Aerodynamic Study of Moroccan Arabic Guttural Consonants

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ABSTRACT

Pharyngeal pressure P and oral air flow U were measured in Moroccan Arabic (MA) guttural continuant consonants in the context aCa, and values were compared with those of [s z] and [l r]. The voiced laryngeal [ɦ] and the voiced epiglottal [ʢ] have the highest and lowest values of U respectively, which was expected since the former is breathy and the latter laryngealized. U is substantially higher in the voiceless epiglottal [ʜ] and uvular [χ] than in [s]. This result suggests that the primary articulation of MA epiglottal consonants is most likely at the level of the glottis and/or aryepiglottic sphincter, and that the supraglottal area is larger in the voiceless uvular than in [s]. P is much higher in uvular consonants than in [l r]. This disagrees with Halle's analysis according to which uvular consonants are sonorants and must be produced without a rise of P.

1. INTRODUCTION

This paper presents a descriptive study of the aerodynamic properties of Moroccan Arabic (MA) guttural consonants, as shown in Table 1. Its goal is to obtain information about glottal and supraglottal apertures allowing us to induce the place and manner of articulation of these consonants, especially the epiglottals whose production mechanisms have not been well understood in the past.

	Uvular	Epiglottal	Laryngeal
Voiceless	[χ]	[ʜ]	
Voiced	[ʁ]	[ʢ]	[ɦ]

Table 1: Chart of Moroccan Arabic guttural consonants.

To our knowledge, very few studies have presented measurements bearing on the aerodynamic properties of Arabic guttural consonants. None of them has carried out intraoral or pharyngeal pressure measurements, and most have been concerned with a subset of guttural consonants. In the present study, we provide pharyngeal pressure (P) and oral airflow (U) measurements of all the MA guttural consonants.

The MA sonorants [l r] and fricatives [s z], whose aerodynamic and articulatory properties are relatively well established, were also included in this study. Aerodynamic properties of these consonants are compared with those of MA guttural consonants to verify whether the latter are more like the sonorants [l r] or the obstruents [s z]. Notice that at the phonological level, the guttural consonants are analyzed as [+sonorant] by some authors and as [-sonorant] by others. In this study we discuss a deduction from Halle's analysis according to which the guttural consonants must be specified as [+sonorant] [6, 7, 15]. Indeed, Halle considers guttural consonants as [-consonantal], and the *[-consonantal, -sonorant] combination as impossible. Halle proposes the following definition for the feature [±sonorant] [6, p. 208]: "Sonorant sounds are produced without a pressure build-up inside the vocal tract; non-sonorant sounds are produced with pressure in the vocal tract that exceeds the ambient atmospheric pressure". If gutturals are sonorants, then, this definition predicts that they and other sonorants must be produced with no rise in intraoral pressure.

Before presenting the aerodynamic data, we summarize the main physiological properties of MA guttural consonants as reported in our previous investigations [15, 16, 17]. In Zeroual [1] it was shown that MA uvular consonants have a major constriction between the dorsum and the anterior part of the velum in the context iCi and between the dorsum and the uvula in the contexts aCa and uCu. The maximal opening of the glottis was larger in [χ] than in [s], and the glottis is not as closed during [ʁ] as during [z]. In Zeroual and Crevier-Buchman [17] it was demonstrated that the two MA guttural consonants which are generally analyzed as pharyngeal consonants [ħ ʕ] are in fact epiglottals [ʜ ʢ]. These consonants have a constriction between the tip of the epiglottis and the posterior pharyngeal wall (i.e. an epiglottopharyngeal constriction) and an anterior-posterior compression of the aryepiglottic sphincter. This latter gesture adds a further articulation between the base of the epiglottis and the tip of the arytenoids, which is narrower in [ʢ] than in [ʜ]. The glottis is wide open in [ʜ] and closed in [ʢ]. The latter consonant is always produced with laryngealized voicing. However, our previous observations did not allow us to determine whether the frication noise in [ʜ] is produced at the level of the glottis, the aryepiglottal sphincter, or the epiglottopharyngeal constriction. MA has only the one continuant laryngeal consonant [ɦ], which is always voiced and breathy. In the production of this consonant the anterior part of the glottis is closed while the posterior part stays open, and there is no intrinsic supraglottal

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constriction [15].

