# VOICE-INITIATING GESTURES IN SPANISH: PRENASALIZATION[1]

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## ABSTRACT

This work reports the use of nasal leakage to achieve the pressure difference for voicing in utterance-initial Spanish stops. Multiparametric aerodynamic and acoustic data were analyzed for six Spanish speakers. Two main patterns of prenasalization were identified in postpausal voiced stops: (i) delayed nasal closure relative to the oral closure and (ii) a momentary nasal opening (nasal burst) before phonation onset. Quantitative analysis showed that the time between oral and nasal closure was longer for voiced than devoiced stops, and for phonologically voiced than voiceless stops. Velopharyngeal closure was related to phonation onset such that as voicing was initiated, the velum began to raise. The results suggest that occurrence of velum leakage is related to vocal fold vibration in Spanish utterance-initial stops.

**Keywords:** voicing, utterance-initial stops, nasalization, Spanish.

## 1. INTRODUCTION

This study analyzes the occurrence of velum leakage in utterance-initial voiced stops in Spanish and its relationship to stop voicing. As other Romance languages do, Spanish uses voicing during the closure to cue the voiced-voiceless contrast; therefore, speakers must make the necessary adjustments to achieve vocal fold vibration during the stop closure.

It is known that closure voicing during an utterance-initial stop is less likely to occur and is typically shorter than medially. This is because the aerodynamic conditions are less conducive to voicing of utterance-initial stops than of medial stops, where subglottal pressure is high and relatively constant [1]. In utterance-initial stops, *subglottal* pressure rises above atmospheric pressure in a characteristically linear manner, following a similar time course to the *oral* pressure increase during the stop constriction. Given that the occurrence of voicing depends to a great extent on the difference between subglottal and oral pressure (and thereby airflow through the glottis),

stop voicing is unlikely to occur utterance-initially without additional maneuvers, simply because the pressure difference is not large enough. This difficulty is aggravated by the fact that after a pause the vocal folds must approximate and be duly tensed and glottal vibration has to be initiated rather than sustained, which requires a greater pressure difference – 3-4cm $H_2O$ *vs* 1-2 cm $H_2O$.

The difficulty to achieve voicing during utterance-initial stops is reflected in phonological patterns: a large number of languages lack (or do not require) actual glottal vibration during initial 'voiced' stops (e.g., American English, German); neutralization of the stop voicing contrast utterance-initially (to a voiceless stop) is not uncommon (e.g., Uzbek, Tamil, Cuna, Ewondo [2]); and utterance-initial stops have phonologized certain maneuvers (e.g., prenasalization, implosivization, d-lateralization, retroflexion) which help to preserve glottal vibration [3].

Some muscularly- (passive tissue expansion) and articulatorily-induced changes in supraglottal volume (e.g., larynx lowering) or oral/nasal leakage may reduce oral pressure and create the conditions for voicing initiation and continuation [4]. This study analyzes the occurrence of velum leakage in utterance-initial voiced stops in Spanish and the response of the vocal folds to time changes in oral pressure brought about by such nasal leakage.

## 2. METHOD

Simultaneous oral pressure, oral airflow, nasal airflow, and audio signal were obtained for ten Spanish speakers, five French speakers, and six English speakers. Only the results for six Spanish speakers (three female (S1, S4, S5) and one male speaker (S3) of continental Spanish; one female Mexican speaker (S2), and one male Uruguayan speaker (S6)) will be reported here. (These 6 speakers showed the higher rate of prenasalized tokens out of the original 10 Spanish speakers). The subjects were instructed to read the following sentences as if they were a dialogue between A and B in order to obtain two isolated utterances, with

the segment of interest beginning the second utterance (the /b/ in Bárbara, the /d/ in Débora,etc).

- A: ¿Cómo se llama ella? (`What's she called?')
  B: **B**árbara [**D**ébora, **P**aula, **T**ábata, **M**arta].

They produced 10 to 13 repetitions of utterance-initial voiced stops /b d/, voiceless stops /p t/, and nasal /m/. 330 tokens (average of 11 repetitions × 5 test words × 6 speakers) were analyzed.

