Universitat de Barcelona
Estudios de Fonética Experimental
Journal of Experimental Phonetics
LF Laboratori de Fonètica

Measurement of the VOT of voiceless plosives: Multiple bursts in Western Andalusian Spanish

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Article info

Article history
Received: 11/03/2022
Accepted: 10/05/2022

Keywords
Multiple bursts
Voice Onset Time
VOT measurement
Western Andalusian Spanish

Abstract

Multiple bursts (MBs) of plosives have been frequently reported but not sufficiently quantified. This study sought to examine experimentally MBs in a Spanish variety and to reveal the role of MBs when analyzing the VOT of voiceless plosives. 567 productions of /p t k/ by twenty-one speakers were analyzed. Findings indicated that two VOT measurement methods in the presence of MBs produced substantially different VOT values. MBs were also conditioned to different degrees by place of articulation, vowel height, and speech rate. This study has significant implications for research on VOT of voiceless plosives.

1. Introduction

Measurement of the voice onset time (VOT) of plosives is one of the most widely analyzed acoustic characteristics of consonants (Foulkes et al., 2010). This observation is more applicable to voiceless than voiced plosives, nonetheless. VOT can be generally defined as “the interval between the release of a consonant (usually a stop [plosive]) and the start of voicing of a following vowel” (Ladefoged, 2003, p. 94). As Ladefoged further states, any phonetic analysis of a language should include VOT measurement. Given the definition of VOT just presented, VOT analysis seems relatively straightforward. However, often it is not. Bóna and Auszmann (2014) note a number of methodological issues raised in VOT measurement. First, the burst (the release of the plosive) may not be seen in the spectrogram. This seems to be most common in voiceless bilabial plosives (Ladefoged, 2003; Nance & Stuart-Smith, 2013). Second, multiple bursts (MBs) can be evidenced for a single plosive. Third, there are different criteria for determining the end point of VOT, that is, the onset of regular voicing (the F1, or F2, or F3). Thomas (2011) for his part remarks that marking the onset of voicing can be problematic, since breathiness or aspiration “frequently make it ambiguous where the vocal pulses begin” (p. 117). In terms of basic methodology, Foulkes et al. (2010, p. 64) offer guidance as to how to measure VOT, basing their recommendations on researchers’ consensus. On the one hand, measurements should be done with reference to the waveform, although on the other hand spectrogram information may be also helpful, sometimes offering more precise onset and endpoints for VOT than the waveform.

The aim of the current study is to examine MBs and also their effect on VOT measurement in Western Andalusian Spanish (WAS). This speech variety comprises the speakers of three Andalusian provinces, namely Seville, Huelva, and Cadiz, with approximately 3.700.000 people in total, making up 8.5% of the Spanish-speaking population within Spain. Researching WAS pronunciation is particularly important as it is considered an innovative accent (Fernández de Molina & Hernández-Campoy, 2018). Sometimes it is classified among the radical accents of the Spanish-speaking world (frequently together with Caribbean accents, e.g., Guitart, 1978; Lipski, 1989).

Whereas MBs have been observed in other Spanish accents, such as Mexican Spanish (Lavoie, 2001) and Castilian Spanish (Asensi et al., 1997; Torres & Iparraguirre, 1996), to date this phonetic event has not been explored in WAS. In fact, Lavoie (2001) is the only researcher that analyzed quantitatively MBs in (Mexican) Spanish, and the current study aims to fill this research gap.

2. Background

2.1. MBs

A MB can be defined as the presence of more than one transient (as shown in the waveform) or plosion bar (as seen in the spectrogram). Figure 1 shows a velar plosive in the Spanish word *cala* [ˈkala] (‘cove’) with two such MBs, clearly displayed both in the waveform (two transients) and in the spectrogram (two plosion bars).

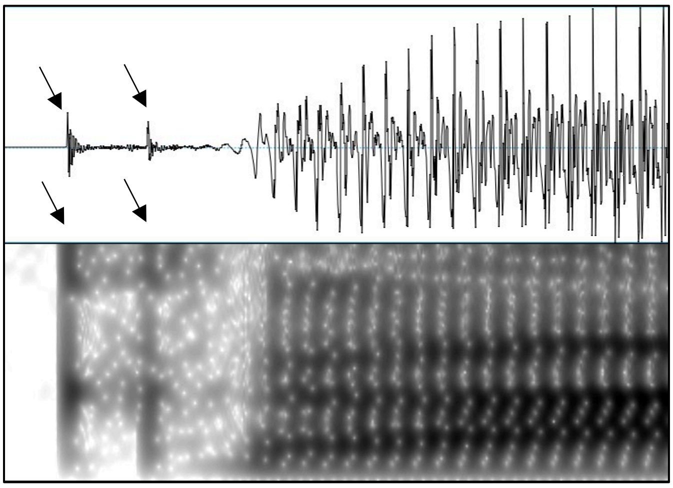

Figure 1. WAS speaker 1 production of *cala* [ˈkala] ‘cove’ with two bursts

The presence of more than one burst in the production of voiceless plosives (normally, reference to /p/, /t/, and /k/ is made) has been noted for a number of languages and speaker populations. However, as Parveen and Goberman (2012) comment, “studies have noted the existence of MBs (also previously called multiple release bursts), although few studies are known to have quantitatively examined MBs in neurologically normal speakers” (p. 266). For example, Davis (1994) investigated voicing in Hindi plosives, and noted in passing that he found that MBs were quite frequent for the velar plosives, but did not quantify this phonetic event any further. For Hungarian, Gráczi and Kohári (2014) offered more objectivized data, since they reported frequency of MBs for /p, t, k/ in this language. Taff et al. (2001) investigated the consonants of Aleut, and reported MBs for both velar and uvular voiceless plosives. Again, rather than quantifying these acoustic events, the researchers noted impressionistically that “several triple bursts as well as double bursts were found … [for] both velar and uvular stops” (pp. 238-239). Lavoie (2001) investigated the number of MBs in English and Spanish plosives (see section 2.1.1. for the latter). She considered whether the plosive (the following examples refer to /t/) was in initial pre-stress position (e.g., *Tucson*), in initial non-pre-stress position (e.g., *Tussaud*), in medial pre-stress position (e.g., *boutique*), or in medial non-pre-stress position (as in *booty*). Lavoie reported across all positions in her data for American English that /p/ had a total of 6 MBs, /t/ had 1 MB, and /k/ had 25 MBs. These totals are from 30 tokens of each consonant per position. Finally, Efstathopoulou (2007) examined the VOT of Greek/English bilinguals, and his findings indicated that more MBs were produced by the speakers when using English (6.3%) versus 3.6% in Greek.

