An Acoustic and Electroglottographic (EGG) Investigation of Preaspiration and Voice Quality in the Italian Four-Way Stop Contrast across Regional Accents

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Abstract

This preliminary study explores the effects of consonant voicing and gemination on preaspiration and voice quality patterns of stops in Italian, a language that features considerable cross-regional variability in the phonetic realization of its four-way stop contrast. Five speakers, each from a different Italian region, produced /maC(ː)a/ words. Findings of an acoustic and dynamic electroglottographic (EGG) analysis reveal that voiceless stops consistently lead to a breathier voice quality in the final 30% of the preceding vowel, while there is no overall effect of gemination on vowel voice quality. Voiceless preaspiration varies by region: Northern speakers preaspirate both voiceless geminates and singletons frequently, while Centro-Southern speakers preaspirate geminates more often. The study concludes that breathy voice preceding voiceless stops may be characteristic in Italian, while preaspiration patterns are influenced by individual, articulatory, and possibly regional factors.

Index Terms: preaspiration, voice quality, EGG, Italian stop contrast, regional variation.

1. Introduction

1.1. Background

Italian is a well-known example of a language exhibiting a four-way stop consonant contrast along two dimensions, voicing and length, as exemplified by the minimal set /rita rida ritːa ridːa/ 'Rita (given name), laugh (pres. subj. 123s), upright (f), ridda (type of dance)'. Voicing and length distinctions find their phonetic expression primarily through the vibration of the vocal folds and the duration of the consonantal gesture, respectively, suggesting a complex interplay between glottal and supraglottal articulations in the implementation of the four-way contrast. Furthermore, substantial variation exists in the realization of this contrast across regional "accents", as outlined below.

1.1.1. Stop voicing and voice quality

Italian features a series of voiced /b bː d dː g gː/ and voiceless stops /p pː t tː k kː/, contrasting singleton (short) and geminate (long) phonemes. Voiced stops are typically produced with active vocal fold vibration, or 'prevoicing' [1], during closure in all contexts across varieties (although the degree of prevoicing especially in geminates may vary cross-regionally [2]). On the other hand, voiceless stop realizations may differ by variety. While voiceless geminate /pː tː kː/ are normally realized as voiceless [pː tː kː] (that is, with little or no vocal fold vibration during closure) cross-regionally, intervocalic singleton /p t k/ can surface either: (a) as also phonetically voiceless [p t k] in the North; (b) with optional prevoicing, e.g. [p̬ t̬ k̬]/[β ð ɣ], in the Centre-South; or (c) as typically voiceless fricatives [ɸ θ h] (but also /k/ > [ɦ] [3]) in Tuscan varieties, a phenomenon known as *gorgia toscana*, involving intervocalic singleton stop spirantization [3], [4]). To actively implement phonetic voicelessness of consonants in a post-vocalic context, speakers can either spread or constrict the vocal folds [5]. The glottal spreading gesture can result in a breathier voice quality in the preceding vowel, which may be accompanied by preaspiration, i.e., a period of glottal friction preceding the onset of supraglottal constriction [6]. The glottal constriction gesture may instead result in a creakier voice quality and concomitant preglottalization. In fact, some preglottalized voiceless stops, alongside more frequent preaspirated ones, have been observed acoustically as separate allophones in Italian [7].

1.1.2. Gemination and voice quality

Italian geminates, as compared to singletons, are cued durationally by: (i) a longer consonant (C) duration (~2x longer in Central varieties [8]-[10]); (ii) a shorter duration of preceding stressed vowels (V) (between ~20-50% shorter across varieties [2], [11]); and (iii) a higher ratio of consonant to preceding-vowel duration (C/V) [2], [12]. In Northern varieties, however, the difference between geminate and singleton C duration and C/V ratio may be reduced due to a phonetic lengthening of voiceless singletons [2], [13] and potential (although not yet proven) geminate shortening, e.g. [14].

