VOT and Acquisition of Stop Consonants in Spanish-English Bilingual Children

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Abstract

English and Spanish speakers learn different phonetic systems in their acquisition of their respective languages. Despite having the same phonemic contrast between voiced and voiceless plosives, the stop consonants of the two languages differ in voice onset time, or VOT. They also have different vowels with different formant values. We hypothesized that bilingual children exposed to both languages would display intermediate VOT and vowel formant values for both languages. Measuring readings from lists from four children aged three to five years, we found this to be the case for VOT for only voiced stops and not voiceless stops. VOT for this group seems to collapse into three categories: strongly positive, slightly positive, and negative, to one of which all of their stop productions belong. Vowels did not appear to have a distinct, discernible pattern among bilingual children.

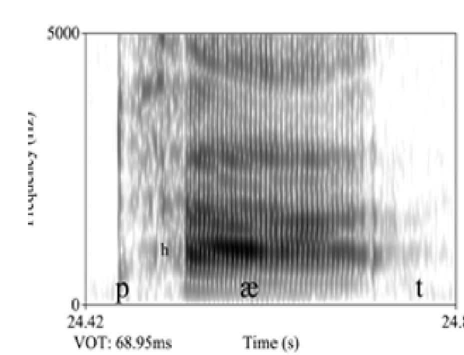
Introduction

Existing research supports the idea that learning two languages at once can cause interactions between the phonetic systems of their two languages (Simonet, 2014). As our world becomes more multicultural and we engage with more and more bilingual speakers, it is important to understand how these types of interactions work. Some speakers have also been found to be able to maintain a distinction between their two phonetic systems (Goldrick et al., 2014). These ideas have been investigated with respect to VOT (Lee, 2012) and Spanish (e.g. Fabiano-Smith, 2010) before. Plosives, or stops, are a type of consonant produced with the complete closure of the vocal tract, stopping airflow, followed by release of the closure. Included in the class of sounds are the /b/ and /p/ sounds in the English words bat and pat, respectively. These two sounds are distinguished by timing (or VOT) of the release of a closure relative to the beginning of voicing. In English /b/, voicing starts at roughly the same time as closure release, whereas in /p/ voicing starts long after the release.

VOT is a dimension upon which there is a phonemic distinction in both English and Spanish, meaning that it alone can distinguish one word from another as in the English pair of words pat and bat or the Spanish word pair pata ‘paw’ and bata ‘robe’. VOT can be positive or negative. Both English and Spanish feature the phonemes /p/, /t/, /k/, /b/, /d/, and /g/; however, these phonemes are realized differently in the two languages.

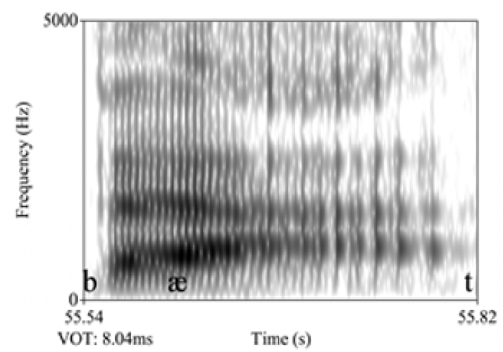
In word-initial position, English voiceless stops are phonetically aspirated. This means they have a strongly positive VOT with a puff of air following the release of the closure before the start of the vowel. An example of this is shown in Figure 1. This spectrogram shows an English speaker reading the word pat (phonemically /pæt/, phonetically [phæt]) (Ladefoged, 1999). Note the long VOT indicated with a superscripted /h/ in the figure.