2. METHOD

Pharyngeal pressure P, oral airflow U, and acoustic data were recorded simultaneously with the Physiologia Workstation [12]. Three Moroccan Arabic native speakers, aged 26 to 38, participated in this experiment, two for the P measurements and three for the U measurements.

P was measured using a small flexible tube (35cm long) inserted through the nostril, and U using an oral mask which was placed against the mouth. The audio signal was recorded with a microphone placed just behind the oral mask. The P, U, and audio data were digitalized and analyzed using the Phonedit program.

During the recording the speakers read a list of meaningful and non-sense words five times in the carrier phrase [gal……ʒuʒ marat]. All test items had the form [ma+CaC+ʃ] where [CaC] is the stem and [ma… ʃ] the morpheme of negation. The test items were [masalʃ] « to flow » [mazadʃ] « to add » [maχafʃ] « to be afraid » [maʜarʃ] «to worry » [maɦaʒʃ] «to be rough (sea) » [maʕafʃ] « to hate » [maʁabʃ] « to go away » [marabʃ] «to collapse » [malamʃ] « to blame ».

3. RESULTS AND DISCUSSION

C	P (cmH_2O)		U (cm^3/s)	
	M	S.D.	M	S.D.
[s]	8,30	1,33	160, 54	49,72
[z]	6,10	1,18	109,47	27,32
[χ]	7,81	1,29	420,80	120,53
[ʁ]	4,45	0,71	138,33	39,62
[ʜ]	3,82	1,00	552,67	203,10
[ʕ]	0,22	0,25	63,00	7,51
[ɦ]	1,23	0,33	798,67	134,63
[l]	0,60	0,27	98,00	26,78
[r]	2,71	1,14	97,33	33,70

Table 2: Mean (M) and standard deviation (S.D.) values of P and U in consonants pronounced in the context aCa. M(U) = 15 measures (5 tokens x 3 speakers). M(P) = 10 measures (5 tokens x 2 speakers).

Table 2 contains mean values of P and U in the consonants [s z χ ʁ ʜ ʕ ɦ l r] produced in the context aCa.

A one-factor ANOVA shows that the mean values of P depend on the nature of the consonant [$F(8, 81) = 104.80$, $p<0.0001$]. Post hoc analysis (PLSD of Fisher) shows that: [s] has the highest value of P which is significantly higher than in all other consonants ($p<0.0001$) with the exception of [χ] ($p=0.24$). The P value of [χ] is significantly higher than that of [ʁ] ($p<0.0001$). [ʕ] has the lowest value of P which is significantly lower than those of [ɦ] ($p=0.018$) and [s z χ ʁ ʜ r] ($p<0.0001$) but not that of [l] ($p=0.36$). The P value of [z] is significantly higher than those of [ʁ ʕ ɦ r l] ($p<0.0001$) and that of [ʁ] is significantly higher than those of [ʕ ɦ r l] ($p<0.0001$).

A second one-factor ANOVA shows that the values of U vary significantly from one consonant to anther [$F(8, 126) = 113.10$, $p<0.0001$]. Post hoc analysis (PLSD of Fisher) shows that: [ʕ] has the lowest value of U which is significantly lower than that of [s χ ʜ ɦ] ($p<0.01$), but not than that of [l r ʁ z]. The U value of [s] in not significantly higher than that of [l] ($p=0,07$), [r] ($p=0,07$) or [z] ($p=0,14$). [ɦ] has the highest value of U which is significantly higher than that of all other consonants ($p<0.0001$). The U values of [ʜ] and [χ] are significantly higher than that of [s] ($p<0.0001$). U is significantly higher in [χ] than in [ʁ] ($p<0.0001$).