Importantly, it has also been shown that singletons and geminates differ not only in acoustic durational properties, but also spatiotemporally. Specifically, Italian geminates, in comparison to singletons, are more constricted [15], [16], are produced with a higher tongue position when lingual [17], and exhibit an earlier initiation of the consonantal gesture relative to the tongue gesture in preceding V [16]. These varying tongue adjustments may result in laryngeal modifications through indirect movements of the tongue root (which is connected to the larynx via the hyoid bone [18]) ultimately affecting voice quality (cf. [19], [20]). On this point, preaspiration, in turn linked to a breathier voice quality in preceding V, has been found in voiceless geminates across Italian regional varieties [21]. Recently, however, it has been demonstrated that preaspiration of Italian singletons may also occur, although its frequency of occurrence may vary cross-regionally, with Centro-Southern varieties showing it less frequently than Northern varieties ([22]; also cf. [23] for a Tuscan variety).

As yet, no previous work has specifically looked at V voice quality patterns in connection with the Italian C length contrast. Moreover, previous studies on voice quality associated with gemination in other languages have mostly focussed on the following vowel. For example, geminate stops in Japanese [24] and Lebanese Arabic [25] have been associated with a creakier voice quality following the release, while in, e.g., Cypriot Greek they have been linked to breathy voice [26], suggesting that voice quality patterns around geminates may be language specific. Furthermore, these previous studies have tended to look at acoustic measures of voice quality exclusively.

1.2. Aims

This preliminary study is the first to examine voice quality through electroglottography (EGG) in relation to both the C voicing and length contrasts in Italian, with two primary aims. First, it seeks to establish a connection between speaker-specific tendencies of preaspiration and/or preglottalization occurrence and breathiness/creakiness in V preceding voiceless stops across consonant length categories. The second aim has a broader scope, namely, to explore the effects of consonant voicing and gemination on V voice quality in Italian.

2. Methods

2.1. Participants

Five adult speakers took part in the study (see Table 1), each from a different city of Italy across three broader regions, according to [27]'s classification. Two participants came from the North (N): N_Tur_F, N_Vic_M; one from Tuscany (T): T_Emp_M; and two from the Centre-South (CS): CS_Rom_F, CS_Cat_M. All participants were born, raised, and resided most of their lives in their city/region of origin, although they had lived in Melbourne, Australia, for a period not exceeding 2.5 years at the time of the study. They reported daily usage of Italian. Details regarding the age, sex, city of origin, and length of stay in Melbourne for each speaker are provided in Table 1.

Table 1: *Participant details.*

Speaker ID	Age	Sex	City	Length of stay (years)
N_Tur_F	37	F	Turin	0.25
N_Vic_M	37	M	Vicenza	2.5
T_Emp_M	19	M	Empoli	0.16
CS_Rom_F	43	F	Rome	2.5
CS_Cat_M	24	M	Catania	2.5

2.2. Materials and procedure

An acoustic and articulatory experiment using EGG was designed for the study. EGG is a non-invasive technique that measures the contact area between the vocal folds, providing information on vocal fold activity at the source, prior to modification by the supralaryngeal articulators [28].

Participants were instructed to produce a series of (mostly) nonce /ˈmaC(ː)a/ words, where C(ː) represents all Italian oral stop phonemes (cf. §1.1.1) as well as nasal /m mː/, used as the baseline for the EGG data (see §3.2). Note that all resulting words adhere to Italian phonotactic rules and are plausible real words in the language. In fact, at least four of the 14 total words, namely /ˈmapːa ˈmatːa ˈmaga ˈmamːa/, meaning 'map', 'mad (f)', 'magician (f)', and 'mum', are commonly employed in Italian. This particular phonetic structure was selected to avoid the confounding effect of different word-initial C on glottal cycle characteristics in the following V, as noted in initial trials using real words. Instead, employing word-initial /m/ for all tokens triggered the smallest amount of glottal cycle perturbation in the following V. Additionally, /a/ was chosen because preaspiration occurs most commonly in low vowels [21], [29].