Figure 1, spectrogram of /pæt/



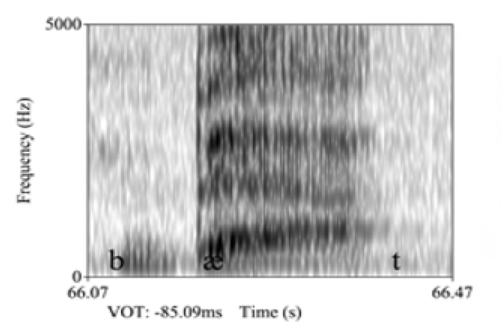
English voiced stops, in word-initial position are typically realized as truly phonetically voiceless stops; that is, their VOT is not negative (with voicing beginning before the release of the closure), but rather close to zero or slightly positive (with voicing beginning concurrently or slightly after the release of the closure). Figure 2 shows an example of this. The spectrogram shows an English speaker reading the word bat (phonemically /bæt/, phonetically [b□æt] where the subscripted circle indicates lack of voicing during the closure). Note the much shorter VOT compared to the /p/ in figure 1.

Figure 2, spectrogram of /bæt/ with zero VOT



More rarely, English voiced stops are produced with a negative VOT as is shown in Figure 3 below. This spectrogram shows a different English speaker reading the word bat, but as is evident, there is voicing before the closure.

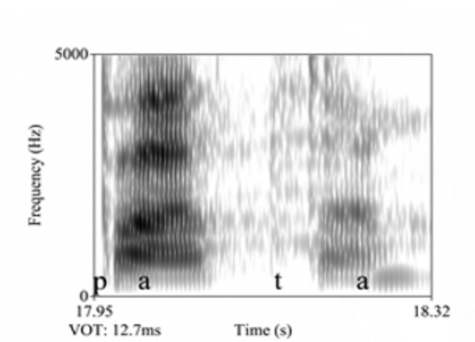
Figure 3, spectrogram of /bæt/ with negative VOT



This pattern does not hold when stops occur in most prevocalic contexts. In positions other than word-initial position, voiced and voiceless stops adopt a pattern wherein voiced stops have negative VOT and voiceless stops vary as a function of stress: in the onset of a stressed syllable, VOT is positive, but in the onset of unstressed syllables or after /s/, VOT is near-zero.

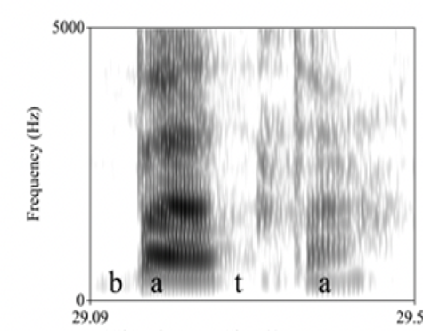
In contrast, Spanish stops are realized differently from English ones and vary more geographically. In general, however, most Spanish speakers realize /t/ and /d/ as denti-alveolars (t□, d□), meaning the tongue makes contact closer to the teeth than to the alveolar ridge. Additionally, postvocalic voiced stops, aside from after a pause or nasal consonant, are produced as fricatives (β, ð, □) or approximants (β□, ð□, □) (Celdrán, Planas, & Carrera-Sabaté, 2003). For our purposes, they are realized as [b, d, g] since we are only considering word initial stops read from a list. In word initial position, voiceless stops do not feature strong aspiration. Instead, they tend to have very short, near-zero VOT. This is shown below in Figure 4. This spectrogram shows a Spanish speaker reading the word "pata" 'paw' (/pata/, [pata]).

Figure 4, spectrogram of /pata/



Voiced stops tend to have strongly negative VOT, as demonstrated in Figure 5, which shows a Spanish speaker reading the word bata 'robe' [/bata/, [bata]).

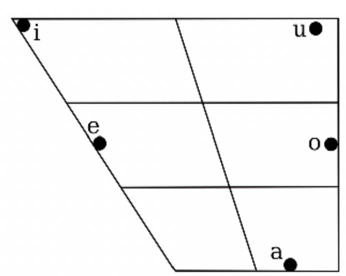
Figure 5, spectrogram of /bata/



To summarize, English and Spanish both have voicing distinctions, but their categorical boundaries are different. For English stops, that categorical boundary lies above zero milliseconds. That is, voiced stops can have small positive voice onset time and still be perceived as voiced (although sometimes English speakers do produce voiced stops with negative voice onset time). In Spanish, that boundary is at zero; any stop with positive voice onset time is phonemically voiceless and any stop with negative voice onset time is phonemically voiced.