For non-adult speaker populations, some studies have found that children and younger speakers tend to produce more MBs than older adults (Imbrie, 2005; Yang, 2018); to the contrary, Parveen and Gobermann (2012) found no significant differences between younger and older adults in the number of MBs produced. Another population of interest when considering MBs are persons with speech or neurological disorders. Parveen and Gobermann (2014) studied specifically MBs in speakers with Parkinson Disease; they found that individuals with this neurological disorder produced more MBs than normals, especially for alveolar plosives. Tar (2014) investigated the acquisition of Hungarian voicing contrast in bilabial and alveolar plosives in children with language disorders, and found that MBs occurred in 40% of the utterances analyzed. Lastly, Wang et al. (2004) reported that individuals with traumatic brain injury presented a tendency to produce MBs when attempting to increase their speech rate.

In summary, MBs have been reported in a diversity of languages and across speaker populations, but they have not been sufficiently quantified.

2.1.1. MBs in Spanish

As previously noted, research on MBs in Spanish is very scarce; to the best of my knowledge, only three studies reported MBs in Spanish. Asensi et al. (1997) reported that in Castilian Spanish velars frequently had two plosion bars and sometimes three, whereas the denti-alveolars[1] sometimes had double bars (i.e., bursts). Torres and Iparraguirre (1996) observed that the velar had multiple bursts, but did not quantify the phenomenon in any more detail. Returning to Lavoie's (2001) study of MBs in Mexican Spanish, recall that she considered the three voiceless plosives in four positions, as shown in the ensuing tokens for /t/: stressed initial position (*toca* 's/he plays'), untressed initial position (*tocar* 'to play'), medial pre-stress (*patón* 'duck foot'), and medial non-pre-stress (*pato* 'duck'). Lavoie found 0 MBs for /p/ across all positions. For /t/, she recorded 1 MB in initial pre-stress position and 1 MB in medial pre-stress position. Finally, /k/, as in other languages, was found to present more MBs: 31 across all positions. These figures are for 24 tokens of each consonant per position.

2.1.2. Explaining MBs

It is far from clear what causes MBs. One hypothesis states that when producing a plosive, the contact between the articulators is released in stages instead of abruptly at once, and each of these stages produces a transient (as seen in the waveform) or plosion bar (as evidenced in a spectrogram) (Foulkes et al., 2010). Plauché (2001), on the other hand, considered the interactions of intraoral pressure which builds quickly during the closure stage and then drops suddenly after the release stage of the plosive. According to this theory, the articulator, when moving slowly to the release stage, may be subject to the Bernouilli force caused by the airflow through the close constriction, and this results in pulling in the tongue surface back toward the palate at fast regular intervals, in turn producing more than one burst.

As we have previously seen, velars are cross-linguistically characterized by evidencing more MBs than other places of articulation (PoAs). Yang (2018) explains this special status of velars in the following manner. Velars normally have a shorter stop stage than other plosives (especially, bilabials), because velar consonants have a smaller cavity behind the constriction, which means that these plosives need less time to build up intraoral pressure. At the same time, velar plosives have a large surface of contact between the back of the tongue and the velum, and this causes change in intraoral pressure and tongue configuration change to be slow (in contrast to bilabial and alveolar plosives), resulting in multiple bursts and comparatively longer burst duration.

2.1.3. MBs and VOT measurement

When confronting MBs in the measurement of VOT, one obvious difficulty is to decide which burst should be taken as the onset of the VOT span. The most plausible answer to this quandary is to mark the first or last burst (whether there are two or more MBs) as the release of the plosive. And in fact this is what most researchers have done when MBs were found in their VOT analyses. In other cases, the burst with highest intensity has been chosen as the release point. Other criteria include more complex methods, such as Johnson's (2016). She determined that if the two bursts were within 20 ms and within 15 dB of each other, the first burst was tagged. If the two bursts were within 15 dB of each other but greater than 20 ms apart, the second burst was tagged. If the bursts differed by 15 dB or more, the burst with greater intensity was marked. Depending on the method chosen, then, the researcher's decision may produce considerably different VOT measurements. Table 1 summarizes the different methods used to measure VOT in the presence of MBs across 38 representative studies.

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[1] Traditionally, Spanish /t/ and /d/ have been described as dental plosives. However, Martínez-Celdrán et al. (2003) described them for Castilian as denti-alveolar. Avelino (2018) characterized these plosives as 'dento-alveolar' in Mexican Spanish. Martínez-Celdrán and Fernández-Planas (2013) offer electropalatography data that confirms the articulatory status of these Spanish plosives as a denti-alveolar. The term 'denti-alveolar' is to be preferred to 'dento-alveolar,' since Trask (1996) lists the former label.

VOT Measurement method	Number of studies	Example
First burst	24 (63%)	Sučková (2020)
Highest intensity	6 (16%)	Jesus & Costa (2020)
Last burst	4 (10.5%)	Kupske (2017)
Other	4 (10.5%)	Johnson (2016)
Total	38 (100%)	

Table 1. VOT measurement method in the presence of MBs, across 38 studies.

