Laryngeal adjustments in the production of consonant clusters and geminates in Moroccan Arabic

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Abstract

The laryngeal adjustments in voiceless consonant clusters and geminates in Moroccan Arabic were examined by means of photoglottography. Findings indicate that speech rate and word boundary have an effect not only on the shape of laryngeal abduction-adduction gestures but also on laryngeal-oral coordination.

1. Introduction

The phenomenon of laryngeal coarticulation or coproduction has previously been investigated in various sequences of voiceless consonants for languages such as Dutch, American English, Icelandic, Japanese and Swedish [5, 6, 7, 8, 9; cf. a review, 12]. Recently, the phenomenon has been studied in German [3, 4], Berber [10] and Arabic [13]. The common method used in these studies was transillumination and fiberoptic video recording. One conclusion that comes out from these studies is that glottal opening and closing gestures are produced with a one-, two-, or more-than- two-peaked shape depending on the phonetic nature of the consonant sequence. In English, Icelandic and Swedish, clusters of voiceless fricative + voiceless plosive generally show a one-peak pattern as the plosive is unaspirated. When the plosive is accompanied by aspiration or frication noise and the cluster is separated by a word boundary, two separate peaks occur with maximum glottal opening during the fricative and just before stop release. Geminated sequences (e.g. /s#s/) are characterized by one single peak in Dutch, English and Icelandic. Another important finding reported by [8] was that the observable presence of a single peak may actually correspond underlyingly to two separate glottal movements. The authors confirmed this assumption by varying speech rate during the production of /s#t/ in the utterance *Kiss Ted*. Results showed that at slow rates show two separate laryngeal gestures occurred, while at fast rates only a single laryngeal gesture was produced. At intermediate rates, partially overlapping movements were observed.

The present paper aims at studying voiceless consonant clusters and geminates in Moroccan Arabic (MA) in terms of coarticulation at the laryngeal level. MA is characterized by the high frequency of complex clusters and reduced vowels. There are three objectives: 1) to examine how a combination of (two) successive laryngeal abduction-adduction gestures are organized and how they influence one another; 2) to investigate the phonetic effect, if any, of speech rate and word boundary on laryngeal adjustments in the production of different sequences of voiceless consonants.

2. Method

Oral air flow, photoglottographic (PGG) and audio signals were recorded simultaneously on three channels of an instrumentation recorder. PGG was performed noninvasively with a photo-sensor and an LED light source. The latter was placed on the lateral neck to illuminate the laryngeal cavity [14] (This technique allows us to record glottal articulation in both open- and close-vowel environments together with an airflow mask.) Measurements were done manually on a computer. for reasons of space, analysis of only PGG data will be reported here. One adult male native speaker of MA (the author) served as subject. The target words were uttered in a frame sentence “galək ….” (“He told you…”) five times. The subject produced the utterances at two self-chosen speaking rates: slow and fast. By slow rate is meant a normal speaking rate.

χəsˤ tuħilu	/sˤ#t/	"He needs to be inspired"
qəsˤtu ħila	/sˤt/	"He is very cunning"
lmeχ tar	/χ#t/	"the brain has revolted"
lmeχtar	/χt/	"personal name"
nʕəs karim	/s#k/	"Karim slept"
lʕəskari	/sk/	"the soldier"
χəsˤ sˤara	/sˤ#sˤ/	"Sara is needed"
χəsˤsˤara	/sˤsˤ/	"wrong-doer"
χəsˤara	/sˤ/	"what a shame"
ħəs sasu	/s#s/	"he examined the foundations"
ħəssasu	/ss/	"his sensitive (man)"
ħisabu	/s/	"his account"

3. Results

3.1. Effect of word boundary

Figure 1 shows PGG patterns for clusters of voiceless consonants produced medially and across a word boundary at slow rate. It can clearly be seen that the presence of a word boundary requires the occurrence of two separate glottal gestures associated with the fricative and the stop, respectively. A closer comparison of these two laryngeal movements reveals that the amplitude of the first movement was higher than the second (as indicated by the measurement given in Figure 2). Also, the initial glottal abduction is rapid, while the following adduction-abduction movements are rather slow. These facts seem to indicate two important tendencies: attaining maximal glottal opening during the fricative rather than the plosive and skewing of the opening peak to the left in cross-boundary geminates. An explanation for this given in [3, 6] suggests that for fricatives the onset of the abductory movement critically requires a rapid and large glottal area so that airflow can generate the frication source. When this requirement is satisfied, it is not critical to maintain this pattern for the following voiceless consonant.