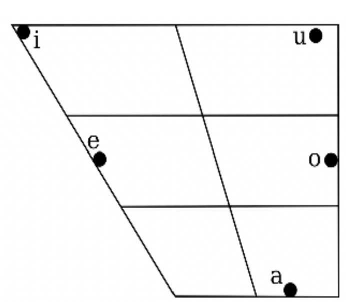
As for vowels, English and Spanish vary even more. English vowels are numerous and vary greatly based on dialect and geography. All the English-speaking subjects in this project were speakers of California English; Figure 6 shows the set of vowels used in this dialect. As described in the methodology section, the vowels used in the world list for this project were /□/, /æ/ and /i/.

Figure 6 (Ladefoged, 1999), English vowel chart



Spanish has a simpler vowel inventory; it uses a five-vowel system that is more consistent across geography than that of English. Figure 7 shows the Spanish vowel chart. For this project, the list from which subjects read contained the vowels /i/, /e/, and /a/.

Figure 7 (Ladefoged, 2001), Spanish vowel chart



It is evident that the English and Spanish vowel spaces vary, as vowels vary in first and second formant values (F1 and F2), as do the categorical boundaries between voiced and voiceless stops. In monolingual speakers, used in this paper to mean people who have one first language (i.e. they primarily had exposure to only one language in their childhood), these categories are relatively cut and dry. There is individual variation, but without the influence of another language or dialect, the average values from group to group of monolinguals with the same accent are similar. However, we contend that for bilingual first language learners, these categories are more malleable. The question we seek to answer is this: how are these categories influenced at a young age by exposure to another language? In immigrant families, children are routinely exposed to multiple languages. Do children differentiate between these languages when it comes to different sounds and different phonetic categories, or do these categories collapse into a single distinction used in both languages? Or are there intermediate values that these children reach in their speech production? Barlow, Jessica & E Branson, Paige & Nip, Ignatius (2013) suggests that they do. They found that in the case of /l/ in English and Spanish, bilingual children have a merged category; they maintain English allophonic variation of /l/ pre-vocallically, indicating that some phonological environments allow the merging of categories cross-linguistically, but not all do. Fabiano-Smith and Goldstein (2010), on the other hand, found that there is evidence for separation and interaction between the bilingual children's two languages in their study. This was a broad study of many characteristics of language acquisition, but they did find that frequency of sounds in the language had no impact on differential accuracy between English and Spanish, suggesting that mergers are based on something other than simply frequency. VOT has been studied this way before in Lee (2012). This study found that before the age of five, Korean-English bilingual children had not developed separate systems for oral stops between the two languages.

All of this considered, we hypothesize that to some degree, English-Spanish bilingual children will display intermediate values in their speech. For voice onset time, we predict that the average VOT value in voiceless stops in English-Spanish bilinguals will be lower than that of English monolinguals but higher than that of Spanish monolinguals, and that the average VOT values of voiced stops will be lower in English-Spanish bilinguals than in English monolinguals (i.e. more strongly negative), but not as strongly negative as seen in Spanish monolinguals. For vowels, the first and second formants of the English vowels may approach closer to the five-vowel system of Spanish. They may also produce vowels in the Spanish list that are closer to English vowels than Spanish monolinguals.

Methodology

In order to compare voice onset time, F1, and F2 values (used here to account for the differences between vowels) between English monolinguals, Spanish monolinguals, and bilingual learners of English and Spanish, we recorded these three groups reading a list of words and compared the values to one another.