As shown in Table 1, the majority of researchers (63%) tag the first burst as the onset of VOT. Comparatively fewer researchers mark the burst with highest intensity (16%) as the point where VOT starts, and the last burst is selected in only 10.5% of the studies. Other methods, such as Johnson's (2016) are equally in the minority (10.5%). A chi-square test showed that these differences are statistically significant, $\chi^2(9) = 12.93$, $p < 0.0001$, with a medium effect size, Cramer's V = 0.55. In other words, the methods appearing in Table 1 differ quantitatively to a comparatively moderate extent; this, in turn, could reflect on substantially diverse VOTs in the presence of MBs depending on the method employed. It may be the case that researchers are not fully aware of this outcome.

In the presence of MBs, Gráczi and Kohári (2014) noted that "most studies do not mention where they measure the VOT from" (p. 1). Gráczi and Kohári found in their analysis of Hungarian MBs for the plosives /p/, /t/, and /k/ that three VOT measurement methods (from the first burst, from the most intense burst, or from the last burst) produced significantly different results according to PoA. To the best of my knowledge, the effect of VOT measurement method with reference to MBs has not been explored in any other studies.

2.1.4. MBs and PoA

VOT has long been acknowledged to vary as a function of PoA (e.g., Docherty, 1992; Klatt, 1975; Lisker & Abramson, 1967). Many studies in several languages report that, for most (but not all) speakers, VOT increases as one moves from the outer part to the inner part of the oral cavity: bilabial plosives have shorter VOT values than alveolar ones, and these in turn have shorter values than velar ones; that is, in terms of VOT, /p/ < /t/ < /k/. This pattern has been well attested for Spanish. Asensi, Portolés, and del Río (1997), Avelino (2018), Castañeda Vicente (1986), Martínez-Belda and Padilla (2021), Roldán and Soto-Barba (1997), Troya Déniz (2005), and Williams (1977), all reported evidence of this relationship. Exception to this pattern was found by Rosner et al. (2000), who observed that labials and dentals differed significantly from velars but not from each other. For WAS, the focus of the current study, Barrera-Pardo (in press) found that there was a statistically significant PoA effect on VOT, and post-hoc tests showed that the velar plosive was significantly different from both the bilabial and the denti-alveolar, and these were significantly different from each other (all $p < 0.001$).

However, there is limited data on the relationship between MBs and PoA. As noted previously, Gráczi and Kohári (2014) investigated the role of MBs in Hungarian voiceless plosives; they found 33 MBs for /p/, 60 MBs for /t/, and 79 MBs for /k/. These differences proved statistically significant, with a medium effect size. Keating et al. (1980) reported more frequent MBs as a function of the backness of the PoA (i.e., the /p/ < /t/ < /k/ pattern referred to above), whereby velars presented more MBs than both alveolars and bilabials, and alveolars had more MBs than bilabials. Lavoie's (2001) findings for MBs in English and Spanish are also to some extent in line with these observations. She found many more MBs for velars in both languages, while the results for bilabials and denti-alveolars were mixed.

Thus, it can be concluded from this review that the distribution of MBs according to PoA parallels that of VOT, with more MBs and a progressively longer VOT as the PoA recedes in the oral cavity.

2.1.5. MBs and vowel height

Research on VOT has found that the height of the vowel that follows the plosive consonant influences the length of this acoustic event; the higher the vowel, the longer the VOT. Rojczyk (2011), for example, noted that "vowel quality has been found to influence VOT values ... high-tense vowels increase the VOT duration ... average VOT of long-lag stops before /i, u/ is about 15% greater than before /ɛ, æ/" (p. 41). With regard to Spanish, Rosner et al. (2000) observed that for Castilian plosives vowel height had no effect on VOT. However, Castañeda Vicente (1986) showed for the same variety that the voiceless plosives tended to have longer VOTs when followed by the high vowels /i/ and /u/ than when followed by lower vowels such as /e/ and /a/. Research on Gran Canarian Spanish by Troya Déniz (2005) yielded a similar tendency for high vowels to lengthen the VOT of the preceding voiceless plosive. Barrera-Pardo (in press), investigating WAS VOT, found that vowel height had a significant effect on the VOT of the voiceless plosives of this variety, such that when /p/ and /t/ appeared before a high vowel (/i/ or /u/), their VOT was significantly longer (by 2.5 ms) than when the consonants were followed by a low vowel (/a/). No significant difference, though, was found for /k/ in the two vowel contexts.

The relationship between MBs and vowel height has received much less attention. Gráczi and Kohári (2014), working on Hungarian MBs, reported that there was no effect of the following vowel, except for /k/ followed by /i/, where 77.5% of the realizations had at least two bursts. In line with this finding, Plauché (2001) also observed that the number of MBs was independent of vowel height, again with the exception of the velars, which showed a moderately higher rate of MBs in front of high vowels. Plauché claims that this exception may follow from a greater surface area of contact for /k/ when followed by /i/ and a concomitant slower rate of release, and this in turn creates the right conditions for the Bernoulli effect (see section 2.1.2). However, Yang (2018), in his research on plosive acquisition in Mandarin, found a significant effect of vowel context on the number of bursts the plosives showed, such that the low vowel /a/ was a context with fewer MBs that the high vowels /i/ and /u/.

2.1.6. MBs and gender

Another factor that may affect VOT length is gender. Across languages, some studies have noted a tendency for female speakers to show longer VOT values than male speakers (e.g., Clothier & Loakes, 2018; Herd, 2020; Kaňok & Novotný, 2019; Ryalls et al., 1997), but there is also ample evidence to the contrary (Munson & Babel, 2019). Males have longer vocal tracts which lead to shorter VOT values, but it needs to be acknowledged that temporal patterns in plosives can also reflect learned models of gender performance (Munson & Babel, 2019).

When gender differences have been reported for Spanish VOT, these generally show a tendency for females to have longer VOTs than males. Asensi et al. (1997) concluded in their study of Castilian Spanish that male speakers produced shorter VOT values than female speakers. On the contrary, and also for Castilian, Rosner et al. (2000) found that gender had no effect on VOT. Troya Déniz (2005) reported longer VOTs for female speakers in Gran Canarian Spanish, especially with reference to the voiceless velar plosives. In WAS, Barrera-Pardo (in press) found that gender had no effect on VOT.

