Geminates *vs.* Singleton Stops in Berber : An Acoustic, Fiberscopic and Photoglottographic study

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ABSTRACT

This article examines the oral and glottal adjustments, as well as their coordination, during the production of singleton and geminate voiceless stops in Berber using fiberscopy, photoglottography and acoustic analyses. Acoustically, closure duration of geminates is longer than singletons. VOT, on the other hand, does not contribute to the distinction of length. At the glottal level, voiceless stops are realized with a glottal opening covering both the closure portion and the aspiration portion. Geminates and singletons differ in terms of timing and size of glottal opening. Geminates have a larger and longer glottal opening than singletons. The interval between peak glottal opening and oral release is significantly higher for geminates than for single stops.

1. INTRODUCTION

Tachelhit Berber (henceforth TB), which is the variety analysed in this study, is spoken in the Southern part of Morocco. Like the other varieties of Berber, TB uses both voicing and gemination distinctively.

Languages with a two way contrast of stops generally use either voicing (e.g. Arabic, Japanese, Slavic and Romance languages) or aspiration as a feature of opposition. Most languages investigated have a two-way opposition based on the presence *vs.* absence of aspiration (e.g. Danish, German, English, Icelandic, Swedish and Mandarin Chinese). Transillumination studies carried out on these languages show that aspirated stops are produced with a large glottal opening the peak of which is coordinated approximately with the stop release. Glottal opening in these languages covers both the closure portion and the VOT portion. Unaspirated stops are realized with a small glottal opening covering the closure portion as is the case for Japanese voiceless stops [1]. Concerning geminates, the most convenient source of information on laryngeal movements for these consonants is a series of articles published by Benguerrel, Yoshioka, Löfqvist, Sawashima and colleagues on French, American English, Swedish and Japanese, but at the exception of Japanese, most of these have dealt essentially with geminates at word boundaries. These languages don't have tautomorphemic geminates.

No information on laryngeal adjustments in Berber consonants is available. This language, which allows long voiceless sequences, with particularly rich varieties of voiceless consonant clusters, different types of geminates and large series of voiceless words provides a very suitable field for examining laryngeal movements.

2. METHOD AND PROCEDURE

2.1. Measurement system

The video-endoscopic experiment (sessions 1 and 2) was performed by means of a flexible nasofibroptic laryngoscopy (Olympus ENF P3) with video recording (25 frames/s). On the film image, the distance between the vocal processes of the arytenoid cartilages was measured frame by frame during the time period corresponding to the consonants examined.

Photoglottography (PGG) consists of a flexible fiberscope and two photo-transistors PGG1 and PGG2 to measure the amount of light through the glottis. The glottal opening-closing pattern was observed by measuring the amount of light through the glottis. PGG1 was placed on the surface of the neck between the thyroid cartilage and the cricoid cartilage. PGG2 was placed below the cricoid cartilage. The examination of the data has shown that PGG1, being closer to the glottis, usually shows higher amplitudes; the signal is more sensitive to vertical laryngeal and epiglottal movements. PGG2 is less influenced and is a more stable transistor. All the results of the transillumination data below are derived from PGG2. Figure 1 below shows the transillumination experimental set-up.

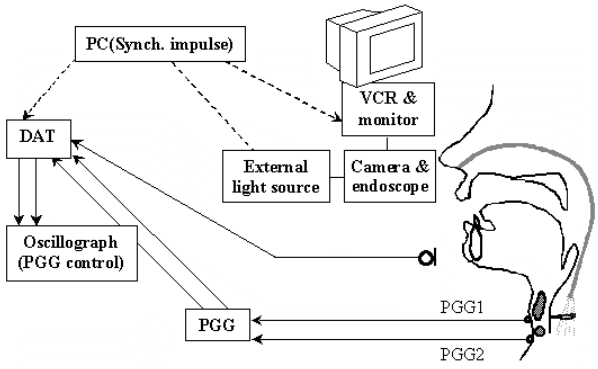

Figure 1 : Schematic overview of the PGG experimental set-up adapted from S. Fuchs [2].