The first task was to prepare a word list. The goal for this was to create a list that would allow us to compare voice onset time, first formant and second formant values between participant groups. Because English and Spanish share the set of plosives /p/, /t/, /k/, /b/, /d/, and /g/, the lists feature minimal pairs or near minimal pairs with word initial consonants differing in the phonemic voicing category of the stop and the following vowel. In Spanish, we used the vowels /a/, /e/, and /i/. The Spanish stimuli used are as follows:

Table 1, Spanish Stimuli

pata[pata]	bata[bata]
paw	*robe*
taba[taβa]	daba[daβa]
ankle bone	*I gave*
cana[kana]	gana[gana]
cane	*desire*
peso[peso]	beso[beso]
weight	*kiss*
tejo[texo]	dejo[dexo]
hopscotch	*I left*
quejar[kexar]	guepardo [gepardo]
complain	*cheetah*
pida[piða]	vida [biða]
request	*life*
ti[ti]	di[di]
you	*I said*
quita[kita]	guitarra [gitara]
removes	*guitar*

For English, we used the same initial consonants, but used different vowels in order to measure the difference between the English and Spanish values. The vowels used were /æ/, /i/, and /□/. Using different permutations of these vowels and consonants, we formulated this word list from which the subject read:

Table 2, English Stimuli

pat [pʰæt]bat [b̥æt]

tart [tʰɑɹt]dart [d̥ɑɹt]

cap [kʰæp]gap [g̥æp]

pot [pʰɑt]bot [b̥ɑt]

taught [tʰɑt]dot [d̥ɑt]

cot [kʰɑt]got [g̥ɑt]

peep [pʰip]beep [b̥ip]

tear [tʰiɹ]deer [d̥iɹ]

key [kʰi]gear [g̥iɹ]

The order of each of the eighteen words in both the lists was randomized so as not to bias participants in any way.

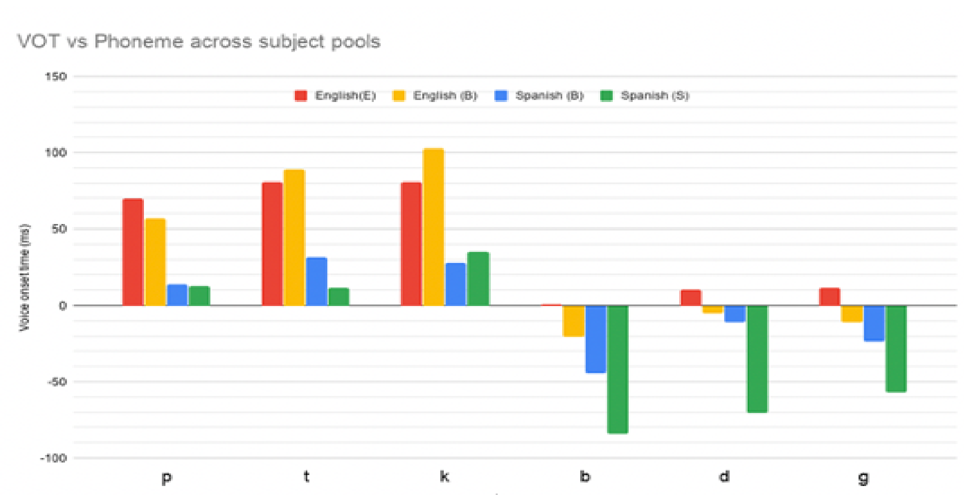
Participants were divided into three pools, Differing in their linguistic experience. Firstly, we recorded monolingual English speakers reading from the English list.

In the data, these participants are labeled as subject group E. These 21 participants were UC Santa Barbara students who participated voluntarily without compensation for their participation. They were instructed to simply read from the randomized list. Being English monolinguals, they read only from the English list. The investigator read the number, then the participant read the corresponding word, ensuring sufficient separation between the words.

