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Research Article

Articulatory adjustments in initial voiced stops in Spanish, French and English ☆,☆☆

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ABSTRACT

This work reports cross-languages differences in the voicing of utterance-initial voiced stops, and in the use of active maneuvers to achieve closure voicing, using correlated aerodynamic and acoustic data. Oral pressure, oral and nasal flow, and acoustic data were obtained for utterance-initial /b d p t m/ for 10 speakers of Spanish, 6 speakers of French and 5 speakers of English. Voiced stops were first classified as prevoiced or devoiced. Then they were classified by shape of the oral pressure pulse and/or occurrence of nasal flow or oral flow during the stop closure in an attempt to relate aerodynamic data to motor adjustments to facilitate voicing. Such adjustments were found to be related to (i) language-specific differences in the use of glottal vibration as a cue to the voicing-distinction, (ii) place of articulation, and (iii) speaker dependent variation. Voiceless stops showed no such active maneuvers except nasal leak (i.e. nasal closure following oral closure). Comparison of the timing of oral-velic closure in voiced and voiceless stops showed that nasal closure took place later in voiced than in voiceless stops. The longer nasal leak in voiced compared to voiceless stops is argued to be related to voicing initiation and maintenance. Finally, we seek to find acoustic evidence of articulatory adjustments to lower oral pressure for voicing. A correlation is found between oral pressure and voicing amplitude during the stop closure in the three languages: as oral pressure rises, voicing amplitude decreases. Thus the time course of voicing amplitude during the stop closure allows us to infer whether (any) motor adjustments to keep a low oral pressure for voicing are present but not specifically which ones.

1. Introduction

It is known that it is difficult to initiate and sustain voicing during stops due to the 'Aerodynamic Voicing Constraint' (AVC) (Ohala, 1983; Ohala, 2011). Vibration of the vocal folds requires appropriate tension and configuration of the vocal folds and a pressure differential across the glottis so that sufficient air flows through the vocal folds. During a stop closure, oral pressure rises and the transglottal pressure difference, and transglottal flow, is insufficient to sustain (or initiate) vocal fold vibration. In spite of this difficulty, a majority of languages—88.9% according to surveys of sound inventories of genetically diverse languages (e.g., Maddieson, 1984), 62% according to studies on linguistic typology (Song, 2011)—use contrastive voicing on stops. Indeed, in some languages the contrast in phrase-initial position does not rely on presence/absence of glottal vibration during the closure (e.g., English, German, Danish, Mandarin Chinese), but in many other languages voicing during the stop closure is used to cue the voiced-voiceless contrast[1] phrase-initially (e.g., Spanish, French, Catalan, Dutch, Hungarian, Bulgarian, Polish, East Armenian, Thai, Japanese, Tamil, Hindi; see, for example, Lisker & Abramson, 1964). In these languages voicing during stop consonants tends to start earlier (and last longer) than would be predicted from aerodynamic parameters (vocal tract volume behind the constriction, rate of transglottal flow in modal phonation, and

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[1] Or 'plain' voiced vs 'plain' voiceless contrast in languages with more than a two-way voice contrast.

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subglottal pressure), which suggests that voiced stops are implemented in ways that are accommodations to the AVC.

Specifically, we address the following question: How do speakers of languages with prevoiced stops, such as Spanish and French, manage to have voicing in initial stops given the AVC which impacts negatively on obstruent voicing? Moreover, initial voiced stops in these languages show longer negative VOT values (i) at slower than faster speaking rates (Kessinger & Blumstein, 1997 for French and Thai; Magloire & Green, 1999 for Spanish[2]), and (ii) in repetitions of incorrectly identified words (Schertz, 2012 for Spanish), indicating that speakers have fine articulatory control over ways to counteract the AVC. This study addresses these questions by examining acoustic and aerodynamic data of utterance-initial voiced stops in Spanish, French and English.