2.2 Experiment and analysis

One adult male native speaker of TB (the author) served as a subject for fiberoptic and for PGG experiments. Two minimal pairs which differ in their intervocalic singleton-geminate voiceless stops,

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[t] *vs*. [tt], [k] *vs*. [kk], were selected as speech material :

i**t**ili	*"for ewe"*	i**tt**ili	*"he has"*
i**k**iyyi	*"for you"*	i**kk**iyyi	*"he passes"*

Each form was repeated 7 times for the fiberoptic experiment and 5 times for the transillumination experiment. The acoustic analysis is based on the data recorded in the PGG and fiberoptic experiments (12 repetitons for each token). The speaking rate was kept as constant as possible within the subject's habitual range.

A number of events were labeled in the acoustic and the transillumination data. In the acoustic data, the following events were labelled: the onset of oral closure (On_C), the oral release (Or_R) and the onset of the following vowel (On_V). The glottal events labelled based on the transillumination data are: the onset of glottal opening (On_G), the maximum glottal opening (Mx_G) and the offset of glottal opening (Off_G). Calculations were made of the time intervals between various combinations of these events based on the transillumination data (Table 1).

Name of variable	*Interval*
Closure duration	Or_R – On_C
Aspiration duration	On_V – Or_R
Total duration	On_V – On_C
Glottal opening duration	Off_G – On_G
Interval Or_R to Mx_G	Or_R – Mx_G
Mx_G	———

Table 1. List of variables used in the experiment

The acoustic events were determined by visual inspection using Praat. Consonant onset was defined in the spectrogram as the end of F2 in the vowel preceding the stop. The release was determined based on a sudden increase of energy in the spectrogram. The onset of the following vowel was determined as the beginning of F2. This vowel onset corresponds to the end of aspiration. Aspiration duration was measured as positive VOT but the focus was not on the begining of voicing of the following vowel but rather on the end of aspiration [3].

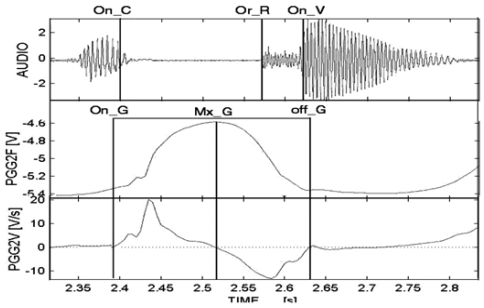

Figure 2. Illustration of the variables used in the PGG experiment

The glottal events were determined algorithmically using the velocity calculation of the transillumination curve. Glottal on- and offsets were defined by using a 5% threshold criterion on the velocity signal (PGG2V in Figure 2 above).

3. RESULTS

3.1. Acoustics

The following durations which could be involved in the single *vs.* geminate distinction were computed: closure duration, VOT, and total stop duration. Closure duration, shown in figure 3 below, is a highly significant correlate of singleton/geminate distinction ($p<0.0001$. SD = 8.10 for singletons and 19.9 for geminates) For dentals our measurements showed that closure duration varies between 35 to 60 ms for singletons and between 145 to 205 ms for geminates. For velars, the duration varies between 40 to 60 ms for singletons and 135 to 155 ms for geminates.

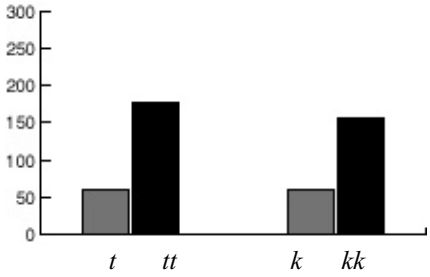

Figure 3. Mean closure durations (ms) for singleton and geminate stops.

Aspiration duration, illustrated in Figure 4, is not a significant criterion for distinguishing between single and geminate stops ($p=0.21$. SD = 9.44 for singletons and 8.88 for geminates) For dentals our measurements showed that aspiration duration varies between 45 to 65 ms for singletons and between 35 to 50 ms for geminates. For velars, aspiration duration varies between 45 to 70 ms for singletons and between 45 to 65 ms for geminates.