The second group of subjects is bilingual children referred to in the data as subject group B. These are children between the ages of three and five who are brought up exposed to both English and Spanish both at home and at a preschool program in Santa Barbara, California. There were four children in this group. Being bilingual, they recorded both the English and the Spanish lists. As children this young generally lack the ability to read well, we did not depend on written lists as stimuli for the children. Instead, we presented them with a series of images, also put into a random order. When a child did not produce the desired word, we would instruct them verbally. Even in these instances when children did not produce the right word based on the images alone, the images were invaluable in keeping children engaged in the task. These images are shown in the appendix.

The last group was the Spanish monolinguals, referred to in the recordings and the data as subject group S. Strictly speaking, the participants in this group are not monolingual as they do use English and a second language to varying degrees. However, they were brought up with Spanish as their only language, so we expect that their Spanish will be unbiased (or at least minimally biased) by English. For this group, we simply asked the parents of the bilingual children (group B) to read from the Spanish list in the same way group E did; therefore, there were also four participants in the group that read only the 18 words in the Spanish list. For their participation and for the participation of their child, participants in group S were paid 15 dollars. Documents related to these recordings, including consent and receipt forms, can be found in the appendix.

Figure 8, average VOT values by consonant and group



All of these recordings were done on a personal voice recorder and loaded into

Praat (Weenink and Boersma 2018), where measurements were taken for VOT, F1, and F2. These measurements were put into a text grid and transferred into a spreadsheet. From this data, we completed our analysis

Results

A. Voice Onset Time

We found a relationship between the group and average VOT, as shown in figure 8. Average VOT and group (bilingual children vs monolingual Spanish speakers both had an effect on voicing contrast (whether a consonant is voiced or voiceless and the duration of VOT). However, as is seen in Figure 8, this relationship is not straightforward. In the case of voiceless stops, the VOT values for the bilingual group (B) seem to match the language they are speaking; when producing English words, voiceless stops exhibited an English pattern with a strongly positive VOT (on average, 82ms compared to the English speakers' 77ms), while from the Spanish list, they exhibited a typically Spanish pattern, with VOT similar to the Spanish group (24ms as opposed to the Spanish monolinguals' (19ms). In both languages, /p/ tended to exhibit the shortest VOT of the voiceless stops while /k/ exhibited the longest. This pattern exists in all three subject groups. The averages for each initial stop for each group is shown in Table 3 below. The standard deviations are shown in Table 4

Table 3, Avg VOT from all consonants and groups

PHONEME	AVG VOT	AVG VOT	AVG VOT	AVG VOT
Language (Group)	English (E)	English (B)	Spanish (B)	Spanish (S)
p	70.22	56.67	13.78	12.98
t	80.43	89.06	31.17	11.54
k	80.96	102.59	28.08	34.71
b	0.72	-20.50	-44.44	-84.19
d	10.65	-4.96	-10.76	-70.65
g	11.75	-10.75	-23.58	-56.57
VOICELESS	77.21	82.78	24.34	19.74
VOICED	7.71	-12.07	-26.26	-70.47

Table 4, VOT standard deviation from all consonants and groups

PHONEME	ST.DEV	ST.DEV	ST.DEV	ST.DEV
Language		English		
(Group)	English(E)	(B)	Spanish(B)	Spanish(S)
p	24.34	33.06	8.47	15.23
t	17.67	25.99	23.56	3.65
k	80.96	102.59	28.08	34.71
b	29.72	43.26	41.92	33.73
d	24.90	37.72	42.55	40.42
g	40.02	53.08	45.86	74.22
VOICELESS	21.01	37.19	17.26	15.94
VOICED	27.64	43.03	45.17	53.30

While children tended to differentiate between languages in the case of voiceless stops, a different pattern was seen in voiced stops. Our hypothesis was borne out by the data in the voiced case; bilingual children have intermediate VOT values between English and Spanish. On average, we see negative values between those of English and Spanish speakers. On the whole, English and Spanish speakers had a VOT for voiceless stops of 7ms and -70ms respectively. On the English list, the bilingual children averaged -12ms, while on the Spanish list they averaged lower at -26ms. Digging deeper, it is clear that there was some variation between the bilingual children; sometimes they adopted something closer to an English pattern and sometimes closer to a Spanish one, but still with intermediate values. The complete data can

be found in the spreadsheets accessed through the URL given in the appendix.

