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An UTI study of alveolar stops in Italian

We investigate lingual articulation in alveolar stops produced by 5 native Tuscan Italian speakers and varying for voicing and phonological length. Both constriction location and overall tongue configuration are evaluated. The results suggest uniformity in constriction location of singleton and geminate stops as well as in voiced and voiceless stops. On the contrary, overall tongue configuration shows different patterns for length and voicing. Moreover, the subjects show individual preferences as far as constriction location is concerned. The findings are discussed with reference to cross-linguistic patterns of articulatory variation as a function of changes in duration and glottal activity associated to the production of alveolar stops.

Keywords: alveolar stops, voicing, gemination, Italian, Ultrasound Tongue Imaging.

1. *Introduction*

Voicing distinctions in obstruents are mostly realized through different laryngeal configurations during the closure phase (as in so-called 'true voicing' languages) or different timing patterns between closure at the oral level and vibratory activity at the glottal level (as in languages where the voice onset time is the major correlate of stop distinctions); languages differ for the relative weight they assign to either laryngeal strategy. Recent studies suggest that differences at the glottal level for obstruent voicing distinction may also have an impact at the level of oral articulators. On a different domain, length distinctions in obstruents (as well as in sonorants and vowels) are mostly realized at the durational level, but may additionally involve duration-related changes at the supraglottal levels. This paper is the first investigation of the lingual characteristics of Italian alveolar stops varying in voicing and length. Its aims are those of documenting patterns of potential variation in target articulations due to either or both phonological distinctions and to relate them to findings available for other languages.

Supraglottal articulatory correlates of the voicing contrast in obstruents have long since been observed in various languages. For instance, /d/ is realized with more extended central contact than /t/ in English (e.g. Dagenais, Lorendo & McCutcheon, 1994) and Japanese (Matsumura, Kimura, Toshino, Tachimura & Wada, 1994); it is produced with lower and more retracted tongue tip, less extensive contact, occasionally incomplete closure and a lower target position for the jaw in German (Fuchs, Perrier, 2003), British English and Norwegian (Moen, Simonsen, 1997), Czech (Skarnitzl, 2013), Japanese (Kochetov, 2014; Kochetov, Kang, 2017) and Moroccan Arabic (Zeroual, Esling & Crever-Buchman, 2008). The tongue body starts lower and ends lower in /g/compared to /k/ in English and Swedish, and this gesture has greater amplitude and higher velocity (Löfqvist, Gracco, 1994). Active oral cavity enlargement has also been detected (Westbury, 1983; Kent, Moll, 1969). These articulatory characteristics are associated to shorter duration of the voiced compared to the voiceless consonant in all the investigated languages, consistently with the observation that stop voicing and stop closure have conflicting aerodynamic requirements (Ohala, 1983; 2011). The articulatory maneuvers mentioned above would then prevent quickly rising intraoral pressure from challenging the maintenance of vocal fold vibration during the closure period.