The timing of the peak glottal opening (PGO) also seems to vary as a function of the word boundary. When the word boundary intervenes within the voiceless sequences /sˁ#t/, /s#k/ and /χ#t/, PGO occurs during the fricative and just before the release of the stop (cf. 3.3. for quantitative data). On the other hand, when /sˁt/, /sk/ and /χt/ are produced medially, one laryngeal gesture occurs. The peak timing of this gesture tends to occur not during the stop period but during the frication noise. It is interesting to note here that plosives in MA are aspirated although they are preceded by fricatives. The tendency to have a two-peak pattern for fricative + aspirated stop combinations in Swedish [11] and English [6] does not apply to MA (cf. a similar result for Berber, [10]). Similar patterns like those for voiceless clusters are also found in geminated sequences /ss/ and / sˁsˁ/, where the presence of the word boundary varies. When /ss/ and /sˁsˁ/ are produced medially only one single glottal gesture is found. However, when a word boundary occurs between /s/ and /s/ or between /sˁ/ and /sˁ/, two consecutive gestures are seen (Figure 1).

3.2. Effect of speech rate

Before we investigate the effect of speech rate on the laryngeal adjustments of the sequences of voiceless segments, we present in Figure 3 the temporal interval between two successive peaks of glottal opening as a function of speaking rate. Speaking rate was indexed by the duration of the interval between the offset of the vowel preceding the first consonant in a sequence and the onset of the vowel following the second consonant in that sequence as in [8].

Figure 3 shows that glottal opening and closing gestures are produced with a one- or two-peaked pattern depending on speech rate. The occurrence of single peak movements is indicated by zero duration for the temporal interval peak- one-to-peak-two. Variation of speech rate is well defined here as there are two separate non-overlapping zones: 1) one peak productions at fast rates with intervowel duration in the range of 150-220 ms; and 2) two peak productions at slow rates with intervowel duration ranging from 460 to 730 ms. The occurrence of one glottal movement at fast rates as opposed to two movements at slow rates applies not only to the clusters /sˁ#t/, /s#k/ and /χ#t/ but also to the geminated combinations /ss/ and / sˁsˁ/ (see Figure 6).

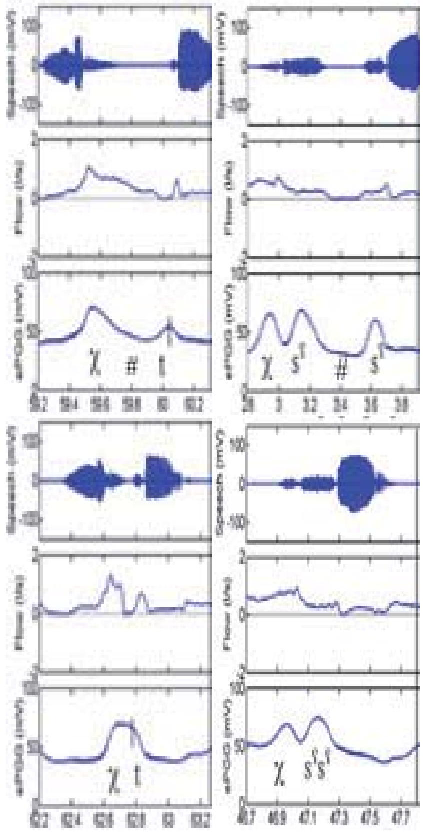

Figure 1: *Production of sequences of voiceless consonants with two laryngeal gestures for /χ#t/ and /sˁ#sˁ/ (top); and with a single laryngeal gesture for /χt/ and /sˁsˁ/ (bottom).*

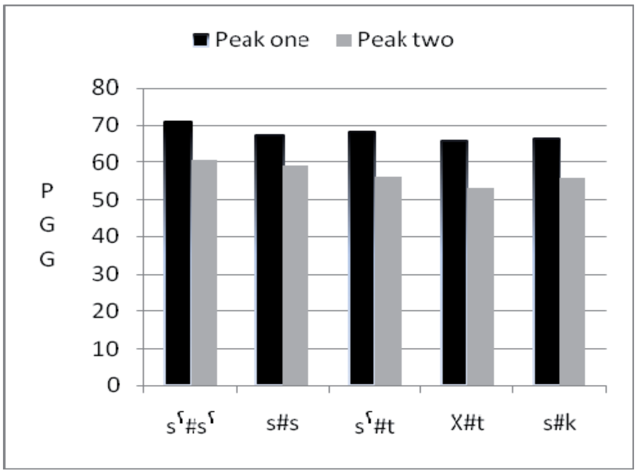

Figure 2: *The amplitude of peak glottal opening in arbitrary units during the initial consonant in the sequence of voiceless consonants across word boundary.*