P in [s z] is much higher than in [l r], which is in accord with previous studies [11]. P is also significantly higher in [r] than in [l], due to the fact that MA [r] is a tap consonant produced with a very short but nearly complete constriction in the vCv context (see annexe). These results do not entirely agree with Halle's definition [6] of the feature [+sonorant] since the MA sonorants [l r] are produced with a small rise of P (see also [11]).

The U values of [z l r] are low and not significantly different [8]. In fact, values of U are known to vary with respiratory effort and the resistance to the stream of air at one or more points in the vocal tract [8]. Notice that the great majority of experimental studies have found that variation of subglottal pressure in stop consonants, which is mainly correlated with the magnitude of the respiratory effort, generally depends on suprasegmental factors (accent, position in the sentence, word, syllable) and not the voiced vs. voiceless or aspirated vs. non-aspirated nature of the stop consonants itself (see [9] for a review). Based on these observations as well as those of Moon et al. [10], we suggest that during the production of consonants in general and in the aCa context in particular, respiratory effort does not vary since the prosodic context has been kept constant. The low U values of [z l r] are thus attributed to the cross-sectional area of the glottal constriction which is smaller than that of the supraglottal constriction in these consonants. Indeed, during the production of continuant consonants and at the release of stop consonants, the complete adduction of the vocal folds constitutes the most important resistance to the air stream [4]. Notice that the U value of [s] is higher than those of [z l r], but not significantly so, this result suggests that the cross-sectional area of the supraglottal constriction of [s] is very small.

P is about the same in [χ] and in [s], and P in [ʁ] is significantly higher than in [l r]. These results are not in accord with Halle's view [6] that continuant uvulars are sonorants and must therefore have P values which are not significantly different from those of (other) sonorants. U in [χ] is also much higher than U in [s] even though their P values are not different.

This regularity shows that the cross-sectional area of the supraglottal constriction is more important in [χ] than in [s].

Even though [ɦ] is voiced, its U value is the highest [1]. As was mentioned above, the phonation type of [ɦ] is not modal voice but breathy voice. Fiberscopic observations [15, 16] show that in the production of [ɦ] in [vɦv], the anterior part of the glottis is closed while its posterior part is open. In another study [3] it was found that in the production of breathy voice as opposed to modal voice, the vocal folds are more relaxed and the glottal cycle has a larger open quotient and a smaller closed phase which is reached less rapidly. These differences result in a decrease of glottal resistance during breathy voice compared to modal voice, which explains the high U value of [ɦ]. Notice that P is slightly positive in [ɦ], even though this consonant does not have a supraglottal constriction. This unexpected result may be due to the high volume velocity of the airstream in this sound, forcing it to be partly channeled through the tube used for the P measurements, which has only one lateral hole [5].

[ʕ] is laryngealized and has the lowest values of P and U. During laryngealized voice, the vocal folds are tenser, the closed phase of their glottal cycle is reached more rapidly, and the open quotient is smaller [3]. Glottal resistance is therefore greater in laryngealized voice than in modal voice, which explains the low values of U and P in [ʕ].

The articulatory mechanisms involved in the production of [ʜ] must be kept in mind in interpreting the P and U values of this consonant. As was pointed out above, [ʜ ʕ] have two supraglottal constrictions: the first between the tip of the epiglottis and the posterior pharyngeal wall (epiglottopharyngeal articulation), and the second between the base of the epiglottis and the arytenoids (aryepiglottal articulation). Our U traces show two regular peaks in [s] but only one in [ʜ] [see also 1, 14]. The distribution of these peaks depends on the coordination of the glottal and supraglottal articulations [11], and may be understood as showing that the glottal and aryepiglottal cross-sectional areas are smaller than the epiglottopharyngeal one. In Zeroual [15, 16] we also observed that the glottal and aryepiglottal constrictions in [ʜ] are larger than the glottal constriction in [ɦ]. However, U is higher in [ɦ] than in [ʜ]. It seems that the turbulence in [ʜ], which is more strident than in [ɦ], is produced at the level of the glottis or the aryepiglottic sphincter constriction and enhanced by the base of the epiglottis which acts analogously to the teeth in the production of the sibilants [s ʃ]. All these observations show that airflow is more turbulent and escapes less freely in [ʜ] than in [ɦ]. P is also higher in [ʜ], which is unexpected since our P measurements were taken above the epiglottopharyngeal constriction. This rise of P in [ʜ] can be attributed, as in [ɦ], to the higher value of U and to the form of the tube used for the P measurements.