Articulatory changes in the geminates compared to corresponding singletons have also been investigated. For Italian, average electropalatographic data in Payne (2006: 90) show that seal contact, when present, is limited to the first front row in /t/ and /d/, whereas it is always present and may extend to the second front row in their geminate counterparts. The data also suggest that /t/ and /t:/ have more extended front contact than /d/ and /d:/, but since the focus of the paper is gemination, potential voicing distinctions are not thoroughly discussed. Zmarich, Gili Fivela, Perrier, Savariaux & Tisato (2006; 2009) and Gili Fivela, Zmarich, Perrier, Savariaux & Tisato (2007) additionally show that geminate stops are not only realized with longer consonantal gestures than singletons, but also differ for being articulated with longer and wider constriction and release gestures; additionally, release gestures are faster, thus suggesting that the kinematic differences between singletons and geminates are stronger at consonantal offset than at consonantal onset. Similar findings are discussed by Fujimoto, Funatsu & Hoole (2015) with respect to Japanese, where /t/ is shown to reach its kinematic peak at about half of the closure whereas for /t:/ the peak is reached far later and closer to the consonantal offset than to the consonantal onset. Longer and more extended contact in word- and utterance-initial geminate coronal stops has also been reported for Swiss German (Kraehenmann, Lahiri, 2008), Tashlhyit Berber (Ridouane, 2007; Ridouane, Hallé, 2017, which also includes utterance-medial word-initial contexts) and Cypriot Greek (Armosti, 2009). Intervocalic alveolar and velar Japanese geminates are also articulated with longer and more extended linguo-palatal contact (Kochetov, 2012; Kochetov, Kang, 2017), coupled with slower tongue movements (Löfqvist, 2007). On the other hand, longer tongue tip contact with no differences in tongue tip target position is reported for Moroccan Arabic alveolar geminates (Zeroual et al., 2008). Bilabial stops have been investigated to uncover potential differences in the coordination between the lip gesture for the consonant and the tongue gesture for the flanking vowels. These studies suggest differences in the lip closing gesture more consistently than in the opening gesture. For instance, Šimko, O'Dell & Vainio (2014) show that the lip closing gesture starts earlier with respect to the lingual movement in geminates than in singletons in Finnish; Türk, Lippus & Šimko (2017) show that the lip closure gesture in Estonian geminates is longer and larger, while maintaining the same average velocity of singletons.

In sum, both voicing and length significantly impact the way in which oral articulators move to realize the consonantal gesture and coordinate with other gestures. The available evidence suggests that some changes are robust cross-linguistically while other are more likely to be differently implemented across languages and phonetic contexts. Voicing and length may also interact, as shown by e.g. Tashlhiyt Berber /t/-/tː/ and /d/-/dː/ contrasts, where the increased linguo-palatal contact of geminates compared to singletons is more evident in the voiceless than in the voiced pair (Ridouane, Hallé, 2017). Most of the reviewed studies are based on tongue or lip movement tracking through electromagnetic articulography (EMA) or measurements of linguo-palatal contact through electropalatography (EPG).

In this paper we investigate the lingual correlates of voicing and length in alveolar stops in Italian by tracking the midsagittal tongue contour through ultrasound tongue imaging (UTI) (Stone, 2005). The study aims to uncover potential differences in tongue tip gesture as well as tongue body configuration during the realization of /t tː d dː/. Based on the findings on other languages reviewed above, we predict that voicing entails a lower and/or more retracted tongue tip if voicing affects the target constriction location, a lower tongue body if voicing affects the overall tongue configuration. On the other hand, length is expected to entail higher tongue tip and/or higher tongue body depending on whether increased closure duration influences more the constriction location or the overall tongue configuration. Our analysis will be limited to average lingual configuration; we reserve the investigation of the dynamic properties of the consonantal gesture (e.g., closing and opening gestures) to a future study.

2. *Methodology*

2.1 Stimuli, participants and procedure

The stimuli analysed here are a subset of a longer list that was recorded in the context of a research project on the production of various consonantal contrasts of Italian and Austrian German (Celata, Meluzzi, Moosmüller, Hobel & Bertini, 2017).

The stimuli were 12 paroxytone dysillabic real words. The target consonants were /t d tː dː/ preceded by stressed /a/ or /ɔ/ and followed by unstressed /a/ or /o/. Word-initial consonants, when present, were bilabials in order to avoid lingual coarticulation effects. The list of stimuli is given in Table 1. The contexts with preceding /a/ and those with preceding /ɔ/ were distinguished in the analysis.

Table 1 - *Experimental stimuli*

C	V1	Singleton	Geminate
Voiceless	/a/	Bata /ˈbata/	batta /ˈbatːa/
	/ɔ/	mota /ˈmɔta/	motto /ˈmɔtːo/
Voiced	/a/	Ada /ˈada/	Adda /ˈadːa/
	/ɔ/		bodda /ˈbɔdːa/

The stimuli were elicited according to a multi-repetition reading task. Three male and two female native Tuscan Italian speakers aged between 19 and 32 years were recorded in the anechoic chamber of the linguistics laboratory of the Scuola Normale Superiore di Pisa. None of them reported current or past speech or hearing disorder. The participants were asked to read aloud each word upon appearance on the screen of a computer, after a hardware pulse, while keeping their speech rate as uniform as possible. Each participant performed the reading task alone on a dedicated session.