The 14 experimental words were embedded in the Italian carrier phrase "*Dico WORD lentamente*" 'I say WORD slowly' and read out five times by all 5 participants, resulting in 350 total tokens. The phrases were displayed through a PowerPoint presentation one by one in random order.

2.3. Data collection and analysis

An EGG-D400 Laryngograph was used to collect the data. The acoustic signal was captured and synchronized with the EGG signal through a RØDE NT3 microphone connected to the Laryngograph, set at a 48 kHz sampling rate. The EGG signal was obtained through a pair of electrodes placed on each side of the participants' thyroid cartilage. The recordings were conducted in a quiet room at the University of Melbourne.

The combined acoustic and EGG signals generated by the Laryngograph were analyzed in Praat. The acoustic signal was force-aligned using WebMAUS [30] to obtain phonetic annotations, and target V boundaries were subsequently adjusted manually where necessary. Boundaries were placed based on the acoustic signal alone, at the onset and offset of vowel-like periodicity and formant structures (see Figure 1). Additionally, voiceless preaspiration of voiceless stops, visible as diffuse aperiodic energy observed in the 0-12 kHz range preceding stop closure, was also annotated and its frequency of occurrence counted.

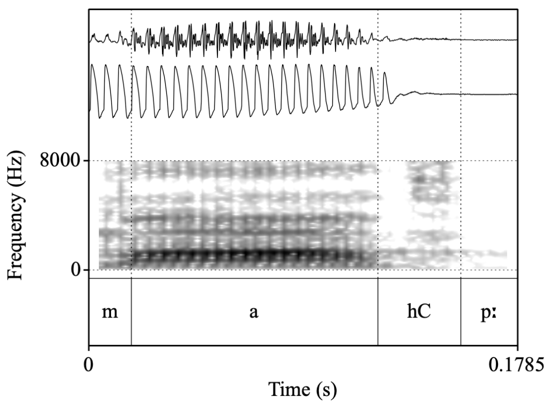

Figure 1: *Annotated example of a /mapːa/ token produced by N_Tur_F. The acoustic waveform is at the top and the synchronized EGG signal is underneath it. The acoustic spectrogram is at the bottom, revealing the presence of voiceless preaspiration, labelled 'hC'.*

The EGG signal was processed using the Praatdet script [31], which extracted open quotient (OQ) measurements across V duration. Following [32], Howard's OQ measure was chosen for the present investigation. OQ is a measure of glottal spreading/constriction and is defined as the duration of glottal opening over the duration of the entire glottal cycle [33]. Hence, the higher the OQ, the breathier (or less creaky) the voice.

2.4. Statistical analysis

For comparability across speakers, the time-aligned OQ data underwent z-score normalization by speaker. Two Generalized Additive Mixed Models (GAMMs) were fitted through the mgcv [34] and itsadug [35] packages in R [36]. GAMM 1 included (a) a parametric (P) interaction between speaker (5 levels) and C type (6 levels: singleton nasal, geminate nasal, voiced singleton stop, voiced geminate stop, voiceless singleton stop, and voiceless geminate stop), resulting in 30 interaction levels, and (b) a smooth (S) term over normalized V duration by the interaction of speaker and C type. Singleton nasals produced by N_Tur_F were set as the baseline (cf. §3.2). GAMM 2 focussed on stops and had voicing (voiced/voiceless) and gemination (geminate/singleton) as parametric (P) terms, with two smooth (S) terms over normalized V duration, the first by voicing and the second by gemination. Both GAMMs included a random smooth term over normalized V duration by speaker. Basis functions were set to ten (k = 11). An AR1 error term was included to address autocorrelation. Post-hoc tests were conducted on parametric differences using the emmeans function and package [37].