The subjects' productions were recorded using National Instruments PCI-6013 data acquisition hardware and the Matlab Data Acquisition Toolbox (20kHz sample rate per channel and 16 bits/sample). Oral pressure was obtained by a catheter introduced through the center of the lips, ending just behind the lips for labials and behind the alveolar ridge for alveolars, and connected to a pressure transducer. Oral airflow and nasal airflow were collected with a split Rothenberg mask and Fleisch pneumotachographs. For further details on equipment and technique, see [5].

First, each voiced token was visually classified as voiced (if voicing lead was present) or devoiced. It was also classified as prenasalized (74% of the tokens) if nasal flow was present during the pressure build up. Measurements of the onset (and offset) of voicing (A) were performed by hand on the acoustic signal and the oral pressure signal. The following measurement points were also identified on the pressure and airflow signals: (B) onset of complete oral closure for the stop (oral flow to zero, see below); onset (C) and offset (D) of velum raising (drop in nasal flow, nasal flow to zero); onset (E) and offset (F) of oral pressure rise ('knees' in the pressure trace), and stop release (F). Oral pressure (G) and nasal airflow (H) values at voicing initiation, and peak oral pressure (I) were also measured. A major difficulty in the study of utterance-initial stops is that it is not possible to unambiguously identify the onset of closure for the stop; for example, for a labial stop, the lips may close well before oral pressure starts to build, or the pressure may build up without an acoustic consequence. The criteria used to determine the beginning of the stop closure were the occurrence of one of the following indicators: (i) oral airflow to zero and pressure buildup. If oral airflow dropped to zero (i.e., the oral articulators closed) at the end of the first phrase without a rise in pressure, then (ii) beginning of oral pressure buildup (which typically occurs approximately 20ms before complete stop constriction, when the articulators start to move to form the constriction),

or (iii) onset of glottal vibration (in Spanish voicing may begin without a rise in pressure, as described below). A randomly chosen ten percent of the measurements were repeated by one of the investigators. Correlations between the original and the remeasured data showed high reliability ($r$ values 0.92 or higher and all $p$ values $< 0.0001$).

## 3. RESULTS AND DISCUSSSION

The multiparametric representation of voiced stop production, involving pressure, oral airflow, nasal airflow and acoustic data, was analyzed qualitatively and quantitatively.

### 3.1. Qualitative analysis of prenasalized stops

A first qualitative analysis of the data showed two main patterns of prenasalization. The first pattern involved *delayed* velic closure relative to the oral closure, that is, velopharyngeal closure following oral closure. Oral pressure buildup for stops typically begins when the oral and the nasal valves are closed. Delayed closing of the nasal valve for some prevoiced stops results in a nasal leak during the closure that slows down oral pressure buildup and helps achieve the transglottal pressure difference needed for voicing. Once voicing is initiated, the velum closes and pressure rises rapidly.

This pattern is illustrated in Figure 1, left. The Fig. shows that glottal pulsing may begin without a rise in oral pressure: since the volume of air escaping through the nose (bottom trace) is roughly the same as the volume of air flowing into the cavity, the oral pressure remains low (trace 3 from the bottom), favoring transglottal flow for voicing. Once voicing is initiated, the velum begins to close (drop in nasal flow, indicated by the first vertical line) and when velum closure is complete (nasal flow to zero, short vertical line), pressure rises abruptly and the amplitude of voicing diminishes. The waveform illustrates the increasing amplitude of glottal pulsing during the prenasalized portion, reflecting the increased flow through the glottis due to nasal leakage (as opposed to decreasing amplitude of voicing in the latter part of the stop with the nasal valve closed). During the first portion of the stop these tokens typically exhibit a slow pressure rise (or lack thereof as in Fig. 1) and concurrent nasal flow. The magnitude of nasal leakage (i.e., volume of air flowing out of the nose) during the initial part of the stop closure tends to be comparable to the

volume of nasal flow at the end of the utterance (see Fig. 1, left) and to the /m/ in 'llama' in the carrier phrase.

In a second pattern, illustrated in Fig. 1 (right), the oral and nasal valves both close (i.e., the oral and nasal flow drop to 0), but a subsequent brief opening of the velum (seen as a burst of nasal airflow) accompanies the initiation of voicing. After voicing initiates, nasal flow drops to 0. That is, a momentary nasal leakage helps kick-start voicing. Voiceless stops do not show such nasal burst.