A microconvex ultrasound transducer (Mindray 65EC10EA 6.5 MHz) was placed under the chin of the participants and blocked by a stabilizing headset (Scobbie, Wrench & Van der Linden, 2008). The ultrasound signal was collected at 30 Hz (corresponding to 60 Hz after de-interlacing) by the Standard Mindray DP6600 system. The acoustic signal was captured through a unidirectional dynamic Shure microphone. The ecographic signal and the acoustic signal were synchronously acquired by the Articulate Assistant Advanced (AAA) software, version 2.16.16 (Articulate Instruments Ltd).

Each word was repeated three times by four speakers and four times by a fifth speaker. The experimental corpus thus includes a total of (7 words × 4 speakers × 3 repetitions) + (7 words × 1 speaker × 4 repetitions) = 112 tokens.

2.2 UTI data preprocessing

Once completed, the recordings were exported from AAA in *.wav format and imported into Praat (Boersma, Weenink, 2016) for the manual segmentation and annotation process. For each stimulus, the target consonant and the preceding vowel were annotated. Phoneme boundaries were established on the basis of the oscillogram and the broadband spectrogram of the acoustic signal. The VOT was included in the consonantal interval.

The annotated acoustic signal was then reimported into AAA for the semi-automatic tracing of the mid-sagittal tongue profiles. A gross recognition of the brightest point of the ultrasound image potentially corresponding to the tongue profile was automatically run in the AAA environment. Then, careful manual correction was carried out frame by frame. The fan set up (i.e., the search area within which the software operates the first gross tongue profile tracking) was customized for each speaker.

The hard palate of each speaker was also tracked according to the same semi-automatic procedure and then superimposed to the lingual profiles for reference. The palate images were obtained from the ultrasound frames relative to the moment of swallowing some water. For each speaker, the palate was traced from its most visible image chosen from different swallowing moments. For Speaker 5, palate location and tracing was problematic, especially in its most anterior region; therefore Speaker 5's productions were evaluated with reference to the rear of the palate only (see below, §3).

The analysis of tongue configuration was done based on average tongue profiles and the area of standard deviation for each relevant context. For instance, the average tongue profile of /t/ as produced by a given speaker was calculated by averaging the position of all tongue profiles included in each annotated interval of each relevant /t/ produced by that speaker.

2.3 Analysis

The acoustic duration of segments was analysed to verify if the target consonant and the preceding vowel varied in duration as a function of stop's voicing and phonological length (two-sample t-tests for the comparison of the means; SPSS 22.0.0).

The differences in tongue configuration across groups of items were evaluated via inspection of tongue mean and standard deviation profiles for each speaker separately. The analysis of profiles was done in the AAA environment.

3. *Results*

3.1 Acoustic duration

Table 2 reports mean and standard deviation values for the duration of each consonant and the preceding vowel. The effect of voicing was found to be significant for the target consonant, voiceless stops being significantly longer than voiced stops ($t = 2.129$, $p < .05$) consistently with what is generally reported in the literature (see above, §1). The effect of voicing was significant also for the preceding vowel, with longer vowels before voiced stops and shorter vowels before voiceless stops ($t = -2.307$, $p < .05$), consistently with the lengthening-before-voicing effect reported for different languages including Italian (Celata, Calamai, 2011).

Phonological length had the expected effect on the duration of the target consonants ($t = -16.871$, $p < .001$) as well as of the preceding vowel ($t = 5.930$, $p < .001$), vowels before geminates being significantly shorter than vowels before singletons (Bertinetto, 1981).