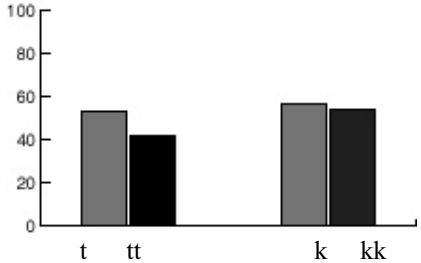

Figure 4. Mean VOT (aspiration) (ms) for singleton and geminate stops.

Hutters [4] has compared aspiration durations of different languages and found a significant reciprocal correlation between closure duration and aspiration duration. Languages having a longer closure duration (e.g. Swedish and English) have a shorter aspiration duration than languages having shorter closure durations (e.g. Danish and Hindi). Our acoustic and PGG data show that this is not the case in Berber, since geminates, which have a considerably longer closure duration have virtually identical aspiration durations than singletons.

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The last acoustic parameter, total stop duration, is shown in Figure 5 to be a highly significant and consistent correlate of the single/geminate oppsoition ($p<0.0001$) like the closure duration. Geminates have a total duration which is more than twice the duration of singletons. This parameter is not an independant variable since it is entirely attributable to closure duration.

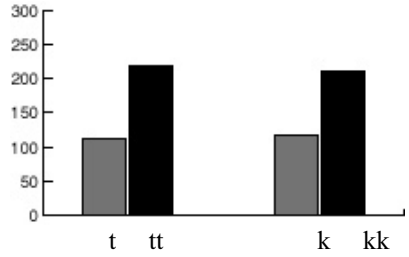

Figure 5 : Results for mean total durations for singletons and geminates.

3.2. Transillumination

A close examination of fiberoptic and transillumination data has shown that the patterns of glottal area obtained by these two methods were practically identical, both in terms of duration and degree of glottal opening. The timing of oral-glottal coordination however cannot be adequately accounted for by the fiberoptic experiment since the filming rate is only 25 frames per seconde. For these reasons, only the data obtained by transillumination (with a frequency of 200 Hz) will be discussed below.

We shall first consider the only non temporal variable measured in this experiment. The maximum glottal opening is measured in arbitrary units, since the light intensity can not be calibrated.

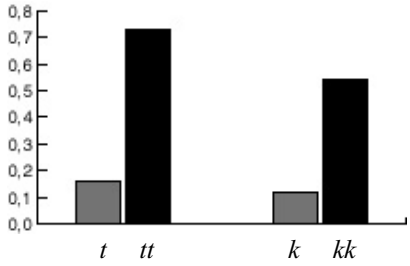

Figure 6. Results for maximum glottal opening for singletons and geminates (arbitrary units).

As is shown in figure 6, the maximum glottal opening for geminates is larger than for singletons. Across all the recordings, geminates are produced with a larger maximum opening of the glottis than singletons. This difference is not categorial (presence *vs*. absence of glottal opening) but rather one of degree. It is generally argued that the degree of glottal opening is a reliable means for distinguishing between aspirated and unaspirated stops, aspirated stops having larger glottal opening than unaspirated ones [1, 5, 6]. But this parameter alone cannot account for aspiration in TB, since singletons which have a smaller glottal opeing are also aspirated.

In several studies based on fiberoptics and photoglottography it has also been observed that there is a larger maximum aperture in the glottal gestures of singleton velar stops compared to labials or dentals [4, 6]. Our PGG data, as well as the fiberoptic filmings, did not show such a difference. Mean values of maximum glottal opening for velars are shown in Figure 6 to be slightly smaller than for dentals. This is in accordance with the observation of Löfqvist [7] who suggested that such a high level for velars is probably due to artifactual influence from vertical movements of the larynx. He recommended that the transducer be placed below the cricoid cartilage. This is the method we adopted in this experiment.

In Figure 7, it can be seen that glottal opening duration, like the parameters maximal glottal opening, closure duration and total duration, is a consistent correlate of the singleton-geminate distinction. Glottal opening is longer in geminates than stops. Glottal opening duration is always longer than total stop duration. This means that glottal opening starts before the onset of oral closure and ends well after the burst.