3. Results

3.1. Preaspiration/preglottalization patterns

Preaspiration of voiceless stops occurred frequently (91/150, 61% of total tokens), while, unlike [7], no instances of preglottalization were found. Table 2 provides counts of preaspirated tokens by participant and phoneme, showing that individual participants varied considerably in rates of preaspiration occurrence. N_Tur_F preaspirated nearly all voiceless stops (28/30 tokens) regardless of length. N_Vic_M preaspirated /t t: k k:/ most frequently (18/20). T_Emp_M only preaspirated geminates (13/15 – but see below). CS_Rom_F also showed a preference for geminate preaspiration (14/15), although singletons were also sometimes preaspirated (5/15). Finally, CS_Cat_M mostly preaspirated velars (5/5 /k:/ and 4/5 /k/), but not other places of articulation (except for 2/5 /t:/ tokens). A qualitative inspection of the corpus showed that CS_Rom_F and CS_Cat_M also tended to exhibit some prevoicing at the onset of /p t/ closure (see more in §3.2).

Region-specific patterns can also be observed. N speakers produced preaspiration more frequently (48/60, or 80% of total tokens) than the T and CS speakers (13/30, or 43% of total tokens for T and 30/60, or 50% of total tokens for CS speakers). This is because N speakers frequently preaspirated singletons as well as geminates (22/30, or 73% preaspirated singletons for N speakers as compared to no occurrences for the T speaker and 9/30, or 30% occurrences for CS speakers).

Table 2: *Counts of tokens exhibiting voiceless preaspiration.*

	/p/	/t/	/k/	/p:/	/t:/	/k:/	Tot
N_Tur_F	5/5	4/5	5/5	5/5	5/5	4/5	28/30
N_Vic_M	0/5	4/5	4/5	2/5	5/5	5/5	20/30
T_Emp_M	0/5*	0/5*	0/5*	4/5	5/5	4/5	13/30
CS_Rom_F	0/5	2/5	3/5	4/5	5/5	5/5	19/30
CS_Cat_M	0/5	0/5	4/5	0/5	2/5	5/5	11/30
All	5/25	10/25	16/25	15/25	22/25	23/25	91/150

Note. *These tokens were all spirantized as [ɸ θ ɦ]

It should be noted that T_Emp_M consistently spirantized /p t k/ as [ɸ θ ɦ], as previously reported for Tuscan Italian [3] (see examples in Figure 2). Preaspiration occurring as voiceless glottal friction, similar to Figure 1, was not found in any of these spirantized tokens (in contrast to [23]).

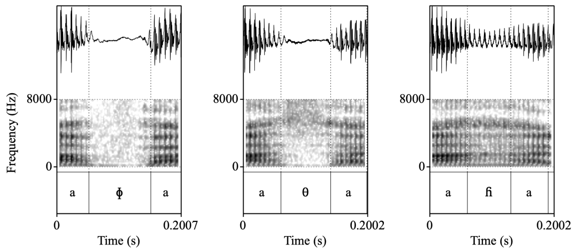

Figure 2: *Annotated examples of /mapa mata maka/ showing intervocalic spirantization produced by T_Emp_M.*

Following the categorical, qualitative analysis of preaspiration occurrence above, we now proceed to a quantitative analysis of V voice quality patterns to examine potential gradience in the voice quality continuum.

