Effects of glottal impedance on subglottal pressure: evidence from voiceless aspirated, non-aspirated and ejectives stops

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1. Introduction

The respiratory system is generally regarded as producing voluntary variations in intensity and perhaps in pitch, but not (at least in most well known languages) producing voluntary increases in pressure for particular sounds. All the changes related to individual segments, such as the drop in subglottal pressure (Ps) that occurs after [h] or the increase in pressure during the [k] closure is considered to be aspects of tract aerodynamics, and not under voluntary control. They can be ascribed to variations in the resistance provided by the vocal folds to the outgoing air (the glottal impedance) or to variations in the stiffness of the vocal tract walls. Löfqvist [1], summarizing the evidence for differences in respiratory activity for different stop categories, concludes that with the exception of Korean fortis stops, the observed variations in Ps can generally be attributed to variations in the glottal impedance. This paper examines variations accompanying different stops consonants in English [p^h, t^h, k^h, b, d, g], French [p, t, k, b, d, g], and Amharic [p, p', t, t', k, k', b, d, g], thus making a comparison between voiceless aspirated and non-aspirated stops with ejectives and voiced stops. The study concludes that the glottal setting has distinct effects on Ps in the three languages.

2. Material and Method

Words and logatoms were recorded with 5 different speakers: 2 native English male speakers (1 English, 1 American), 2 French male speakers and 1 Amharic male speaker. English and French speakers produced logatoms in a small carrier sentence including the different consonants between the vowel [a] (e.g. 'Say papa again' (5 times) or 'Dis papa encore' (5 times). Amharic data were recorded in the same context but in real words [2]. Data were collected in simultaneous and synchronized recordings of subglottal pressure (Ps), intraoral pressure (Po) [Ps and Po measured in hPa (1 hPa = 1.2 cm H_20)] and the speech acoustic signal. Data were acquired using a *Physiologia* workstation [3]. Subglottal pressure (Ps) was measured by direct tracheal puncture with a 2mm diameter needle inserted in the last ring of the trachea. The Po measure was obtained with a small flexible plastic tube inserted through the nasal cavity into the oropharynx. The same recording procedures were applied for the three languages. The procedure preserved the rights and welfare of human research subjects, in respect of the ethical committee's rules (https://www.erasme.ulb.ac.be/fr/ethique).
Ps and Po were measured simultaneously at 4 points for the voiceless stops [p^h, p] (Figure 2 & 5) and 3 points for the ejective [p']. 15 measures were made for each consonant. Subjects are identified as S1, S2 for English, S3, S4 for French and S5 for Amharic. This abstract only presents results from voiceless bilabial stops, as they are almost strictly comparable from their context. Voiced stops alveolar and velar stops will be presented in a second phase.

3. Results

Mean Po and Ps values taken at the 4 points identified in Figure 2, for voiceless bilabial stops: (1) At the start of the bilabial closure, (2) at the 1st Po peak, (3) at peak oral closure, (4) at he lowest value of Ps in the VOT. Ejectives have only 3 points of measures (start, peak, end) as shown on Figure 5. Ps values show a gradual increase towards peak Po but for the ejective [p'] which doesn't vary much between the 3 measurements points. (> 9.2 hPa, < 9.6 hPa). ΔPs/Po shows an important difference between S1 and S2. This is also observed for the 2 French speakers. Po is much higher than Ps in the ejective (up to 8.3 hPa). Ps values measured

at the lowest point during the VOT vary between 0.5 hPa and 1.7 hPa. There is almost no drop of Ps during for the ejectives VOT (0.2 hPa).

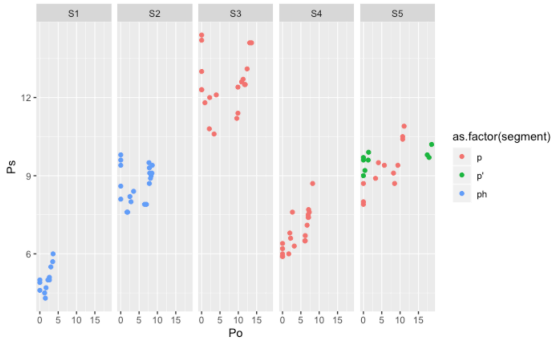
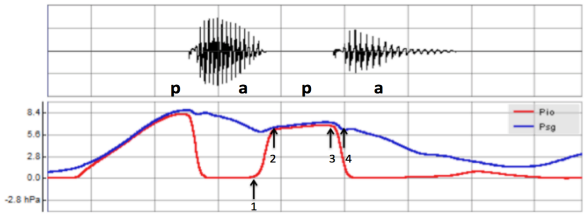
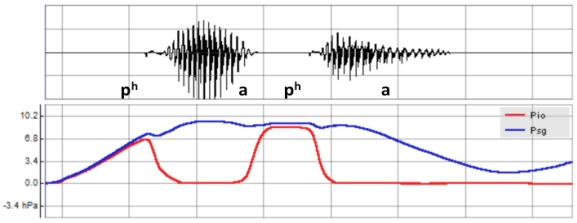
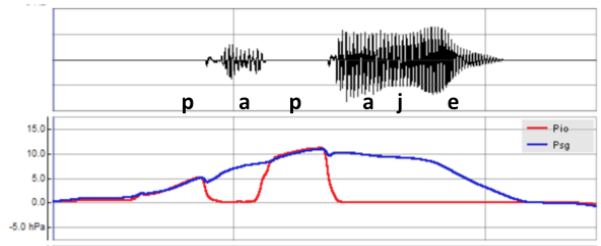


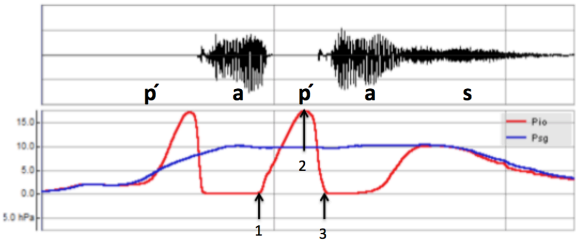
Figure 1. Ps in function of Po for the 5 subjects (S1, S2, S3, S4, S5) for the different bilabial segments [p^h, p, p']





Figures 2 & 3. Audio waveform, Ps and Po for the logatoms [papa] & [pa^hpa^h] produced by a French and a British English speaker. Points 1 to 4 refer to the measurements points.





Figures 4 & 5. Audio waveform, Ps and Po for the words papaje 'papaya' and p'ap'as (Church Patriarch) produced by a native Amharic speaker. Points 1 to 3 on Figure 5 are the measurements points.

4. Discussion.

Results show that there is no clear difference between aspirated stops [p^h] and non-aspirated stops [p] in terms Ps and Po. S1 show a greater difference in Ps and Po than S2. This is likely due to speaker specific features rather than between English varieties. Both for English and French, there is a speaker with Ps & Po values higher than the other. Two points about ejectives deserve a comment. Ps is rather constant during the production of [p'] and there is virtually no Ps drop during the VOT. The constant value of Ps is likely explainable by the fact that the tracheal pull effect of the larynx's rising squeezes the trachea and thus acts to reduce the laryngeal tube volume. This keeps Ps higher than expected. The glottis remaining closed after the bilabial release explains the quasi absence of Ps drop during the VOT. These results confirm Löfqvist [1] study on Swedish stops but with pulmonic and non-pulmonic stops in other languages. This also shows that Ps has a strong tendency to remain constant irrespective of the presence or absence of aspiration, larynx movement or voicing. The glottal setting differences account for the Ps patterns of each language. Similar trends are observed in alveolar and velar stops.

References

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