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LARYNGEAL BEHAVIOR IN VOICELESS WORDS AND SENTENCES: A PHOTOELECTROGLOTTOGRAPHIC STUDY

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ABSTRACT

An important challenge in the study of speech production is to gain theoretical understanding of how laryngeal and supralaryngeal movements are coordinated, and to determine which factors influence this coordination. This study investigates how these movements are coordinated during the production of completely voiceless words and sentences in Tashlhiyt Berber. Results show that the glottis does not simply remain open but that glottal aperture is continuously modulated in a manner that can be related quite systematically to the phonetic nature of the segments present in the sequence.

Key words: (gestural aggregation, laryngeal gestures, voiceless words)

1. 1. INTRODUCTION

This study investigates the nature of laryngeal and supralaryngeal adjustments during the production of Tashlhiyt Berber words and sentences composed of voiceless obstruents only. An important challenge in the study of speech production is to gain theoretical understanding of how supralaryngeal and laryngeal movements are coordinated, and to determine which factors influence this coordination. Understanding this is of special interest in creating models of speech production as well as in uncovering the relations between phonetic and phonological specifications. Voiceless consonant sequences are of special importance in handling this issue since the production of such clusters requires specific coordinated activities of the laryngeal and supralaryngeal articulatory movements.

Numerous studies have shown that the coordination between laryngeal and supralaryngeal events plays a major role in accomplishing the phonemic distinction of voicing and aspiration in several languages. In

addition to the study of single phoneme combinations, other studies, though less numerous, have also focused on finding out how voiceless consonant clusters are organized at the level of the glottis. Germanic languages (English, German, Icelandic, and Swedish) are by far the most studied languages. Pétursson [1], Löfqvist and Yoshioka [2], Yoshioka et al. [3], and Jessen [4], for example, observed glottal adjustment and the number of glottal abduction gestures in fricative-stop clusters separated by word boundaries. A comparable study has also been conducted on similar data drawn from Tashlhiyt Berber [5]. One major generalization that came out from this study was that sequences produced with n fricatives are most often produced with n peak glottal openings; these peak glottal openings are located during the production of these fricatives. These results are in general agreement with those obtained from some of the Germanic languages mentioned above. We thus have additional evidence from different unrelated languages that laryngeal activity during the production of voiceless obstruent clusters is organized in several glottal-opening peaks and that the manner of articulation of obstruents and their position in the cluster play an important role in determining both the number and the location of these peaks (in addition to speech style, etc.).

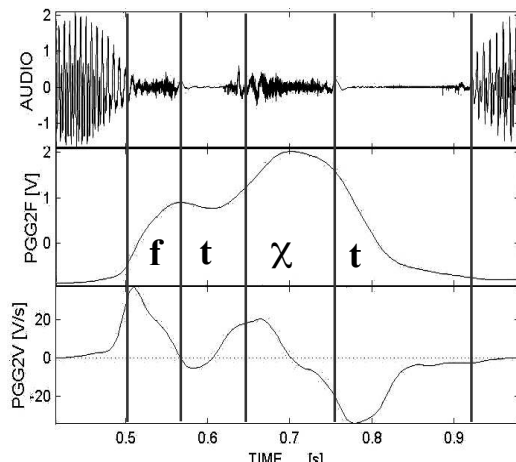
This study follows up on the examination of how laryngeal and supralaryngeal adjustments are coordinated during unvoiced clusters. We will focus on much more complex clusters, since the data examined include completely voiceless words and sentences. How are such words organized at the glottal level? Knowing that these items are produced with no vocal folds vibration, one may expect that the "devoicing gesture" may be considered by the

speakers as superfluous and simply eliminated, leaving the glottis in constant opening degree. If, on the other hand, the glottal aperture is rather continuously modulated, it will be important to determine the nature of these modulations and the mechanisms that govern them. This study may thus provide important insight into coarticulatory phenomena at the level of laryngeal adjustments and provide evidence for the interpretation that a static glottal opening position of the glottis is unlikely to occur (e.g. Munhall & Löfqvist [6], Yoshioka et al. [3]), since we included combinations of up to 15 voiceless consonants in our data.