The relationship between MBs and gender has only been explored by Plauché (2001). This researcher reported no significant differences by gender in the number of MBs.

2.1.7. MBs and speech rate

In general and expectedly, VOT has been shown to decrease as the rate of speech (normally measured as the number of syllables uttered per second) increases (Herd, 2020; Torre & Barlow, 2009). As Yao (2007) explains, this phenomenon is caused "as a speaker slows down the speaking rate, all the phonetic segments would be stretched and therefore they should all show an increase in duration" (p. 184). Martínez-Belda and Padilla (2021) found in spontaneous emotional speech that VOT was reduced in duration as a function of speech rate, thus confirming the results of more controlled contexts reported in previous studies.

These findings lead to the plausible hypothesis that a faster speech rate will lead to more MBs; data provided by Wang et al. (2004) for patients with traumatic brain injury supports this hypothesis.

3. Research questions

Given the findings of the literature reviewed in the preceding sections, the current study sought to answer the following research questions:

a) What are the effects of measuring VOT in WAS according to different MB measurement methods?

b) What are the relative effects of the factors PoA, vowel height, gender, and speech rate on MBs in WAS?

Based on the data presented in the literature review, the different methods of VOT measurement in the presence of MBs are expected to yield substantially different VOT values for the voiceless plosives of WAS (as in Gráczi & Kohári, 2014 for Hungarian). In addition, based on the results reported in previous studies, it is expected that the number of MBs will vary as a function of PoA (Keating et al., 1980; Lavoie, 2001, for Mexican Spanish), whereby velars will have more MBs than denti-alveolars and bilabials, and these in turn will differ from each other. With respect to vowel height, and notwithstanding the paucity of data, the initial hypothesis is that high vowel contexts will favor more MBs than low vowel contexts (e.g., Yang, 2018). Gender is not expected to play a significant role in the production of MBs (Plauché, 2001), and finally it is anticipated that a faster speech rate will be associated with more MBs (Wang et al., 2014).

4. Method

4.1. Participants

21 speakers were recruited for the study through personal contacts of the researcher. All of them were undergraduate students from the Facultad de Filología of the Universidad de Sevilla at the time of the experiment. There were 12 females and 9 males. At the time of the study, their ages ranged from 19 to 23 (mean = 20.4, SD = 1.16). These participants were from the WAS region (5 from the Cadiz area and 16 from the Seville area).

4.2. Material

Following the methodological recommendations of Foulkes et al. (2010), the data for the study were controlled in the form of wordlists of disyllabic words, with the voiceless plosives followed by a high vowel (/i/ or /u/) and a low vowel (/a/) as presented in Table 2.

Plosive	**High vowel**	**Low vowel**
/p/	pito, pulla, pino, pura, piso	pata, para, paso, pala
/t/	tito, tino, tuya, tuna, tira	tala, tara, tasa, talo
/k/	cuya, cuna, quito, quiso, kilo	cala, casa, calo, cara

Table 2. Target words for the reading task.

4.3. Procedure

Participants were convened at the Phonetics Laboratory of the Universidad de Sevilla, under the presence of the experimenter. At their own pace, each speaker read out the 27 target words in Table 2 in the carrier sentence *Digo la palabra* ______ ('I say the word ______'). The recording was done at a 44.1 kHz and 16 bps sampling rate in a sound-proof booth, using a Marantz Professional PMD671 solid-state recorder and a Shure SM48 microphone. After completing the reading task, the participants were asked to fill out a background questionnaire that consisted of questions about their age, place of birth, place of longest residence, educational level, and gender. The session at the lab took approximately 15 minutes per participant.

4.4. Analysis

The reading task produced a total of 567 tokens (21 subjects x 27 words). Acoustic analyses were carried out in *Praat* (Boersma & Weenink, 2021). MBs were identified in the waveform and in the spectrogram, as shown in Figure 2 for the word *cuna* 'cradle', Figure 3 for the word *pulla* 'gibe,' and Figure 4 for the word *cuya* 'which' [fem.]. The plosive bursts were identified on the waveform as a clear rapid transient, indicative of the release of the consonant. On the spectrogram, the burst was indicated by a clear vertical bar (the plosion bar).

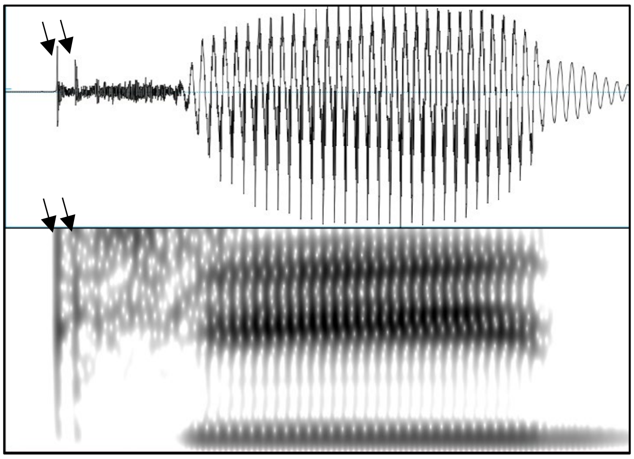

Figure 2. WAS speaker 3 production of *cuna* [ˈkuna] ‘cradle’ with two bursts.

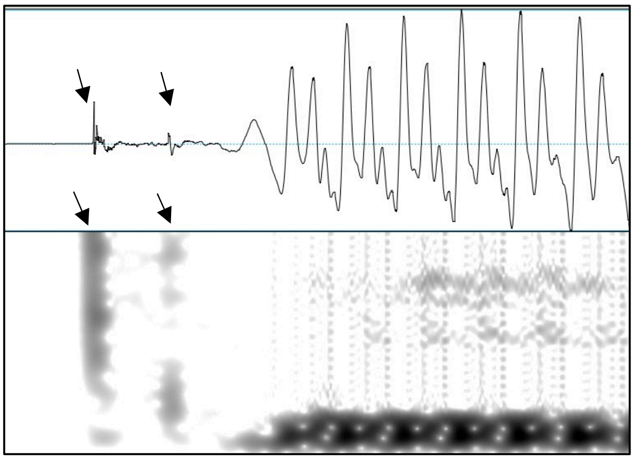

Figure 3. WAS speaker 22 production of *pulla* [ˈpuɟ͡ʝa] ‘gibe’ with two bursts.