4. CONCLUSIONS

Our results show that the consonant [ɦ] has the highest value of U, which was expected since this consonant is produced with breathy voice and has no supraglottal constriction. [ʜ] has also a high value of U, which is however lower than that of [ɦ] even though [ʜ] is voiceless. The evidence from the present study and our previous articulatory investigations suggests that this unexpected pattern can be explained if we consider that the major articulation for the consonants [ʜ ʕ] is at the level of the glottis or the aryepiglottic sphincter. Notice that [ʕ] has the lowest value of U and P, which is explained by the fact that this voiced consonant is laryngealized. P in [χ] is much higher than in [s], while P in [χ] is as high as in [s]. Combining these two observations we can say that the supraglottal constriction of [χ] is larger than that of [s]. Notice that P in [χ ʁ], which is substantially higher than in [l r], constitute a clear departure from interpretations of Halle's analysis. Indeed, according to Halle [6, 7] uvulars and the rest of guttural consonant are sonorants and must be produced without rising of P.

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REFERENCES

[1] A. Butcher, and K. Ahmed, "Some acoustic and aerodynamic characteristics of pharyngeal consonants in Iraqi Arabic," *Phonetica* 44, pp. 156-172, 1987.

[2] J.C. Catford, *Fundamental Problems in Phonetics*, Edinburgh University Press, Edinburgh, 1977.

[3] D.G. Childer, C.K. Lee, "Vowel quality factors: analysis, synthesis, and perception," *JASA*, vol. 90, pp. 2394-2410, 1991.

[4] R.P. Dixit & W.S. Brown, "Peak magnitudes of oral air flow during Hindi stops (plosives and affricates)," *Journal of Phonetics* 13, pp. 219-234, 1985.

[5] W.K. Haag. "Oral air flow and airflow in German stop consonants," *Phonetica* 34, pp. 31-39, 1977.

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[6] M. Halle, “Phonological features”, in W. Bright (ed.) *International Encyclopedia of Linguistics*. Oxford University Press, N.Y., pp. 207-212, 1992.

[7] M. Halle, “Feature geometry and feature spreading,” *Linguistic Inquiry*, vol. 26, pp. 1-46, 1995.

[8] N. Isshiki and R. Ringel, “Airflow during the production of selected consonants,” *Journal of Speech and Hearing* Research, vol. 9, pp. 498-518, 1966.

[9] A. Löfqvist, “A study of subglottal pressure during the production of Swedish stops,” *Journal of Phonetics*, vol. 3, pp. 175-189, 1975.

[10] J.B. Moon, J.W. Folkins, A.E. Smith, and S. Luschei, “Air pressure regulation during speech production,” *JASA*, vol. 94, pp. 54-63, 1993.

[11] K. N. Stevens, “Articulatory-acoustic-auditory relationships,” in *The Handbook of Phonetic Sciences*, W.J. Hardcastle and J. Laver, Ed., USA and Oxford: Blackwell, Cambridge, pp. 462-506, 1997.

[12] J.D. Subtelny, J.H. Worth, and M. Sakuda, “Intraoral pressure and rate of flow during speech,” *J. of Speech and Hearing* Research, vol. 7, pp. 233-244, 1964.

[13] B. Teston and B. Galindo, “A diagnostic and rehabilitation aid workstation for speech and voice pathologies,” *4th Eurospeech Proceedings*, pp. 1883-1886, 1995.