2. METHOD AND PROCEDURE

Two male native speakers of Tashlhiyt Berber (RR and RF) were recorded by means of simultaneous transillumination, fiberoptic filming, and acoustic recordings. Acoustic and transillumination data have a sampling frequency of 24 kHz, transillumination data were further downsampled to 200 Hz, and the fiberoptic data have the standard video format of 25 i/s. An example of our data is presented in Figure 1. The top panel shows the acoustic waveform of the form [fχt] "roll it" (embedded in a carrier sentence). The second panel shows the glottographic pattern, which indicates the duration, degree, and number of glottal-opening peaks. The vertical axis shows the amount of light in arbitrary unit. In this figure, we can see that two glottal-opening peaks were produced, being located during the production of the fricatives /f/, and /χ/. The third panel indicates the velocity of glottal-opening and -closing gestures (i.e. the derivative of the transillumination data).

Figure 1: Acoustic waveform and glottal abduction pattern for [fχt] as realized by RR.



The number of glottal-opening peaks in voiceless words was calculated algorithmically as the number of (negative) zero crossings in the velocity signal. The number of peaks averaged over all repetitions is indicated in the following figures with ensemble-averaged data (voiceless sentences were not averaged). To obtain some further basic information on the shape of the glottal movements, we also counted the number of positive velocity peaks during opening movements and the number of negative velocity peaks in closing movements. The simplest movements are those in which each glottal-opening peak is associated with exactly one positive and one negative velocity peak. The speech material consisted of 17 voiceless words and 3 voiceless sentences, embedded in a carrier sentence "inna ... jat twalt" (he said ... once). The whole data consisted of 208 tokens.

Table 1. Linguistic material. Number of consonants in bold. Numbers within parentheses indicate the number of repetitions, first value for RR and second value for RF.

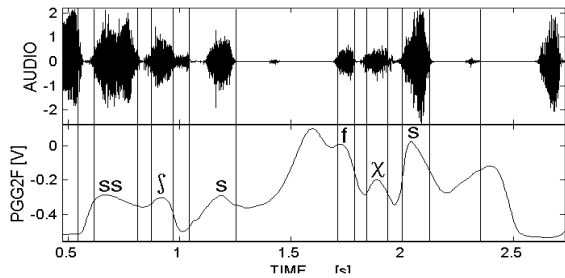
3. ftf "crush" (7,5)	6. tkkststt "you took it off" (7, 5)
3. fkt "give it" (7, 5)	6. tssfχt "you made him roll" (5, 4)
3. kst "feed it on" (7, 5)	6. tsskft "you dried" (6, 4)
3. tks "she feeds on" (7, 3)	7. tftχstt "you rolled it" (7, 5)
4. fχt "roll it" (7, 5)	7. tftkstt "you sprained it" (7, -)
4. tftf "she crushed" (8, 2)	8. tssfktstt "you made him sprain it" (7, -)
4. tkst "you feed it on" (-, 2)	8. tssfχtstt "you made him roll" (9, -)
5. tftf "you crushed" (6, 8)	8. tsskftstt "you dried it" (7, 6)
6. tftkstt "you gave it" (7, 4)	
13. tftkstt tftkstt "you sprained it and you gave it" (7, 5)	
14. tsskftstt tftkstt "you dried it and gave it" (7, 5)	
15. tsskftstt tftχstt "you dried it and rolled it" (7, 5)	

3. RESULTS

Can the glottis maintain a static open position in speech? Data from Tashlhiyt Berber clearly shows that this is not the case, since glottal area is continuously changing even in completely voiceless sentences (see figure 2 below). We thus have important evidence that the glottis is unlikely to keep a constant opening degree, showing that glottal articulation is "cyclical" in nature. A biomechanical interpretation of this fact has been suggested by Yoshioka et al. [3].

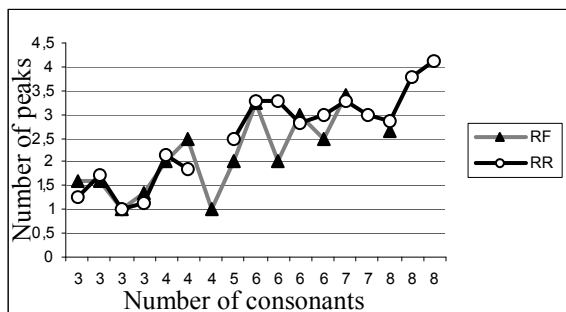
According to them, there is an upper and lower limit on the velocity of glottal opening and closing gestures during speech, and the lower limit implies that a static open position of the glottis is unlikely to occur or at least difficult to maintain, and the glottal aperture is thus continuously modulated.