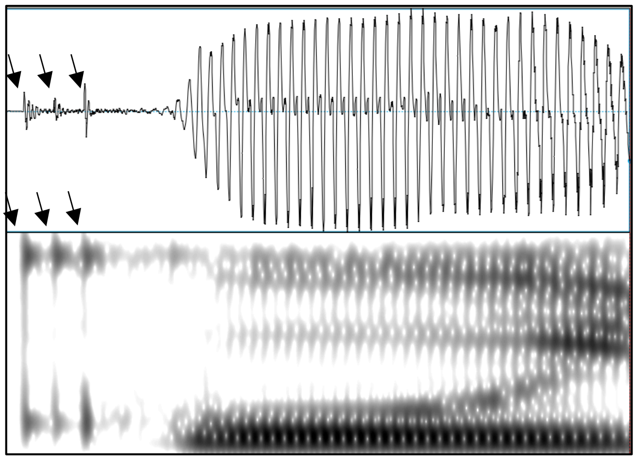

Figure 4. WAS speaker 6 production of *cuya* [ˈkuɟ͡ʝa] ‘which’ [fem.] with three bursts.

The number of bursts for each consonant in the two vowel contexts was tallied. Next, VOT was measured from the first and last burst for each MB. The method of measuring VOT from the most intense burst was not registered, for two reasons. First, in a number of occasions it was not feasible to determine burst intensity, and second, as Keating et al. (1980) noted, in MBs production the latter release may be the intended one, given that high intraoral pressure, as explained in section 2.1.2, causes the appearance of the first one. Thus, only the first and last bursts were marked for VOT measurement in the analysis. Figures 5 and 6 illustrate this procedure for the word *pura* ‘pure’ [fem.].

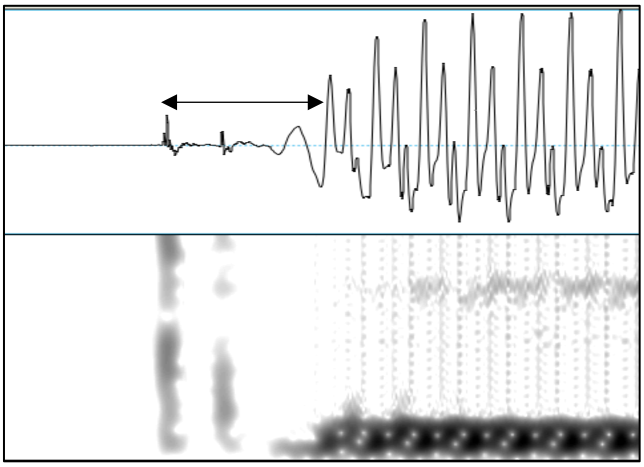

Figure 5. WAS speaker 22 production of *pura* [ˈpuɾa] ‘pure’ [fem.], measurement of VOT from the first burst (21 ms).

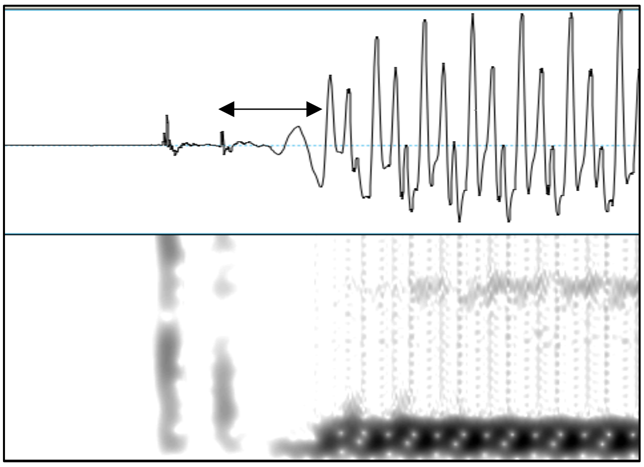

Figure 6. WAS speaker 22 production of *pura* [ˈpuɾa] ‘pure’ [fem.], measurement of VOT from the last burst (12 ms).

Each token was analyzed both from the first burst or the last burst to the onset of periodicity, marked by a strong F2 (e.g., Millasseau et al., 2019). Combining reference to the waveform and spectrographic information when measuring both the number of bursts and VOT therefore provided a sufficiently objective analysis of these two acoustic events. To assess the reliability of the data measurements, the researcher reanalyzed 20% of the data, a month after the first round of measurements, obtaining a very high correlation ($r = 0.95$, $p<0.001$) between both series of measurements.

5. Results

5.1. MBs and VOT measurement

The two methods employed to measure VOT in the presence of MBs yielded appreciably different results. Table 3 presents the descriptive statistics of this outcome. Clearly, there is some difference for the bilabials, when VOT is measured from the first burst (VOT = 18.1 ms) or the last burst (VOT = 12.1 ms). The contrast between both methods is very similar for the denti-alveolars (15.1 ms versus approximately 10 ms), whereas for the velars the variation is much more pronounced (29 ms versus 15 ms). Note also that the standard deviations (i.e., the variability in the data) are very similar if not identical (respective to their means) across the three plosives in both measurement methods.

	VOT First burst		**VOT Last burst**	
Plosive	**Mean**	**SD**	**Mean**	**SD**
Bilabial	18.1	6.29	12.1	5.33
Denti-alveolar	15.1	5.52	9.97	4.04
Velar	28.9	10.2	15.4	4.04

Table 3. MBs and VOT measurement by PoA.