B. Vowels

Figure 9, F1 by group

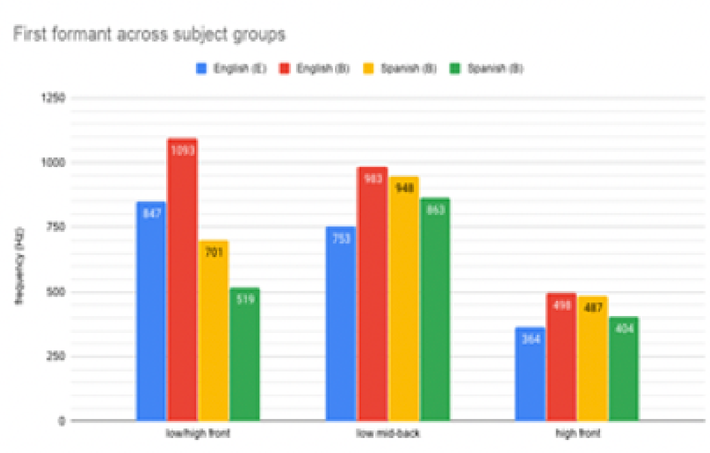
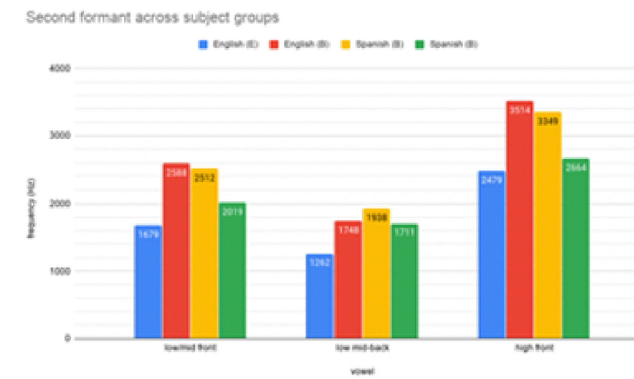


Figure 10, F2 by group



We grouped English /æ/ with Spanish /e/ as "low/mid front," hypothesizing that this category would converge to one in bilingual children. What we saw was that in English monolinguals (producing /æ/), the F1 and F2 were 847Hz and 1678Hz respectively. In Spanish monolinguals producing /e/, they were 518Hz and 2018Hz. Bilingual children produced the English /æ/ with an F1 of 1092Hz and an F2 of 2587Hz and Spanish /e/ with F1 and F2 values of 701Hz and 2511Hz. The second grouping was /□/ and /a/, grouped together as "low mid-back". The English monolinguals produced /□/ with an average F1 of 753Hz and an F2 of 1261Hz, while Spanish speakers had average F1 and F2 values of 863Hz and 1710Hz for Spanish /a/. Meanwhile, bilingual children had average values of 982Hz and 1748Hz for English /□/ and 947Hz and 1938Hz for Spanish /a/. The last grouping is perhaps the most relevant, as both English and Spanish use the same vowel: /i/. English monolinguals produced this vowel with average F1 and F2 values of 363Hz and 2478Hz respectively. Spanish monolinguals had average values of 404Hz and 2664Hz. For English /i/, the bilingual children had average values of 497Hz and 3513Hz. For Spanish /i/, they had average values of 487Hz and 3349Hz.

Vowels across all phonemes did not exhibit the pattern we hypothesized. As is evident from the graphs in Figures 9 and 10, the bilingual children did not exhibit intermediate values for the first and second formants of the vowels. There was no defining pattern that the bilingual children exhibited that monolinguals did not. Rather, the formants were simply higher in the bilingual group, likely due to the fact that the vocal tracts of children are smaller than those of the adults.