Table 2 - *Means and standard deviations of the duration of consonants and preceding vowels (in ms) averaged across speakers*

Target Consonant	V		C	
	Mean	St. Dev.	Mean	St. Dev.
/t/	165,9	20,9	110,2	27,0
/d/	186,0	18,8	84,9	13,0
/tː/	133,1	31,6	224,0	28,5
/dː/	151,2	25,6	177,1	19,0

3.2. Tongue profiles

Figure 1 shows the mean tongue profiles and the standard deviation of the tongue for the voiceless-voiced comparison, separately for each speaker and for the two phonetic contexts (after /a/ and /ɔ/). The blue lines represent the tongue profile in voiceless consonants, whereas the red lines represent the voiced consonants. Whenever the two profiles are distant enough to show no overlap of the area defined by upper and lower limits of the standard deviation, the tongue configuration in that region can be considered to be significantly different.

Figure 1 shows that there are significant differences in both phonetic contexts for speakers 1, 2 and 5, whereas the differences are significant in the /a/ context only for speaker 3; speaker 4 does not show any significant difference between voiceless and voiced stops in any of the two contexts. In all of the cases, the tongue profile for producing the voiced consonant is lower than for producing the voiceless consonant; this difference is mostly visible in the regions of tongue dorsum and post-dorsum, and in the predorsum in one case only (speaker 1, /ɔ/ context).

There are no significant differences between voiced and voiceless stops as far as the position of the tongue tip is concerned.

Figure 1 also shows that the constriction location can be different across speakers. Speakers 1 and 2 make a constriction with the the tongue tip approaching the upper part of the alveolar ridge, whereas speakers 3 and 4 show a comparatively more fronted constriction location, with the tongue tip approaching the lowest part of the alveolar ridge, closer to the teeth. The constriction location of Speaker 5 is difficult to ascertain because of the reported problems in tracing the speaker's palate.

Figure 2 shows the tongue mean profiles and the standard deviation of the tongue for the singleton-geminate comparison, again separately for each speaker and for the two phonetic contexts (after /a/ and /ɔ/).

In this graph, the blue lines represent the tongue profile in singleton consonants, whereas the red lines represent the geminate consonants.

According to Figure 2, geminate consonants tend to show a higher overall tongue position compared to singletons, although the difference is significant only in the /ɔ/ context for speakers 1 (tongue dorsum), 2 (dorsum-predorsum) and 3 (dorsum) and in the /a/ context for speaker 4 (mostly in the dorsum and predorsum) and possibly of speaker 5 (the tongue root is more posterior in the geminate than in the singleton).

The position of the tongue tip is unaffected by the phonological length of the consonant, with the potential exception of speaker 2 in the /ɔ/ context, where the geminate appears to have a higher tongue tip compared to the singleton.

The cross-subject differences in constriction location observed in Figure 1 for the voiceless-voiced contrast were consistently observed also in Figure 2 for the singleton-geminate contrast, with Speakers 1 and 2 showing a more retracted constriction location than Speakers 3 and 4.

Figure 1 - *Mean (thick line) and standard deviation (thin line) of voiceless (blue) and voiced (red) target consonants as a function of preceding vowel (columns) and speaker (rows). Black upper lines represent the speaker's palate*