These data were subjected to a two-way ANOVA test, with VOT as the dependent variable, and measurement method (first burst, last burst) and PoA (bilabial, denti-alveolar, velar) as factors. Results from this analysis showed that VOT varied significantly by burst measurement (first, last) $F(1, 276) = 61.71$, $p < 0.001$, $\eta^2p = 0.18$, mean difference = 8.21, and by PoA $F(2, 276) = 44.62$, $p < 0.001$, $\eta^2p = 0.24$. There was a significant interaction between burst measurement and PoA, $F(2, 276) = 9.50$, $p < 0.001$, $\eta^2p = 0.06$. Post-hoc Tukey tests on this interaction revealed that measuring the bilabials from the first or last burst resulted in a marginally significant mean difference of 6 ms, $t = 2.65$, $p_{\text{tukey}} = 0.05$, $d = 0.78$. For the denti-alveolars, there was a statistically significant mean difference of 5 ms, $t = 2.83$, $p_{\text{tukey}} = 0.04$, $d = 0.65$. Finally, for the velars, measuring these consonants from the first or last burst resulted in a significant mean difference of 13.51 ms, $t = 11.16$, $p_{\text{tukey}} < 0.001$, $d = 1.75$.

5.2. MBs and PoA

25% of 567 VOT measurements had more than one burst, that is, they had MBs. A chi-square test on this outcome resulted in a statistically significant difference, $\chi^2(1) = 44.2$, $p < 0.001$, Phi = 0.25. It was found that 9.5% of bilabials had MBs, and the percentages for the denti-alveolars and velars were 15.22% and 33.33% respectively. These differences are significant, with a very large effect size, $\chi^2(4) = 77.52$, $p < 0.001$, Cramer's V = 0.82. Table 4 displays the frequency of occurrence of MBs (in percentages) by PoA. Both the bilabial and the denti-alveolar were more frequently realized with two bursts. The velar realizations are split between two bursts and three and four bursts, with only five per cent five bursts. A chi-square test on these data was statistically significant, with a medium effect size, $\chi^2(6) = 60.91$, $p < 0.0001$, Phi = 0.45.

Plosive	**2 bursts**	**3 bursts**	**4 bursts**	**5 bursts**	**Total**
Bilabial	95.91	4.08	0	0	100
Denti-alveolar	73.91	21.74	4.35	0	100
Velar	50	31.67	13.33	5	100

Table 4. Occurrences of MBs across PoA, in percentages.

Table 5 shows the mean number of bursts across PoA. As the PoA is articulated further back, the mean number of bursts increases, and especially so for the velars. Additionally, it can be observed that the variability in the data, as indicated by the standard deviations, also rises from the bilabials to the velars; the latter have a much higher standard deviation.

Plosive	Mean bursts	SD	Min	Max	N
Bilabial	2.04	0.20	2	3	23
Denti-alveolar	2.21	0.47	2	4	37
Velar	2.69	0.80	2	5	81

Table 5. Mean bursts by PoA.

These data were not normally distributed, and therefore were run on the non-parametric equivalent of a one-way ANOVA, the Kruskal-Wallis test. This test showed that PoA of the plosive had a statistically significant effect on the number of bursts, $\chi^2(2) = 24.22, p < .001$, $\eta p^2 = 0.17$. This means that 17% of the variance in the number of bursts is explained by PoA of the plosive. Post-hoc tests with Bonferroni correction showed there were significant differences between /p/ and /k/, $p < 0.001$, with a medium effect size $r = 0.39$, between /t/ and /k/, $p = 0.001$, with a medium effect size $r = 0.32$, but no significant difference between /p/ and /t/, $p = 0.11$, with a medium effect size $r = 0.20$.

5.3. MBs and vowel height

Table 6 displays the mean number of bursts by vowel height. The plosives had more MBs in the context of a high vowel than in the context of a low vowel, although the difference does not seem to be large. The consistency of these data is acceptable, with the high vowel context presenting slightly more variation than the low vowel context, as evidenced by their standard deviations.

Vowel	Mean bursts	SD	Min	Max
High	2.58	0.79	2	5
Low	2.28	0.52	2	4

Table 6. Mean bursts by vowel context.

As the data were not normally distributed, a Kruskal-Wallis test was run. This showed that vowel height had a statistically significant effect on the number of bursts, $\chi^2(1) = 24.22, p = .015$, $\eta p^2 = 0.04$. This means that 4% of the variance in the number of bursts is explained by the height of the following vowel.

For the bilabial, in the context of high vowels, 10% of the realizations had MBs (i.e., at least two bursts); in the context of the low vowel, 4.3% of the bilabial plosives had MBs. A chi-square test yielded a significant difference between both contexts, with a medium effect size, $\chi^2(1) = 16.63, p < 0.0001$, Phi = 0.40. For the denti-alveolars, in the context of high vowels, 10% had MBs, and 12.3% in the context of the low vowel. A chi-square test indicated that this difference was significant, with a small effect size, $\chi^2(1) = 3.88$, $p = 0.04$, Phi = 0.16. 40.3% of the velars had MBs when followed by a high vowel, and 22.5% had MBs in the low vowel context. This difference was statistically significant, with a small effect size, $\chi^2(1) = 28.41, p < 0.0001$, Phi = 0.29.

The mean number of MBs when the consonant was followed by a high or low vowel was not significantly different for the bilabials nor for the denti-alveolars (both $p = 1.00$), but it reached significance for the velars, $p = 0.017$, which had 2.87 MBs in the context of a high vowel and 2.38 MBs in the context of the low vowel.

5.4. MBs and gender

The mean number of bursts by gender is displayed in Table 7. The female and male speakers showed a very similar number of bursts, and their variability, as indexed by the standard deviations, was also comparable.

Gender	Mean bursts	SD	Min	Max
Female	2.47	0.73	2	5
Male	2.44	0.67	2	5

Table 7. Mean bursts by gender.

A Kruskal-Wallis test showed that gender did not have a statistically significant effect on the number of bursts, $\chi^2(1) = 0.002, p = 0.96$, $\eta p^2 = 0$. No significant differences were found between female and male speakers in the production of MBs for any of the consonants (all $p > 0.5$).