[14] M. Yeou and S. Maeda, “Uvular and pharyngeal consonants are approximants : An acoustic modeling and study,” *Proceedings of the XIIIth International Congress of Phonetic Sciences, Stockholm*, vol. 2, pp. 586-589, 1995.

[15] C. Zeroual, “A fiberscopic and acoustic study of « guttural » and emphatic consonants of Moroccan Arabic. *Proceedings of the XIVth International Congress of Phonetic Sciences*, San Francisco, pp. 997-1000, 1999.

[16] C. Zeroual, *Propos controversés sur la phonétique et la phonologie de l’arabe marocain*. Thèse de Doctorat, Université de Paris 8, 2000.

[17] C. Zeroual and L. Crevier-Buchman, “L’arabe marocain possede des consonnes épiglottales et non pharyngales,” XXIV^{es} Journees d’Etude sur la Parole, 24-27 June 2002, Nancy, France, pp. 237-240, 2002.

ANNEXE

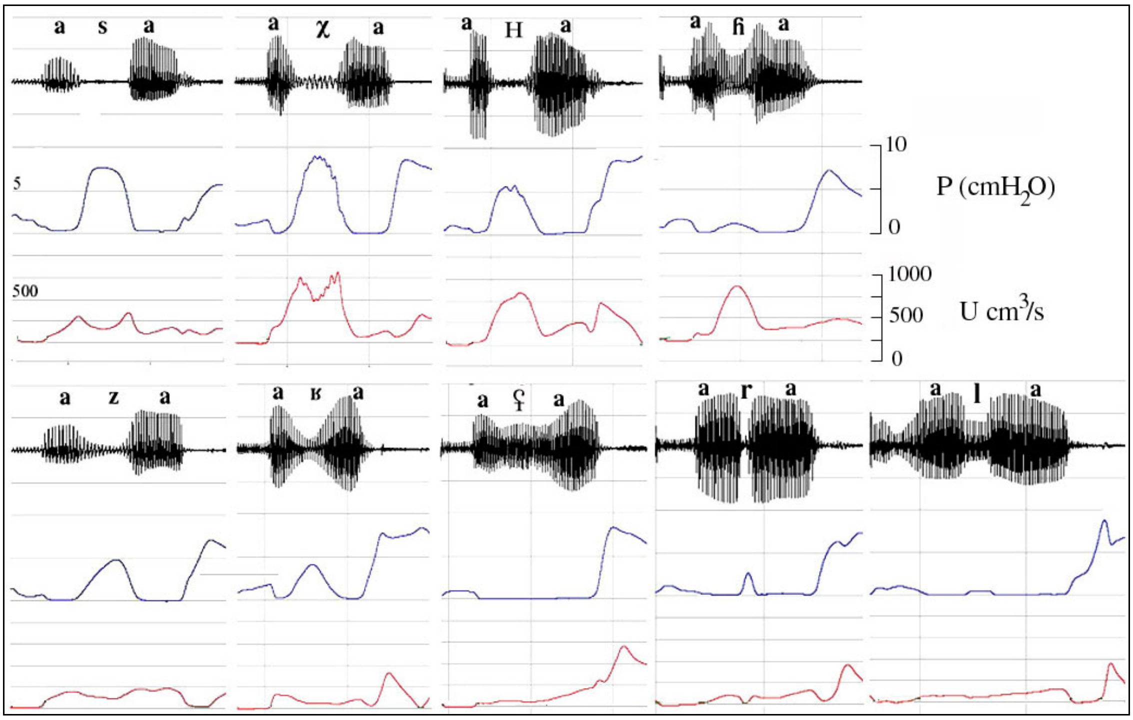

Figure 1 : Traces of audio, pharyngeal pressure P, and oral air flow U of aCa in the words [masalʃ], [maχafʃ], [maʜar], [maɦaʒʃ], [mazadʃ], [maʁabʃ], [maʕafʃ], [marabʃ], [malamʃ].