A number of studies have investigated and modeled the aerodynamic conditions required to maintain voicing during a stop closure (e.g., Koenig & Lucero, 2008; Müller & Brown, 1980; Ohala, 1983; Rothenberg, 1968; Westbury, 1983; Westbury & Keating, 1986), and have described the characteristic voicing patterns in stops in different languages (e.g. Abdelli-Beruh, 2009 for French; Castañeda, 1986 for Spanish; Cuartero, 2002 for Catalan; Docherty, 1992 for British English; Jessen, 1998 for German; Pape & Jesus, 2015 for European Portuguese, Italian and German). Most studies have focused on postvocalic word-initial, intervocalic, or word final stops. Fewer studies (but see Westbury, 1983; Westbury & Keating, 1986) have looked at the aerodynamic conditions to *initiate* voicing in utterance- or phrase-initial stops (in part due to the difficulty to unambiguously identify the beginning of the stop closure post-pausally). This study analyzes cross-language differences in the voicing of utterance-initial voiced stops and in the use of active maneuvers to achieve closure voicing. Specifically, it analyzes aerodynamic and acoustic data of voicing in initial stops in Spanish and French, with prevoiced stops (Borzone de Manrique & Gurlekian J, 1980; Lisker & Abramson, 1970; Villamizar, 2002 for Spanish; Abdelli-Beruh, 2009; Benguerel, Hirose, Sawashima, & Ushijima, 1978; Caramazza & Yeni-Komshian, 1974; Laeufer, 1996 for French) and English, with typically devoiced stops, though voiced stops occur (Flege, 1982; Jacewicz, Fox, & Lyle, 2009; Lisker & Abramson, 1970; Smith, 1978).

1.1. The aerodynamic voicing constraint and phonological patterns

It is well-established that it is difficult to produce vocal fold vibration during voiced stops due to challenging aerodynamic conditions. In medial and final stops, air accumulates in the oral cavity during the stop closure, oral pressure (P_o) rises and the pressure differential ($P_{subglottal}$-P_o) falls below the threshold for voicing (1–2 cmH_2O; Baer, 1975; Hirose & Niimi, 1987). Thus medial and final stops tend to devoice ('passive devoicing') after a few tens of ms following the stop closure in the absence of additional articulatory adjustments. The duration of voicing during the stop closure has been shown to vary with several factors: place of articulation of the consonant—labials retaining voicing more readily than velars—due, it is hypothesized, to differences in the amount of compliant surface area that could accommodate the glottal airflow (Ohala & Riordan, 1979); the length of the consonant closure, with longer closures tending to devoice as air accumulates in the oral cavity over time (Ohala, 1983); phrasal position (Westbury & Keating, 1986); voicing in adjacent segments (Shih, Möbius, & Narasimhan, 1999); and vowel context, with high vowels favouring voicing over low vowels due to a larger pharyngeal cavity volume (Ohala & Riordan, 1979; Pape, Mooshammer, Hoole, & Fuchs, 2006). Note that all these factors have an impact on intraoral pressure and transglottal flow, and hence on voicing.

In utterance-initial stops closure voicing 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 (Westbury & Keating, 1986), where voicing continues from the preceding vowel/sonorant. Utterance-initial stops involve different initial conditions for the respiratory system and the laryngeal system. For example, the subglottal air pressure (P_s) must rise above atmospheric pressure (while in medial stops P_s is high and relatively constant), the vocal folds must be adducted and properly tensed, and vocal fold vibration has to be initiated rather than sustained, which requires a twice as large transglottal pressure differential—3–4 cmH_2O vis-à-vis 1–2 cmH_2O (Baer, 1975; Hirose & Niimi, 1987)—due to the need to overcome inertial effects. Hanson, Stevens, Kuo, Chen, and Slifka (2001) note that these three variables—vocal fold adduction and tension, and a minimum pressure difference across the folds—are interdependent; thus the pressure difference needs to be higher if the folds are relatively tense or partly adducted. The aerodynamic conditions for phrase-initial stops are illustrated in Fig. 1, which shows subglottal pressure (obtained with tracheal puncture) and oral pressure, in the penultimate panel, for 3 repetitions of phrase-initial English /bɑː/. It can be observed that *subglottal* pressure rises above atmospheric pressure in a characteristically linear manner, following a similar time course to the *oral* pressure increase during the stop closure.[3] 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, resulting in devoiced stops.

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., English, German and Germanic languages in general – with the exception of Dutch (Van Alphen & Smits, 2004) as already noted earlier). Utterance-initial neutralization of the stop voicing contrast (to a voiceless stop), while the contrast is retained medially, is not uncommon, e.g., Tamil, Cuna, Ewondo (Westbury & Keating, 1986), Lac Simon, an Algonquian language (Steriade, 1997), Totontepec Mixe, a Mixtecan language (Schoenhals & Schoenhals, 1965). Kim

[2] Asikin-Garmager (2015) also reports that Hindi voiced stops are produced with longer prevoicing – and breathy voiced stops with both increased prevoicing and breathy voice (aspiration) – at slower than faster rates.

[3] Note that subglottal pressure is assumed to be constant during the production of a phrase. However, pauses associated to phrase boundaries, as is the case for the three tokens of 'ba' in Fig. 1, involve a decrease in P_s due to a reduction in the net expiratory muscular force and an increase in P_s for the following phrase (Slifka, 2000: sections 7.1 7.2).