5.5. MBs and speech rate and speaker identity

A non-parametric Spearman's rho correlation found a marginally significant relationship between speech rate (defined as the number of syllables per second) and the number of bursts, $\rho = 0.15$, $p = 0.08$. This means that a faster speech rate is associated with a larger number of bursts, but only to a limited extent, since the correlation represents a weak effect size.

A Kruskal-Wallis test showed that speaker identity did not have a statistically significant effect on the number of bursts, $\chi^2(20) = 20.3, p = 0.44$, $\eta p^2 = 0.007$. None of the pairwise comparisons among the speakers reached statistical significance and their associated effect sizes were negligible.

6. Discussion

The results of the current study will be discussed in terms of statistical significance, but also by making appropriate reference to the effect sizes detected in the corresponding statistical analyses (e.g., Cummings, 2012; Ellis, 2010). Succinctly, the *p*-value of a statistical test indexes whether there is an effect of one variable on another variable, or whether there is a relationship between variables, with a certain amount of predetermined certainty (the so-called alpha level). The effect size, on the other hand, provides richer information, quantifying the magnitude of the effect. It goes without saying that quantitative researchers may logically be more interested in 'how much of an effect has been found' (i.e., the effect size) than simply whether 'there was an effect or not' (the *p*-value).

The first research question asked about the differential effects of two VOT measurement methods (first burst, last burst) when MBs are detected. Most researchers seem to select the first burst, and fewer researchers choose the last burst. It was hypothesized in the current study that this methodological decision would probably produce substantially different VOT values for the voiceless plosives. Overall, it was found that these two methods varied statistically significantly by at least 8.21 ms, which is a crucial difference when quantifying the minute value variations typical of VOT measurement. A difference of 8 ms, for instance, may result in a consonant as being characterized as having long-lag instead of short-lag in some languages. The effect size for this finding was large, $\eta p^2 = 0.18$. This means that 18% of the variance in VOT values can be attributed to the MB measurement method, and therefore it may be concluded that choosing the first or the last burst when measuring VOT has potentially sizable consequences in the analysis of this acoustic event. This finding is in accordance with the statistical variation reported by Gráczi and Kohári (2014) for the three VOT measurement methods they tested.

As mentioned in section 2.1.3., researchers who set out to analyze VOT may not seem conversant with this methodological issue, and this could perhaps result in divergent VOT values for the same or close varieties of a phonological system (this might be the case with Spanish, a point which is entertained below).

In addition, the first research question sought to discern the role that PoA and measurement method may play in the values observed for VOT in the presence of MBs. A statistically significant effect of PoA on VOT was found, with a large effect size, $\eta p^2 = 0.24$. Thus, almost a quarter of the variance in VOT values can be explained by membership to the three PoAs. This is a likely outcome, based on the literature findings previously presented. A significant interaction between the two factors (measurement method and PoA) was observed, with a small effect size (only 6% of the variance in VOT can be ascribed to this interaction). To further elucidate this relationship, post-hoc tests revealed the following. There was a somewhat significant different of 6 ms in the measurement method for the bilabial; irrespective of the *p*-value, the effect size (Cohen's *d*) is nonetheless large, and therefore this result needs to be acknowledged as important. For the denti-alveolar, the difference in VOT measurement method was also significant, with a medium effect size, and lastly for the velar the effect of measurement method was significant, yielding a noteworthy mean difference of 13.51ms, with a very large effect size (Cohen's $d = 1.75$, that is, almost a two standard deviation difference between the two measurement methods).

These globally large differences between the two VOT measurement methods in the presence of MBs may raise concern about the values obtained in previous studies of other accents of Spanish. Barrera-Pardo (in press) compared VOT values reported in studies for Castilian and Latin American Spanish with the values he obtained for WAS. He found statistically significant and large to very large differences (as per the effect sizes obtained) among the three PoA of the voiceless plosives. Specifically, the bilabial differed between Castilian and WAS, a finding that can be extended to the comparison between Latin American and WAS for this consonant. The denti-alveolar followed the same pattern of comparison, as did the velar, whose differences between WAS on the one hand, and Castilian and Latin American on the other were extremely large (slightly more than 13 ms, with effect sizes of almost four standard deviations). These discrepancies can be certainly explained in a number of ways. For example, the WAS study recruited young speakers, and the age ranges for the Castilian and Latin American experiments were much wider; VOT has been reported to vary significantly with age (e.g., Torre & Barlow, 2009; Yao, 2007). However, it must be remarked that in studies on Castilian VOT such as Asensi et al. (1997) and Torres and Iparraguirre (1996), the occurrence of MBs is noted in passing (although, as previously remarked, not quantified). This leads to the question of whether these researchers (and many others), upon encountering MBs in their VOT analyses, marked the start of VOT at the first burst, the last burst or any other point. Depending on the answer, substantially different values may have been obtained, as the results of the present study have clearly revealed. Hence, in the presence of MBs, researchers should probably be urged to state their measurement criteria and proceed accordingly with a consistent methodology.

The second research question aimed at discerning the role of PoA, vowel height, gender, and speech rate in MBs. With respect to PoA, a quarter of the three voiceless plosives evidenced MBs, a finding that connotes the magnitude of this acoustic event. With reference to Hungarian, Gráczi and Kohári (2014) found MBs in almost 48% of the plosive realizations. This difference between the two results may be language-specific, as Gráczi and Kohári investigated young speakers of both genders, the same target population the current study focused on. In (American) English, Lavoie (2001) reported a much lower rate of MBs, approximately 9%, and for (Mexican) Spanish she found 11.5% of MBs in her data. It needs to be observed that Lavoie considered plosives both in stressed and unstressed syllables in her analysis of English and Spanish; the current study elicited plosives only in stressed position, where VOT is known to be longer and therefore more prone to MBs (this last point is corroborated by the fact that velars, which have a longer VOT, concomitantly have more MBs).