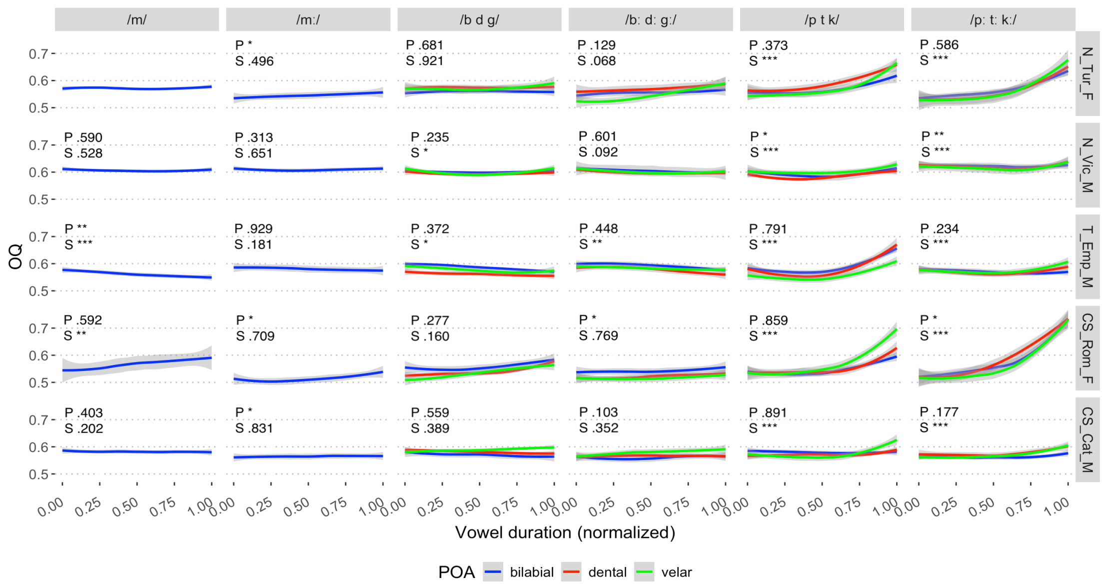

Figure 3: *Mean trajectories of open quotient (OQ) across normalized durations of preceding vowels by consonant type and place of articulation (POA) for each speaker.*

3.2. Voice quality in the preceding vowel

Figure 3 displays average OQ trajectories across the duration of V preceding target C types by place of articulation (POA) for each speaker. The same figure shows results of GAMM 1, reporting significance levels of parametric (P) and non-linear smooth (S) differences in the z-score data compared to the baseline /m/ trajectory produced by N_Tur_F. Significant differences are marked with asterisks, indicating $p < .05$ or lower, while actual p-values are provided for non-significant differences. Note that the baseline trajectory serves as an ideal reference for other trajectories, as it is nearly a straight horizontal line centered at 0 in the z-score data.

Overall, OQ trajectories differ substantially in shape across voiceless and voiced stop tokens, as signalled by the non-linear smooth term 'S'. For V preceding singleton and geminate voiceless stops, they have a non-flat shape, all at $p < .001$ – specifically, they are rising for all speakers, indicating a progressively breathier voice towards V offset. By contrast, OQ in V preceding voiced stops tends to stay level throughout V duration across speakers, with two exceptions: (i) for T_Emp_M, OQ decreases slightly towards V offset preceding both singletons and geminates, pointing to creakier voice; (ii) N_Vic_M, exhibits a somewhat falling-rising OQ contour preceding singletons. Another thing to note is the speaker-specific variation in voice quality preceding /m/, with a OQ trajectory that is falling for T_Emp_M and rising for CS_Rom_F, highlighting speaker-specific voice quality patterns even in the supposedly more neutral /mVm/ context.

Parametric differences from the baseline, denoted by 'P', were also detected. For voiceless stops, overall higher OQ values were observed in N_Vic_M for both singletons and geminates, and in CS_Rom_F exclusively for geminates. For voiced stops, lower OQ values preceding geminates are displayed by CS_Rom_F alone. For nasals, lower OQ preceding geminate /mː/ was detected in three speakers: N_Tur_F, CS_Rom_F, and CS_Cat_M. By contrast, only T_Emp_M exhibited lower OQ than other speakers preceding singleton /m/.

Post-hoc tests were run to investigate the effect of gemination on OQ trajectories in preceding V for each individual speaker across voiced and voiceless stop series. There was only one significant parametric difference between singleton and geminate voiceless stops for N_Vic_M ($\beta = -1.325$, $SE = 0.211$, $t = -6.295$, $p < .001$), with V preceding /pː tː kː/ exhibiting higher OQ than V preceding /p t k/ for this speaker. Voiced stops and nasals did not show significant singleton-geminate differences for any of the speakers.