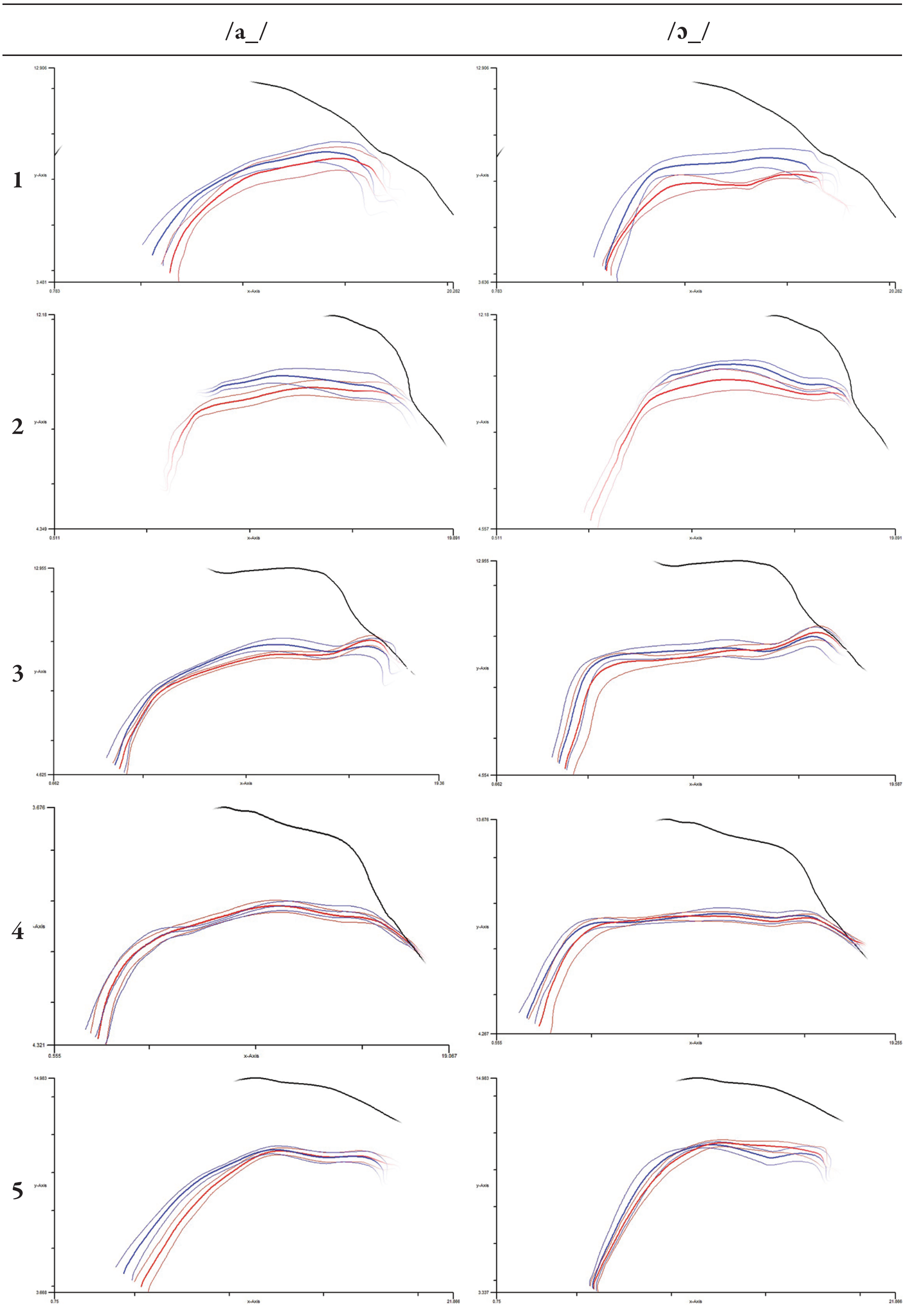