Discussion

A. Consonants

The results presented for VOT indicate that our hypothesis that bilingual children would show intermediate values between those observed for monolingual speakers of the two languages has some validity. However, it only seems to hold for voiced stops (see Figure 1 in section IV). In fact, in the case of /k/, the expected pattern almost seems to be reversed, as bilingual children exhibit higher VOT values for English /k/ than monolinguals and lower values for Spanish /k/. On the other hand, voiced stops exhibit exactly the pattern we predict; English monolinguals have, on average, slightly positive VOT, while Spanish monolinguals have strongly negative VOT and the bilingual children have intermediate negative values. VOT is less strongly negative, on average, for the English list than for the Spanish list among the bilinguals. The Spanish values also show some accommodation to English in being less strongly negative. There are numerous ways this data could be interpreted. This might indicate that there are some inherently different aspects of child speech. It is clear that children can distinguish between voiced and voiceless stops in both languages, and that, at least to some degree, they are able to distinguish between English and Spanish in this respect. However, it is also clear that their speech differs in some ways from the monolingual adult speech.

One explanation for what we have observed is that bilingual children, instead of arriving at intermediate VOT values for stops, actually form a number of different categories that can apply to both languages. While in this paper we have for the most part operated under the assumption that there are four classes into which VOT can fit (English and Spanish voiceless, English and Spanish voiced), it is possible that bilingual children collapse these categories into three. With near-zero VOT English voiced stops are somewhat comparable to Spanish voiceless stops. Strongly negative VOT exists for Spanish (and sometimes English) voiced stops, and strongly positive VOT exists for English voiceless stops; children might acquire these two "extreme" cases and collapse the intermediate cases into a single category. Due to exposure from Spanish, children may require negative VOT for voiced stops, even in English, whose voiced stops can alternate between negative and slightly positive VOT while the slightly positive category from Spanish voiceless stops can spill over into the English voiced stops, since they would have already learned it in Spanish. English voiceless stops, on the other hand, are unique to English, so are maintained only in that language in the strongly positive VOT category. This explanation is further supported by the fact that most of the children in the study are raised with Spanish first and are primarily English learners, so Spanish would likely have a greater influence on their phonetic patterns. If Spanish is the more dominant language of the two for these speakers, then it is possible that it would have a greater impact on English than English would have on Spanish (Tsui et. al., 2019). This idea is shown graphically in Table 5 below.

Table 5, proposed VOT categories

Category	**Negative**	**Slightly Positive**	**Strongly Positive**
VOT Range	<0ms	0-50ms	>50ms
Examples	English voiced stops Spanish voiced stops	Spanish voiceless stops	English voiceless stops

This also explains why we witnessed variation in the English voiced stops among the bilingual children; while all three of these categories exist in English, only two of them exist in Spanish. Therefore, while English voiced stops can be influenced by Spanish, and are more frequently produced with negative VOT than among English monolinguals, the same is not true of Spanish voiceless stops because the strongly positive VOT category does not exist in Spanish. This idea is supported by Barlow et al. (2013) who found that English /l/ was influenced by Spanish /l/ only in pre-vocalic contexts; the category only merges in certain environments while still allowing the natural allophonic variation between dark and light /l/ in English. Similarly, with voice onset time, the bilingual children merge the VOT category only along certain lines, while still maintaining distinct phonetic systems.

However, if the Spanish and English voiced stops are not collapsed, this would argue for them belonging to distinct categories (i.e. there are two negative VOT categories). One other factor to consider is that there could be both articulatory and perceptual constraints at work in shaping the VOT patterns among the bilingual children. In the case of the vowel formant data (to be considered below), the production constraints offer a compelling account of the patterns. To tease out the possibly interfering effects of perceptual and production constraints, it would be helpful to have a control group of monolingual children. A more extensive data set would also allow for one to assess whether VOT values for voiced stops in the two languages, despite being very similar among the bilinguals in the current experiment, might actually be differentiated,

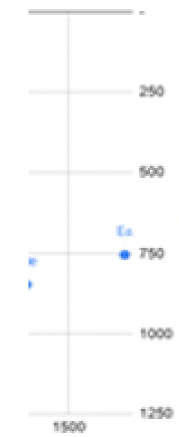
though these differences are small in magnitude.

