3	10.0%	27	90.0%	0	0.0%	30	100.0%
stimulus24+54ms	3	10.0%	27	90.0%	0	0.0%	30	100.0%
stimulus25+63ms	3	10.0%	27	90.0%	0	0.0%	30	100.0%
stimulus26+72ms	3	10.0%	27	90.0%	0	0.0%	30	100.0%
stimulus27+81ms	3	10.0%	27	90.0%	0	0.0%	30	100.0%
stimulus28+90ms	4	13.3%	26	86.7%	0	0.0%	30	100.0%
stimulus29+99ms	0	0.0%	30	100.0%	1	3.3%	29	96.7%
stimulus30+108ms	0	0.0%	30	100.0%	0	0.0%	30	100.0%
stimulus31+117ms	0	0.0%	30	100.0%	0	0.0%	30	100.0%
stimulus32+126ms	0	0.0%	30	100.0%	1	3.3%	29	96.7%
stimulus33+135ms	0	0.0%	30	100.0%	0	0.0%	30	100.0%

Table A.8. Perception of Mandarin, English and Spanish stops by Group B.

	English				Mandarin				Spanish			
	b		p		b		p		b		p	
	Count	%	Count	%	Count	%	Count	%	Count	%	Count	%
stimulus01-99ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	30	100.0%	0	0.0%
stimulus02-91ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	30	100.0%	0	0.0%
stimulus03-82ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	30	100.0%	0	0.0%
stimulus04-73ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	29	96.7%	1	3.3%
stimulus05-64ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	30	100.0%	0	0.0%
stimulus06-55ms	29	96.7%	1	3.3%	30	100.0%	0	0.0%	30	100.0%	0	0.0%
stimulus07-46ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	29	96.7%	1	3.3%
stimulus08-37ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	30	100.0%	0	0.0%
stimulus09-28ms	29	96.7%	1	3.3%	30	100.0%	0	0.0%	29	96.7%	1	3.3%
stimulus10-24ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	29	96.7%	1	3.3%
stimulus11-18ms	30	100.0%	0	0.0%	29	96.7%	1	3.3%	29	96.7%	1	3.3%
stimulus12-13ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	30	100.0%	0	0.0%
stimulus13-9ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	30	100.0%	0	0.0%
stimulus14-4ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	30	100.0%	0	0.0%
stimulus15-0ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	29	96.7%	1	3.3%
stimulus16+4.5ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	29	96.7%	1	3.3%
stimulus17+9ms	30	100.0%	0	0.0%	30	100.0%	0	0.0%	29	96.7%	1	3.3%
stimulus18+13.2ms	18	60.0%	12	40.0%	27	90.0%	3	10.0%	22	73.3%	8	26.7%
stimulus19+18ms	13	43.3%	17	56.7%	22	73.3%	8	26.7%	14	46.7%	16	53.3%
stimulus20+22ms	10	33.3%	20	66.7%	12	40.0%	18	60.0%	8	26.7%	22	73.3%
stimulus21+27ms	6	20.0%	24	80.0%	10	33.3%	20	66.7%	6	20.0%	24	80.0%
stimulus22+36ms	1	3.3%	29	96.7%	4	13.3%	26	86.7%	0	0.0%	30	100.0%
stimulus23+45ms	0	0.0%	30	100.0%	2	6.7%	28	93.3%	0	0.0%	30	100.0%
stimulus24+54ms	0	0.0%	30	100.0%	1	3.3%	29	96.7%	0	0.0%	30	100.0%
stimulus25+63ms	0	0.0%	30	100.0%	0	0.0%	30	100.0%	0	0.0%	30	100.0%
stimulus26+72ms	0	0.0%	30	100.0%	1	3.3%	29	96.7%	1	3.3%	29	96.7%
stimulus27+81ms	0	0.0%	30	100.0%	1	3.3%	29	96.7%	0	0.0%	30	100.0%
stimulus28+90ms	0	0.0%	30	100.0%	0	0.0%	30	100.0%	0	0.0%	30	100.0%
stimulus29+99ms	1	3.3%	29	96.7%	0	0.0%	30	100.0%	0	0.0%	30	100.0%
stimulus30+108ms	0	0.0%	30	100.0%	0	0.0%	30	100.0%	0	0.0%	30	100.0%
stimulus31+117ms	0	0.0%	30	100.0%	0	0.0%	30	100.0%	0	0.0%	30	100.0%
stimulus32+126ms	0	0.0%	30	100.0%	0	0.0%	30	100.0%	0	0.0%	30	100.0%
stimulus33+135ms	1	3.3%	29	96.7%	0	0.0%	30	100.0%	0	0.0%	30	100.0%