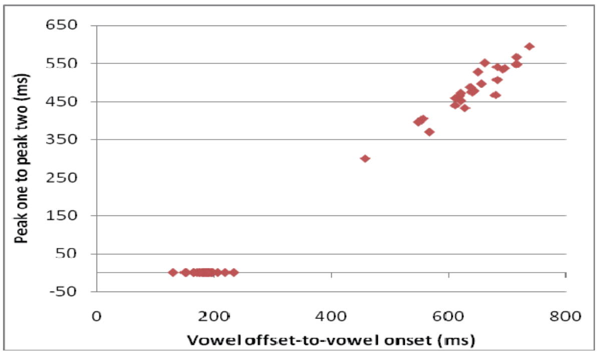

Figure 3: *Peak to peak interval as a function of vowel-offset-to-vowel-onset.*

3.3. Laryngeal-oral coordination

We have already noted in § 3.1 the effect of word boundary on the coordination between laryngeal and oral articulation. Figure 4 compares the location of peak glottal opening (PGO) for the different sequences of voiceless consonants produced at a slow rate. PGO location was calculated in % as follows: 100 x position of PGO relative to fricative onset / duration of fricative. For the geminated sequences /ss/ and /sˤsˤ/, PGO generally occurs in the first half of the frication phase indicating that these geminates are articulated with an early devoicing gesture. On the other hand, for singleton /s/ and /sˤ/, PGO is attained just before the consonant mid-point. As for the clusters /sˤt/, /sk/ and /χt/, the location of PGO varies as a function of the word boundary. When these sequences span a word boundary, PGO is just before mid-frication, similar to singleton /s/ and /sˤ/. The absence of the boundary, however, produces a delaying of PGO, which occurs later than mid-frication. A similar peak delay, which is probably due to the perturbing effect of the adjacent plosive, was reported to occur for final /st/ in English by Saltzman & Munhall (1989) cited in [12]. [2] also notes that PGO may be delayed in fricative-stop sequences compared to single fricatives. Other researchers [3, 10] have also indicated that the location of PGO is not systematically aligned with the midpoint of the fricative. The peak of glottal opening is delayed even more when the sequence of fricative + plosive is produced at fast rates as illustrated by Figure 5. The peak occurs in the second half of the frication phase and sometimes towards the frication end. This result is in agreement with the finding reported in [3]. So it seems that the location of PGO is not systematically aligned with the midpoint of the fricative and this contradicts with a rule that formulates laryngeal-oral coordination as follows: "if a fricative gesture is present, coordinate the PGO with the mid-point of the fricative…[2: 446]"

We have already seen that PGG data revealed a difference in the number of laryngeal gestures for sequences of voiceless /sˤt/, /sk/ and /χt/, as a function of speech rate and presence or absence of a word boundary. Variation in these two factors produces differences in the glottal condition at the oral release of the stop following the fricative. When one single laryngeal gesture is produced for both the fricative and the plosive, PGO occurs during frication noise and the glottis starts closing before the release of the stop. In this case, it is not possible to identify a specific opening gesture for the plosive, the laryngeal articulation of which is a continuation of the adduction phase for the adjacent fricative. On the other hand, when two consecutive gestures are produced for the fricative and the stop, respectively, a different laryngeal timing pattern occurs. The glottis is open at the stop release and PGO is attained around that release. To be more specific, in 3 cases, PGO was synchronized with the stop release, while in the remaining cases, PGO is achieved a little before the release. On average PGO leads by 10 ms in /χ#t/, 20.6 ms in /sˤ#t/, and 27 ms in /s#k/.

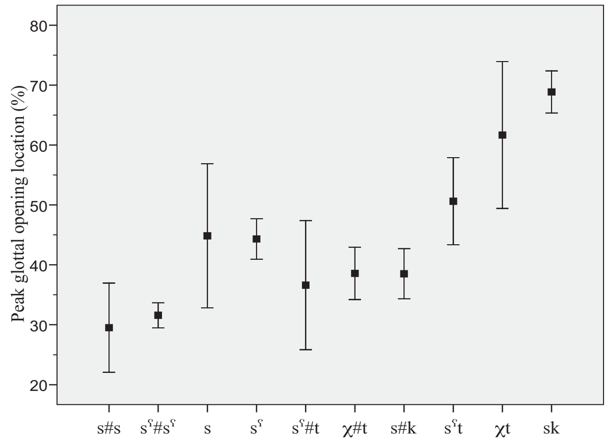

Figure 4: *Location of peak glottal opening in % relative to the duration of the fricative (slow rate production).*