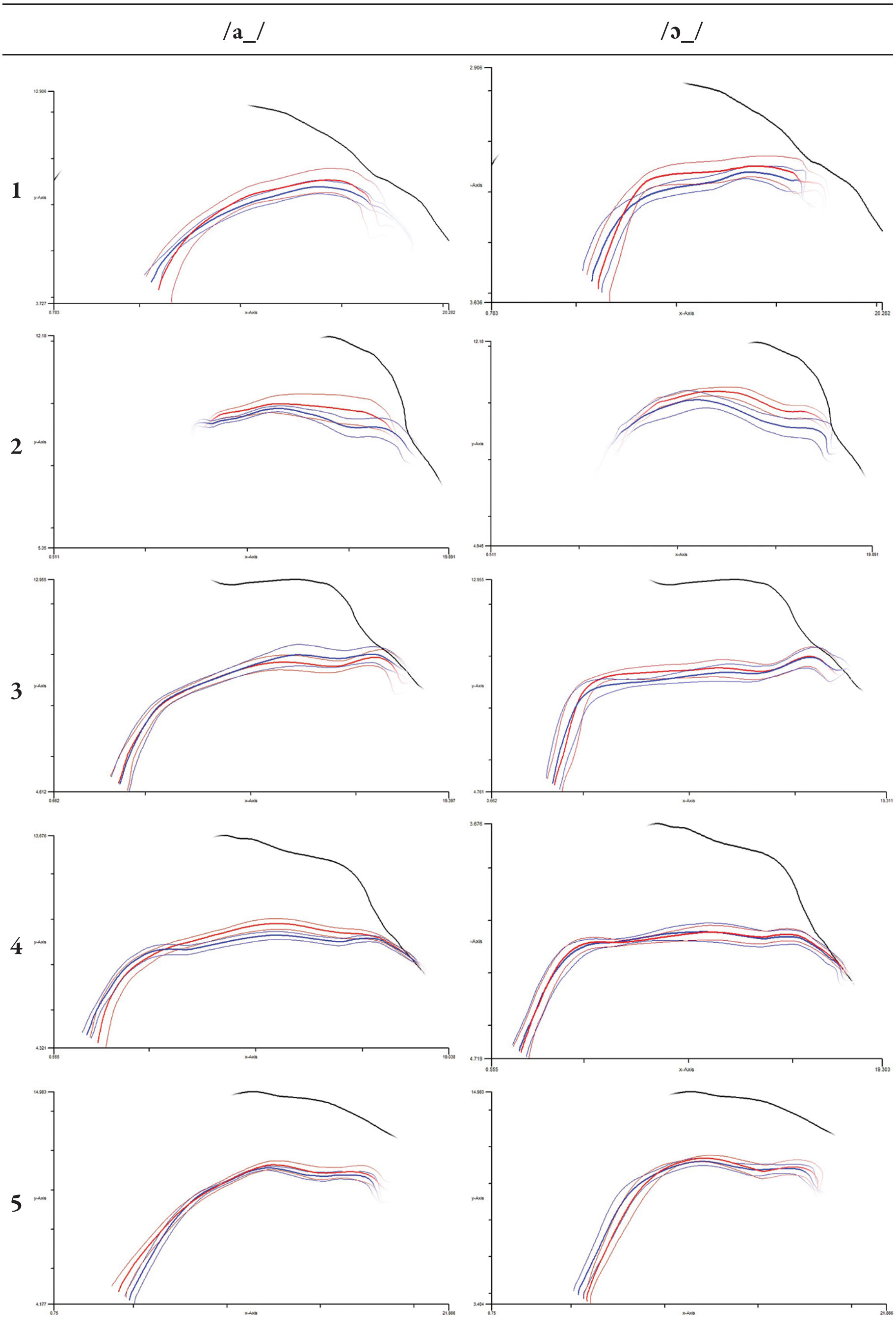