Significant differences and a very large effect size were revealed among the number of MBs for the three plosives. This accords with the Hungarian data obtained by Gráczi and Kohári (2014). They found however many more MBs by PoA: 27.5% for the bilabial, 45% for the alveolar one, and 66.4% for the velar plosive. Lavoie' (2001) figures for English are 5% for /p/, 0.8% for /t/, and 21% for /k/. Her Spanish data showed fewer MBs per PoA: 0% for the bilabial, 2% for the alveolar, and 32.3% for the velar. The latter is consonant with the results of the current study, which revealed that the velar had 33.3% of MBs. Again, Lavoie analyzed the consonants in both stressed and unstressed positions, whereas the consonants in the present study appeared in stressed syllables exclusively. In sum, although the specific percentages vary, the tendencies are generally for bilabials to show fewer MBs than the alveolars or denti-alveolars, and these in turn have fewer MBs than the velars.

Turning to the number of bursts per PoA, it is evident that as the articulation recedes from the bilabial area to the velar area the amount of MBs increases exponentially. The bilabial consonant showed almost all MBs in the 2-burst category; the denti-alveolar had a majority of MBs in the same rank, with a sizeable amount of MBs in the 3-burst tier. The velar had a more widespread distribution, with 50% MBs in the 2-burst category and 45% MBs distributed between the 3- and 4-burst ranks. These differences were significant and associated with a medium effect size. For Hungarian, Gráczi and Kohári (2014) found a somewhat similar dispersion for the three consonants, especially in the case of the bilabial.

All differences among the PoA of the voiceless plosives had a significant effect on the number of MBs, with medium effect sizes. 17% of the variance in the amount of MBs can be ascribed to PoA, a result that leaves 73% of the variability in the number of bursts unexplained.

Another factor that may play a role in the variability of MBs is the height of the following vowel. For VOT, this factor has been found to play a significant role, such that VOT increases when the plosive is followed by a high vowel. The evidence to this effect in MB research is yet inconclusive (see section 2.1.5). The findings of the current study support to a certain extent (the effect sizes found are medium to small) the hypothesis that vowel height has an effect on the number of MBs. While statistically significant, such effect was found to be small (4% of the variance explained). For both the bilabial and velar plosives, the high vowel context produced more realizations with MBs, with medium and small effect sizes respectively. However, the denti-alveolar showed the reverse pattern: more MBs when the consonant was followed by the low vowel /a/ than when a high vowel (/i/ or /u/) occurred after the consonant. The effect size associated with this result is very small (Phi = 0.16), and therefore it should be taken with caution. In addition, it was found that, similarly to other studies (e.g., Plauché, 2001), the velar had significantly more MBs in the high vowel context than both the bilabial and the denti-alveolar; in fact, for these two consonants the mean number of MBs did not differ in the two vowel contexts. In sum, vowel height seemed to pay some role on MBs, such that high vowels triggered more MBs realizations, particularly in the case of the velar plosive.

In line with previous studies, speaker gender did not seem to be associated with MBs realizations, both at a global level and individually for each of the plosives. This may be related to the differing findings with respect to a possible link between VOT and gender reported in the literature (see section 2.1.6).

Finally, speech rate played a minor role in the number of MBs, as per the correlation observed between both variables. This result is expected given the results reported in previous studies. It needs to be acknowledged that the data for the current study were elicited in a formal, controlled task: reading out sentences of exactly the same length, and evidently this resulted in similar speech rates across all speakers. It was also found that MBs did not differ significantly across speakers, and that less than 1% of the variance was explained by this factor. This contrasts with the speaker variability indexed in other studies, whereby VOT differed significantly by speaker identity (see Yao, 2007, for a review).

7. Conclusion

While MBs have been noted in the literature for a number of languages and speaker populations, this acoustic feature has been rarely quantified in a systematic fashion. This study aimed at exploring quantitatively MBs in WAS, as well as to reveal which factors played a role in the production of MBs. A total of 567 tokens of /p t k/ were acoustically analyzed, MBs identified, and VOT measured according to two methods (from the first or last burst). Findings indicated that the differential effects of the two measurement methods in the presence of MBs were substantial, and therefore researchers who set out to gauge the VOT of voiceless plosives are commended to proceed accordingly. The three plosives showed significantly different VOTs depending on the method employed when finding MBs, and this to a large extent according to the effect sizes observed. PoA also proved significant with respect to MBs; as in other studies, /p/ had fewer MBs than both /t/ and /k/, which also differed from /p/ and /t/ to a moderate extent, as indexed by the effect sizes obtained. The percentage of MBs also increased as the PoA spanned from /p/ to /t/ and then /k/. Other studies reported similar results. Perhaps more importantly for future studies of VOT in Spanish, these findings might be related to the fairly large dissimilar VOT values reported by previous experimental work. Despite the dearth of quantitative data on MBs in Spanish, some researchers have noted (albeit impressionistically) MBs when measuring the VOT of voiceless plosives. However, they did not report the method used to measure VOT in the presence of these MBs; since it seems that most researchers have routinely marked the first burst as the onset of VOT, perhaps the VOT values obtained in previous studies of Spanish are crucially shaped by this methodological decision. It is hoped that the results presented in the current investigation will provoke further consideration of this matter. Other factors that may impact on MBs are vowel height and gender. The former did seem to play some role in the distribution of MBs, such that high vowels gave rise to more MBs, but only for /p/ and /k/, and to a certain extent, given their medium to small effect sizes. Gender had no appreciable influence on MBs, and speech rate did but to a very limited degree. No noticeable difference in MBs across speakers was observed.

The current study is not without limitations. The speakers had a very restricted age range (19 to 23), and were all university students. Future studies could advance our knowledge of MBs if they include older cohorts of speakers and more sociolinguistically diverse talkers. Further research could also include more speakers from other WAS areas, such as the Huelva region. It would also be worth investigating MBs in other Andalusian dialect areas, such as Eastern Andalusian.

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