Figure 2: Acoustic waveform and glottal abduction pattern for [tssk]ftstt tftχtstt as realized by RF.



Voiceless words and sentences are produced with multiple glottal opening and closing gestures. These typical continuous gestures are not strictly related to the number of consonants each form contains. As shown in figure (2), the number of glottal opening peaks does not systematically increase as the number of consonants increases (though some trend in this direction is clearly visible). For example, a form composed of four consonants (e.g. [ftχt], see figure 1) may be produced with the same number of glottal opening peaks as a form composed of 7 or 8 consonants (e.g. [tftkstt] see figure 6). Notice also that there are often different numbers of peaks for the same number of segments (compare [ftχt] and [tkst]).

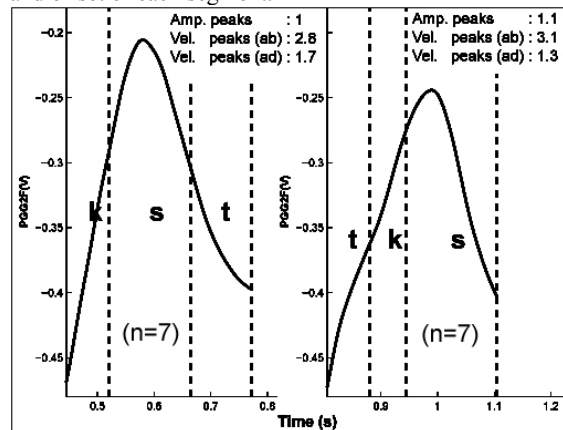
Figure 3: The number of glottal opening peaks produced during the production of the 17 voiceless words. Words are arranged following the same order as in table 1.



Closer examination of the data reveals a general tendency that may account both for the number and the location of glottal opening peaks. Though some variability exists both within and between subjects, it appears that the laryngeal-supralaryngeal adjustments produced

during the production of voiceless words and sentences is often related to the phonetic nature of the obstruents present in the sequence. More specifically, the number and the location of glottal opening peaks are often determined by the number of voiceless fricatives in a sequence. A form containing one voiceless fricative is often produced with one peak glottal opening located during the fricative. This laryngeal timing is illustrated in the figure below which shows the averaged glottal abduction pattern for [kst] and [tks].

Figure 4: Averaged glottal abduction pattern for the forms [kst] (left) and [tks] (right) as realized by RR. Each figure displays the number of amplitude peaks as well as the number of abduction and adduction velocity peaks. The number of repetitions of each sequence is indicated between parentheses. The dashed lines delimit the onset and offset of each segment.



Forms containing two voiceless fricatives, on the other hand, are most often produced with two peak glottal openings located during the two fricatives. Figures 5 and 6 provide an illustration of this pattern for [tkkststt] and [tftkstt], respectively.

Figure 5: Averaged glottal abduction pattern for the form [tkkststt] as realized by RF. Symbols as in Figure 4.