Both types of prenasalization diminish oral pressure and facilitate the initiation of voicing. As soon as voicing is initiated, the velum typically closes. While speakers show a preference for using one type or the other, and some subjects use one type exclusively, half use both. There appears to be no difference in the frequency of occurrence of prevoicing in the two patterns and they do not appear to be associated with place of articulation of the stop (labial vs apical).

**Figure 1:** Waveform, 0-7 kHz spectrogram, oral pressure, oral flow, and nasal flow for two tokens of Spanish *Débora*. Left: 'delayed velum raising' token of /d/. Right: 'nasal burst' token of /d/. The long vertical line indicates onset of velum raising (C).
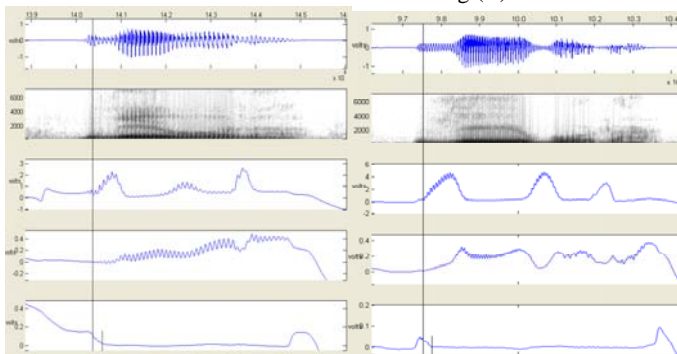


The occurrence of one or the other pattern largely depends on whether or not the velum is open at the beginning of the utterance. If the velum is open (e.g., inhalation between phrases or rest position, note the burst of nasal flow at the end of the utterance), then velum closure tends to be delayed relative to oral closure. If the velum is closed, then it momentarily opens for voiced but not voiceless stops. Speakers also vary in whether they use nasal leak only to initiate but not maintain voicing –with nasal flow rapidly decreasing after voicing onset– or to initiate and maintain voicing throughout the stop closure. As other studies have demonstrated [5], prenasalization may be used singly or in combination with other voice facilitating

maneuvers. For example, Fig. 1 right shows spirantization of the latter part of utterance-initial /d/, that is, oral flow during the pressure buildup for the stop, resulting in high amplitude of voicing throughout the closure.

### 3.2. Quantitative analysis

The first question addressed is whether timing of nasal closure relative to oral closure is related to voicing initiation; if it is, a difference in the timing of the two gestures for voiced, devoiced and voiceless stops is expected. Alternatively, nasal closure may lag behind oral closure due to the sluggishness of the velum, and no difference would be expected between voiced, devoiced and voiceless stops. Fig. 2 shows the time lag between the oral closure for the stop (measurement point B) and velopharyngeal closure (nasal flow to zero, measurement D) for all voiceless, voiced and devoiced tokens (regardless of their prenasalized/not prenasalized realization). Articulatory movements are aligned at the moment of complete nasal closure, hence time left of zero is the prenasalized portion of the stop. Stops at the labial and apical place of articulation were pooled because they did not show significant differences in oral-to-nasal closure [$F_{(1, 217)} = 0.117$, p=0.732]. The figure shows that nasal closure follows oral closure (range 11-94ms) in all initial voiced (and devoiced) stops produced by the six speakers. Interestingly, devoiced tokens show a significantly shorter prenasalized portion than prevoiced tokens for the same speakers (speakers 1 and 5; [$F_{(1, 42)} = 9.206$, p=0.01]), suggesting that an early velopharyngeal closure may prevent the initiation of glottal vibration in phonologically voiced tokens.

Indeed, prenasalization is of no consequence to glottal vibration in voiceless stops, and the timing of oral and nasal closure varies considerably across speakers, with nasal closure typically following but also preceding oral closure (speakers 2, 4). A two-way ANOVA with Subject and Voicing (phonologically voiced *vs* voiceless) as factors revealed that nasal closure takes place significantly later in voiced (both prevoiced and devoiced) than in voiceless stops in 4 out of 6 speakers [$F_{1(1, 217)} = 19.862$, p<0.0001]. (The two speakers who did not show significant differences exhibited predominantly devoiced realizations (S5), or relatively short prenasalized portions (S6)). The different timing of velum closure in voiced and

voiceless stops for 4 out of 6 Spanish speakers cannot be attributed to the sluggishness of the velum vis-à-vis the oral articulators, but suggests that speakers utilize nasal leakage as a voice-initiating gesture. Preliminary results of the English-speaking subjects, whose 'voiced' utterance-initial stops are predominantly devoiced, indicate no comparable differences in the time between oral and nasal closure in phonologically voiced and voiceless stops.