Figure 2 - *Mean (thick line) and standard deviation (thin line) of singleton (blue) and geminate (red) target consonants as a function of preceding vowel (columns) and speaker (rows). Black upper lines represent the speaker's palate*



4. *Discussion*

The findings of the present experiment show that both stop voicing and phonological length may have an impact on the lingual configuration that is used to produce alveolar stops in /a/ and /ɔ/ contexts by Tuscan Italian speakers. These effects are subtle and do not concern the entire profile of the tongue, but only selected portions of it. Nonetheless, they are consistently present in many of the speakers and in both phonetic contexts, thus suggesting that both voicing and length have an impact on tongue configuration in this language. Therefore, this study provide additional evidence in support of the existence of supraglottal consequences of stop voicing as well as of modifications in oral configuration as a function of temporal variations. In the relevant literature, such effects are mostly reported for linguo-palatal contact or articulators' movement (see the relevant literature in §1); by contrast, the present study shows that these effects are also visible through inspection of midsagittal lingual profiles.

With respect to the voicing distinction, the fact that the tongue was found to be lower in voiced stops compared to voiceless stops, particularly as far as tongue dorsum and post-dorsum are concerned, might be consistent with the observation that the jaw is lower and the linguo-palatal contact is less complete in voiced stops compared to voiceless in languages such as English (e.g. Dagenais et al., 1994), German (Fuchs, Perrier, 2003), Swedish (Moen, Simonsen, 1997) or Arabic (Zeroual et al., 2008). In those studies, a lower jaw and tongue tip configuration is interpreted as a strategy to enlarge the oral cavity during the production of a voiced stop, thus preventing intra-oral pressure to rise and vocal fold vibration to extinguish during stop closure. It might be hypothesized that among the consequences of such articulatory manoeuvres to keep voicing during closure is a lowering of the back of the tongue. This lowering might either be passive, i.e. a direct consequence of jaw lowering, or active, i.e. to provide more room for the airflow in the oral cavity and consequently reduce intraoral pressure. However, the current study does not allow answering such a question.

The absence of significant changes in the position of the tongue tip might be interpreted as evidence of the fact that the constriction location of alveolar stops does not change as a function of stop voicing. Under this hypothesis, the Italian data presented here would therefore differ from what is reported for other languages, where voiced and voiceless stops differ in constriction extension and location (e.g. Fuchs, Perrier, 2003 for German; Dagenais et al., 1994 for English). However, it must be recalled that the UTI technique only provides evidence on the midsagittal contour of the tongue and no direct information can be deduced about the contact with the palate or the position of the lateral regions of the tongue. Moreover, the tracing of the tongue tip from ultrasound images is subject to empirical errors because of the potential shadowing of the tongue exerted by the mandibular bone in the most advanced region of the oral cavity (Stone, 2005; Davidson, 2012). Therefore, no conclusive data about the constriction location of alveolar stops can be drawn from UTI analysis. The current data indicate that no visible differences in the tongue tip raising gesture are consistently related to voicing distinctions. More research, possibly including linguo-palatal contact data, is needed in order to definitively rule out the hypothesis that voicing differences induce a variation in the constriction location of alveolar stops.

The results of the singleton vs geminate analysis further suggested that the constriction location of singletons and geminates is not significantly different, but still with the caveats expressed above about the potential incompleteness of UTI data. However, geminates were found to be variably articulated with a higher tongue dorsum than singletons, especially in the context of a preceding /ɔ/; in some cases, increased tongue height for geminates also extends to predorsum. Taken together, these data only indirectly support the view that geminates are produced with more extended constriction than singletons, as proposed in the context of EPG and EMA studies on different languages (e.g. Kraehenmann, Lahiri, 2008 for Swiss German; Ridouane, 2007 for Tashlhyit Berber; Kochetov, 2012 for Japanese) as well as on Italian (Payne, 2006). However, the findings of the current study are consistent with the view that geminates are articulated with a wider tongue gesture, aiming at an overall higher lingual target (e.g. Gili Fivela et al., 2007).

Finally it is worth noticing that, as usual in articulatory studies, the lingual strategies used to achieve a given phonological target may change across individuals. The speakers of the present sample varied in the exact location (alveodental or alveolar) where the tongue approaches the palate surface, although being internally consistent in that choice across stimuli and phonetic contexts. The speakers also differed in the way they realized the phonological contrasts under investigation, with some of them enhancing both contrasts by means of secondary tongue configuration differences, some others showing enhancement in only one of the two contrasts and/or in a subset of the phonetic contexts, and finally others showing no secondary difference in any of the phonological contrasts.

In conclusion, this study has shown that, in the Tuscan Italian variety investigated here, the voicing distinction in alveolar stops is often associated to changes in lingual configuration involving a lower tongue body in voiced as opposed to voiceless stop. Similarly, the distinction between singletons and geminates can be associated to non-durational variations in tongue configuration involving a higher tongue dorsum in geminates as opposed to singletons. Both results are interpretable as articulatory strategies used to facilitate voicing during closure (in the first case) or as articulatory correlates of increased temporal extension (in the second case). Further analysis will have to clarify if voiceless and geminate stops are produced with a different, possibly more extended, linguo-palatal contact than voiced and singleton stops, respectively, and if changes in articulatory configurations also imply changes in the dynamic properties of lingual gestures.

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