B. Vowels

As described in section IV, the vowels did not exhibit the pattern we predicted. In all cases, the first and second formants were higher in the bilingual children than in the

monolingual adults. However, this is to be expected, since children's formants are at a higher frequency as a result of their smaller vocal tracts. Aside from the higher frequency, there is no discernible pattern to the variation from the adult speech. In fact, in many cases, the pattern is the opposite of what we would expect. In Figure 11, all of the vowels are graphed with the average first formant on the y-axis and the average second formant on the x-axis. Each point is labelled with the subject pool and vowel; for instance, the bilingual subject group average values for /i/ from the English list are marked as BiE. It is evident here that there is no clear relationship between one vowel, its counterpart in the other language, and the bilingual values.

Figure 11, vowels plotted by formant (F1 and F2)



While conclusions must be regarded as speculative in the absence of monolingual children as a control group, one explanation is inherent to child speech in general. Bilingual children have many different vowels to produce; between the eleven in English and the five in Spanish, they are unable to produce specific targets for F1 and F2, especially given their higher F0 compared to adults. Because their speech coordination and physiology are not fully developed, more precise production of vowels is difficult, which might have impacted our ability to measure differences. This is supported by McGowan (2014), who found that while the vowel space is well defined quite early in life, it takes 48 months to develop very precise vowels, and regional variation (which is relevant to our discussion of bilingual language acquisition) does not arise until that time. Since our subjects are between the ages of three and five, it would be reasonable to believe that even bilingual children cannot produce these vowels precisely enough to have a unique pattern that stands out from monolingual speakers in any significant way.

C. Other comments and criticisms

There were several problems we encountered that limit the scope of this study. Firstly, the recordings for this study were conducted in early 2020 and were interrupted by the global COVID-19 pandemic. We had more recording sessions scheduled when schools closed and shelter in place orders were implemented; unfortunately, this impacted our project. We were initially planning on having more child subjects, but the global situation prevented us from doing so.

Secondly, we used adults as controls instead of children. Many other similar studies use monolingual children to compare to multilingual children. This would have been useful, particularly in our discussion of the vowel space and formants, as it would have been much easier to compare children (who all have higher formants than adults) to each other than to compare children to adults. Rather than manipulating two variables (age and bilingualism), we could have instead manipulated one for better results. This could have also changed or improved our results for the discussion of VOT.

Conclusion

We hypothesized that for vowels and stop consonants, bilingual children would produce sounds with intermediate values between their two native languages. This study has found that bilingual children exposed to both English and Spanish do indeed exhibit different patterns from monolinguals for certain categories of sounds. Although we did not find any evidence that vowels are affected, at least between the ages of three and five, there is evidence that there is an effect on stop consonants. Voiced stops seemed to be particularly affected, as bilingual children had VOT values between the slightly positive values of English monolinguals and the strongly negative values of Spanish monolinguals. The VOT categorical boundaries that exhibit in English seem to be affected by those in Spanish, and the Spanish boundaries affect the English ones.

Further investigation will be needed to confirm this, ideally comparing bilingual children to monolingual children of the same age, as this study simply compared bilingual children with monolingual adults. The effect observed could also exist for other classes of sounds aside from just stops; this could also be a topic of further research. From a practical perspective, research in this area could help to improve language pedagogy in young language learners, as understanding how bilingual children develop categorical boundaries could provide insight into how they acquire language in general. Additionally, in an increasingly multilingual world, understanding these types of phonetic transfer effects may become more important in the future.

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