**Figure 2:** Mean time of oral closure (and release) relative to velopharyngeal closure (time 0) for voiceless (thick lines), voiced (dashed lines) and devoiced stops (thin lines) for each speaker. Only speakers 1 and 5 showed devoiced realizations. Labial and apical stops pooled. The arrow indicates onset of glottal pulsing.
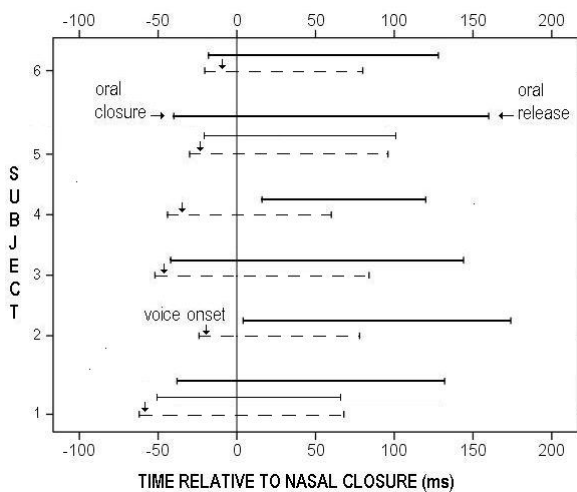


A second way to examine the relationship between nasalization and voicing is to analyze the timing of the two events. In the previous section it was noted that in prevoiced stops the velum started to close shortly after glottal pulsing initiated, suggesting that the timing of velopharyngeal closure was related to stop voicing. Fig. 3 shows the short time interval (mode 14ms, mean 19.12 ms, SD 15.46) between voicing onset and *onset* of velum closure (measurement points A-C) – rather than offset of velum closure as in Fig. 2– for prevoiced stops, which lends support to this interpretation. Some extreme high values (between 60-85ms) reflect that for some speakers and tokens the voiced stop is nasalized throughout, that is, velum leakage may be utilized to initiate and also to sustain voicing during the stop closure.

Finally, prenasalization may be used in combination with other adjustments (e.g., cavity enlarging gestures) to keep oral pressure low and thus achieve the pressure difference for voicing
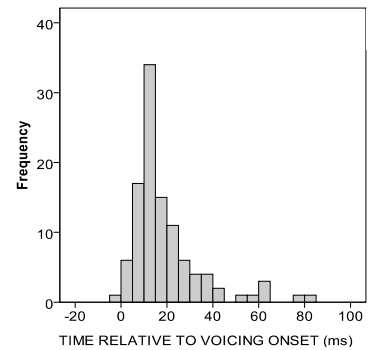


**Figure 3:** Frequency distribution of onset of nasal closure relative to phonation onset (time 0) in Spanish prenasalized voiced stops. N= 107.

initiation. In fact, the data indicate that these adjustments are very effective at keeping oral pressure low for voicing in Spanish. Even though oral pressure changes rapidly over time, and therefore varies greatly depending on the measurement point, the data show that for all utterance-initial voiced stops the mean oral pressure at voicing initiation is $0.45cmH_2O$ (SD 0.62; range $-0.90 – 3.01cmH_2O$).

## 4. CONCLUSIONS

The aerodynamic and acoustic data reveal that nasal leakage may be used in Spanish utterance-initial stops to promote transglottal airflow for voicing. The results show that voiced stops with a delayed nasal closure or a nasal burst are more likely to have prevoicing than those with an early velic closure (which tend to be devoiced), and that voiceless stops tend to have an earlier nasal closure than voiced stops. The different timing of velum closure in voiced and voiceless stops indicates that Spanish speakers may utilize nasal leakage as a voice-initiating gesture. The association between phonation onset and nasal closure, such that once voicing is initiated the velum begins to close, also points in the direction that velum leakage is a maneuver to keep oral pressure low for voicing.

## 5. REFERENCES

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