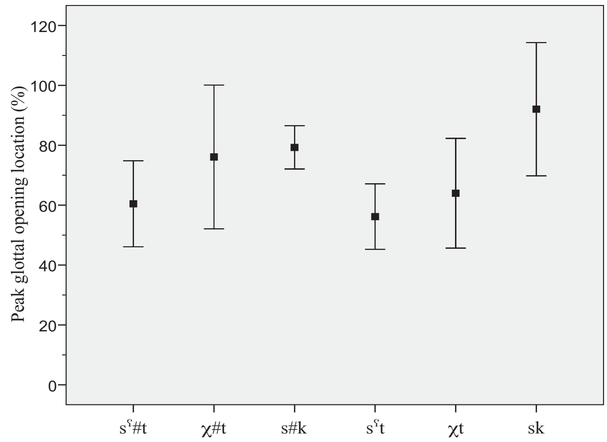

Figure 5: *Location of peak glottal opening in % relative to the duration of the fricative (fast rate production).*

Another interesting aspect of laryngeal adjustment concerns the production of the schwa /ə/ between voiceless obstruents. It was observed in most productions of consonant clusters that the glottis tended to begin opening while the vocal folds were still vibrating for the schwa /ə/ preceding fricatives.

Generally abduction for the fricatives was found to be synchronized with the onset of this vowel. An explanation for this devoicing gesture is that since the two consonants in the cluster are voiceless, the presence of the schwa would require a rapid change from a very abducted glottis to a brief moment of voicing for the vowel to, again an abducted glottis for the voiceless stop.

4. Conclusion

The overall patterns of laryngeal adjustment in sequences of voiceless consonants reported in the present paper are in general agreement with previous studies. Speech rate and word boundary have an effect not only on the shape of laryngeal abduction-adduction gestures but also on laryngeal-oral coordination. An explanation for such effects would be that the airflow during voiceless fricatives and stops is mainly controlled by the oral constriction. The requirement for the glottal control is to maintain the glottis area greater that the oral constriction area so that the frication noise generated at the oral constriction becomes dominant over aspiration noise at the glottis. This is why the glottal gesture can "freely" vary in function of presence-or-absence of word boundary and of speaking rate as the requirement for the glottis is relatively weak. For voiceless stops, however, to generate the dominant aspiration noise, the glottis or rather the vocal folds must be controlled after the release so that the glottal area is smaller than the oral constriction area.

5. Bibliography

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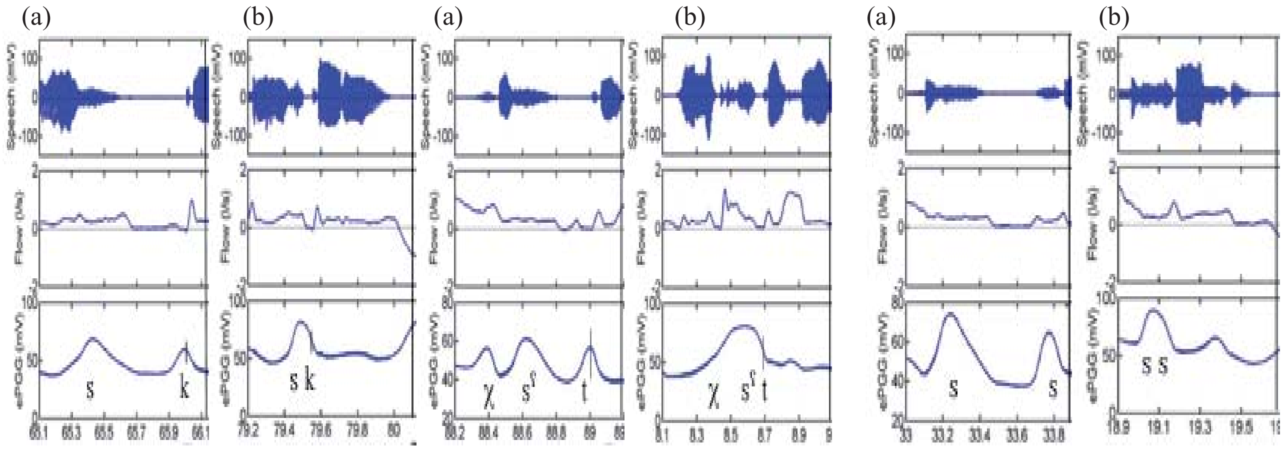

Figure 6: *Productions of sequences of voiceless consonants with (a) two laryngeal gestures at slow rate and (b) a single laryngeal gesture at fast rate for /s#k/, /sˤ#t/ and /s#s/, respectively. The small lines on the glottal movements for the plosives correspond to the release.*