GAMM 2 tested the overall effects of stop voicing and gemination on the OQ trajectories across speakers. Parametric differences were statistically significant between voiceless and voiced stops, at $p < .01$, but not between geminate and singleton stops, at $p = 0.784$. Non-linear smooth differences were significant for both voicing and gemination, both at $p < .001$. Figure 4 illustrates that OQ is slightly lower for V preceding voiceless stops up to ~50% of V duration, with this trend reversing from ~70% of V duration where OQ becomes higher for voiceless stops with this difference increasing steeply towards V offset.

Some variation in OQ trajectories specific to the place of articulation of the following stop can be observed in Figure 3, although this was not tested statistically for lack of space here. Generally, it appears that V preceding velars has a higher OQ than preceding non-velars towards its offset in the case of singletons produced by the CS speakers, while the T speaker shows the opposite trend (note, however, that this speaker produced /k/ as a voiced [ɦ] in all cases). This phenomenon may be due to an observed tendency for the CS speakers to produce /p t/, but not /k/, with some vocal fold vibration in the first ~20% of stop closure duration. This observation is mirrored by the low rate of occurrence of preaspiration of /p t/ for these speakers reported in Table 2.

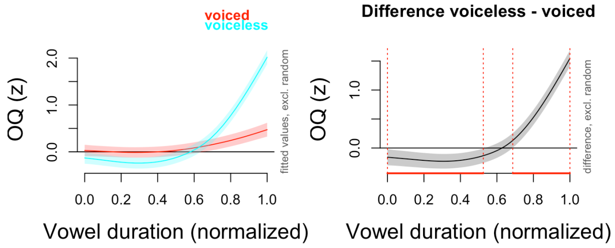

Figure 4: *Predicted smooths (left) and smooth differences (right) of OQ (z) for voiced and voiceless stops over normalized preceding-vowel duration.*

4. Discussion and conclusion

This study finds that voiceless stops, as compared to voiced stops, and regardless of phonological length, are characterized by a breathier voice quality (higher OQ) in approximately the final 30% of preceding-V duration across regional varieties of Italian. This finding aligns with and adds to [38] who looked exclusively at singletons. Moreover, increased creakiness (lower OQ) or preglottalization never occurred before voiceless tokens in the present data, although somewhat creakier voice surfaced preceding voiced tokens in some cases.

Another key finding is that C gemination does not have an overall effect on the voice quality of preceding V, although one Northern speaker (N_Vic_M) did produce increased breathiness preceding voiceless geminates vs. singletons. Furthermore, the occurrence of voiceless preaspiration appears to be partly speaker- and potentially region-specific. In our data, Northern speakers exhibit comparable rates of preaspiration for voiceless geminates and singletons, whereas Centro-Southern speakers show a higher propensity to preaspirate voiceless geminates, corroborating findings from [22]. However, data from more speakers for each region are needed in future studies to support this generalization. Additionally, the lower OQ observed preceding tendentially pre-voiced singleton /p t/ produced by Centro-Southern speakers suggests that these speakers may not spread the vocal folds before voiceless singletons as actively, or to the same extent, as they do for voiceless geminates. Conversely, Northern speakers actively devoice all voiceless stops (cf. [2], [22]). Interestingly, this devoicing is always implemented through glottal spreading in this study, and never through glottalization as observed in some cases by [7]. As for the Tuscan speaker, who regularly spirantized /p t k/ intervocalically, breathy voice in preceding V was more pronounced for singletons than geminates, supporting the notion that (voiceless) fricatives typically exhibit substantial breathiness in the V-C transition [39].

In conclusion, this study suggests that breathy voice towards V offset, indicative of glottal abduction, is a gradient phenomenon that may be characteristic of voiceless stops in Italian while voiceless preaspiration occurs more variably, influenced by factors such as: (a) speaker-specific tendencies, (b) C length, (c) C place of articulation, and possibly (d) regional pronunciation.

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