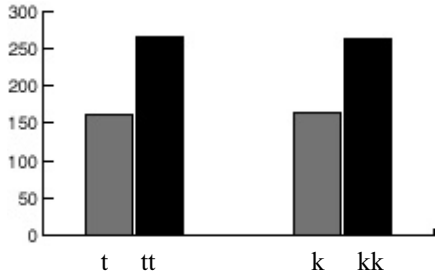

Figure 7. Results for mean glottal opening durations for singletons and geminates.

The interval between peak glottal and oral release opening is significantly higher for geminates than for single stops as illustrated in figure 8. For dentals, this interval varies between 0 to 10 ms for singletons and between 55 to 120 ms for geminates. For velars, the interval varies between –10 to 20 ms for singletons and between 55 to 70 ms for geminates.

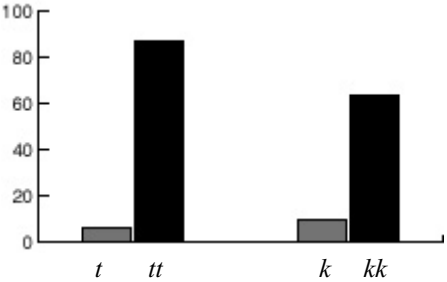

Figure 8. Results for the interval between peak of glottal opening and oral release.

One important topic in relation to this observation concerns the correlations between the timing of glottal opening and aspiration. A number of papers about aspiration focus on the timing between

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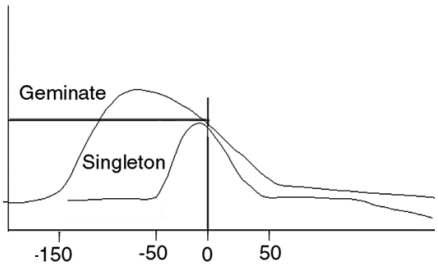
oral explosion and the peak glottal opening as the controlling factor of aspiration. This parameter is considered as a reliable cue for distinguishing aspirated, with a peak glottal opening timed around the oral release, from unaspirated stops, where the peak glottal opening is timed well before the oral release. Löfqvist in several writings points out that this timing between laryngeal and oral events is a more basic means of distinguishing unaspirated from aspirated stops than the size of glottal opening [8, 9]. Our results show that although geminates are realized with a peak glottal opening timed well before the oral release, they are still aspirated just like singletons which are produced with a peak glottal opening timed around the burst. Clearly, timing alone cannot adequately account for aspiration in TB. It seems to be safe to assume along with Kim [10] that aspiration is a function of the degree of glottal opening at stop release. Figure 9 below, which is arranged so as to show the glottal opening of a minimal pair involving a geminate and a singleton stop, shows that the size of glottal opening at stop release is nearly identical for both singletons and geminates which may thus explain the fact that aspiration duration for both stops is virtually identical.



Figures 9 : Illustration of the glottal opening during the production of the stops in [ittili] and [itili]. The vertical bar indicates the onset of oral release.

One last observation which can be inferred from the different results drawn so far is that geminates, like singletons, have the form of a single opening and closing gesture with only one single peak. This is in accordance with the observations of Sawashima on Japanese geminate stops [1]. In American English [11], the heteromorphemic geminate *kk* appears to be characterized as well by one single peak although a word boundary intervens within the geminate. A number of differences exist however between TB and these two languages. In American English, the glottal opening is at its maximum around the burst of the geminate. In Japanese, the glottal width of the geminate *kk* is in the same range as its singleton cognate. We have seen that in TB geminates have a larger glottal opening and that the peak of this gesture occurs well before the burst.

4. CONCLUSIONS

In summary, we have investigated the acoustic and glottal characteristics of singleton-geminate contrasts in Tachelhit Berber. We have found that acoustically, the differences in duration between the two stops are fully realized during the closure alone. Aspiration durations are stable across the two categories although they are produced with two different oral-laryngeal timings. Geminates were found to have significantly longer glottal opening durations due to their longer closure duration. They are also different from singletons in terms of glottal opening amplitude. The larger glottal opening for geminates may be considered either as a function of glottal separation duration or as an inherent feature of voiceless geminates which may require a high rate of air flow and build up of oral air pressure. We are currently conducting further instrumental investigations to explain this aspect of dental and velar geminate voiceless stops.

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