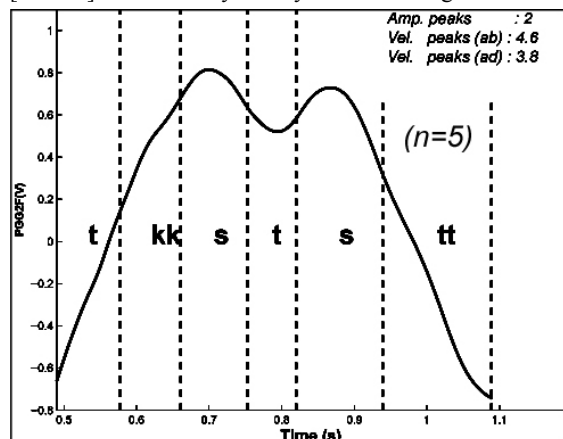
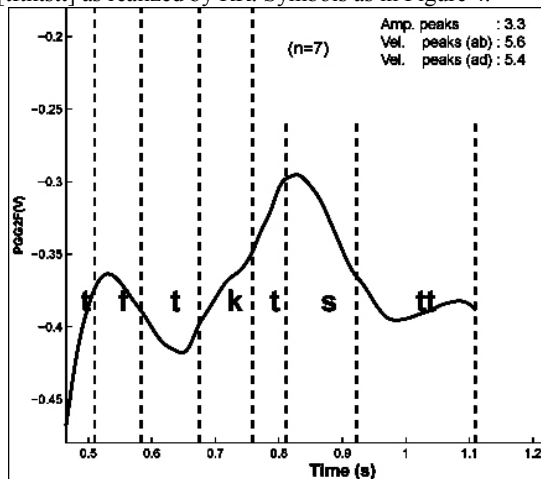
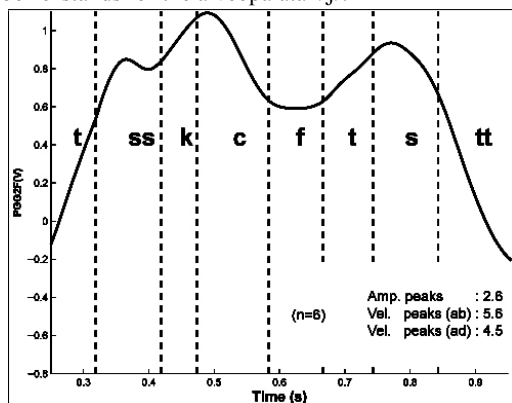


Figure 6: Averaged glottal abduction pattern for the form [tftktstt] as realized by RR. Symbols as in Figure 4.



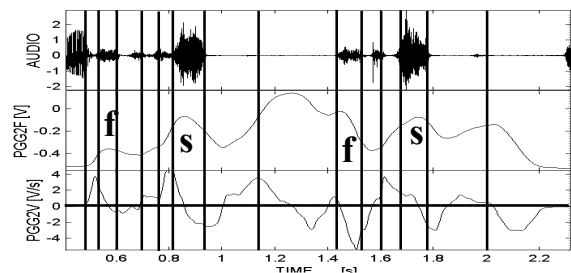
Notice that the data discussed so far include only sequences where a fricative is surrounded by stops. In case a sequence contains two adjacent fricatives, these fricatives are often produced with only one peak glottal opening located during the leftmost fricative. This is for instance the case of the form [tsskftstt] "you dried it", as shown in figure 7. The labial fricative /f/ is produced within the closing phase of the glottal gesture for the preceding fricative and within the opening phase for the following /s/ segment.

Figure 7: Averaged glottal abduction pattern for the form [tsskftstt] as realized by RF. Symbols as in Figure 4. The label 'c' stands for the alveopalatal /j/.



The general pattern observed in voiceless words may also account for the laryngeal-supralaryngeal adjustments observed in voiceless sentences. The form [tftktstt tftktstt], for example, contains four fricatives and is often produced with four glottal opening peaks located during these fricatives. This pattern is illustrated in figure 8 (see also figure 2 for the sentence [tsskftstt tftxtstt] which contains six non-adjacent fricatives and is produced with six peaks located during these fricatives).

Figure 8: Acoustic waveform and glottal abduction pattern for [tftktstt tftktstt] as realized by RR.



4. CONCLUSION

The first important result of this study is that the glottis, even in completely voiceless words and sentences, does not simply remain open, but rather that the glottal aperture is continuously modulated. The second important result is that this laryngeal modulation is quite systematically related to the phonetic nature of the individual segments present in the sequence: segments produced with a high rate of oral airflow are produced with a separate laryngeal-opening gesture. This result is in general agreement with those obtained from some Germanic languages (e.g. [2], [6]). From these previous investigations, it is clear that the continuous change in glottal opening is actively controlled by muscular activity. This active laryngeal modulation with respect to supralaryngeal events even in clusters up to 15 voiceless obstruents suggests that the larynx and the oral articulators are functionally coupled as a unit during speech. This provides a compelling demonstration of how intimately laryngeal and oral articulations are linked.

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