INFLUENCE OF ARTICULATOR AND MANNER ON STIFFNESS

Kevin D. Roon[1,2], *Adamantios I. Gafos*[1,2], *Phil Hoole*[3], *Chakir Zeroual*[4,5]

[1]New York University, Dept. Linguistics; [2]Haskins Labs; [3]IPS, Munich University; [4]University Sidi Mohamed Ben-Abdellah-Morocco; [5]Laboratoire de Phonétique et Phonologie, Univ. Paris III

Email: kdroon@nyu.edu

ABSTRACT

Comparatively little is known about the role that the speed of different articulatory movements plays in speech production. Using 3D Electromagnetic Articulography, the present experiment analyzes articulatory data from Moroccan Arabic for independent influences of oral articulator and manner on stiffness, an important property of articulator movement. Tongue back movements were found to have lower stiffness than those of the tongue tip or lower lip. No differences based on manner were found. Relevance to phonetics and phonology is discussed.

Keywords: stiffness, manner, primary articulator, electromagnetic articulography, Moroccan Arabic.

1. INTRODUCTION

Knowledge about the speed of various speech movements—especially, how "quick" one articulatory movement is compared another—is crucial for a better understanding of the temporal aspects of speech production, yet relatively little is known about this in articulatory phonetics. An important task is to determine the relevant measures of the speed of articulatory movements. The peak velocity achieved during movement is one possibility. It is not an ideal measure, however, since in experimental data [9] and some models of speech production [14], an articulator's peak velocity increases with physical displacement.

Stiffness is a measurement of articulator movement that characterizes speed independent of its displacement, defined in (1) in section 2.4 below. In the motor control literature, it is an abstract control parameter with a complex of consequences in the time-space behavior of the system [7]. For an intuitive idea of what stiffness is, imagine two springs alike in all aspects other than the material they are made of. If each spring is extended the same distance, the one that returns to its resting position faster has higher stiffness.

Browman and Goldstein [4] speculated that stiffness "could be the basis for natural classes… [G]estures for stops…might be stiffer than those for fricatives". Some authors have also speculated that there may be a relationship between stiffness [3] or velocity [12] and specific articulators. Little phonetic research has been conducted to see whether these speculations are supported.

The relative speed of articulatory movements has received recent attention in phonology. It has been argued that articulatory velocity differences between consonants in a cluster result in differences in overlap, causing different patterns of place assimilation [12], but a precise notion of velocity is not formally spelled out. Stiffness may be the relevant property in these cases.

Stiffness is formally incorporated into the task-dynamics model used in Articulatory Phonology [2], and is the parameter that has the greatest effect on the duration of articulator movement [5]. Manipulating stiffness has the effect that gestures with higher stiffness result in shorter duration movements [14]. Researchers have investigated the role of stiffness in various prosodic effects, including final lengthening [8], gestural timing across prosodic boundaries [5], and intonation [1]. Stiffness may also be a crucial consideration for production models of coarticulation, e.g. DAC of Recasens *et al.* [15].

2. EXPERIMENT

Given the importance of stiffness to phonetics and phonology, the present experiment used articulatory data from a larger study of Moroccan Arabic to determine whether primary oral articulator and manner of articulation were reliable influences on stiffness of articulator movement.

2.1. Participants

Two male native speakers, ages 38 and 28, of the Oujda dialect of Moroccan Arabic were recorded.

2.2. Materials

All stimuli were real words presented in Arabic script within a carrier phrase. The carrier phrase for Speaker 1 was *gal* _____ *tɨlt mɨrrat* 'he said _____ three times'. This occasionally resulted in the tongue tip gesture of the [l] of *gal* merging with word-initial tongue-tip gestures in some tokens. These tokens were excluded from all analyses. To avoid the problems of merged tongue tip gestures found with Speaker 1, the carrier phrase for Speaker 2 was changed to *galha* _____ *hnaya* 'he told him _____ here'. The consonants of interest occurred in two phonetic contexts where the preceding segment could be controlled for, since it is the stiffness of the closing phase of the articulator movement that is of interest (see Analyses). The first context was word-initial consonants occurring before a vocoid, e.g., the [g] in *gɨdra* '(cooking) pot'. These consonants were always preceded by the first word of the carrier phrase, and therefore the preceding segment was constant for each speaker. The second was word-internal consonants occurring after [a], e.g., the [b] of *sabga* 'to be ahead of'. Some adjustments were made to the stimuli between the recording sessions for Speaker 1 and Speaker 2, resulting in different numbers of tokens per speaker.

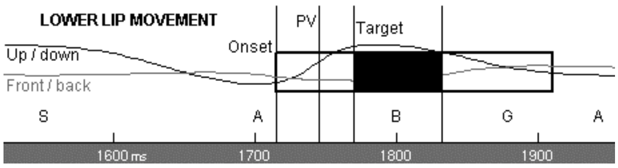
2.3. Procedure

Articulatory recordings were made as each speaker read five randomizations of stimuli from a computer screen. The movement of speech articulators was tracked with 3D Electromagnetic Articulography [11] at 200 Hz sampling rate. EMA receivers included for analysis in the current study were attached to each speaker's lower lip (LL), tongue tip (TT), and tongue back (TB).

2.4. Analyses

Articulator movements were calculated using a MATLAB-based program for analyzing EMA data ("MVIEW"). The EMA receiver used to delineate each consonantal gesture was the one corresponding to the articulator that stops or critically constricts the airflow for that consonant, i.e., its "primary oral articulator": LL for [b], TT for [d, t, r, l, s, z, ʃ], and TB for [g, k]. For each articulator movement, the closing phase of the articulator was identified as the period from onset of movement toward the target closure (the first point immediately preceding the target closure at which the articulator exceeded 20% of the peak velocity of that articulator in that utterance) to the achievement of the target constriction (the subsequent point at which the articulator velocity fell below 20% of its peak velocity). Peak velocity (cm/sec) and maximum displacement (cm) of the articulator were calculated by MVIEW for the closing phase of each articulator movement, shown in Figure 1.

Figure 1: Example of Onset, timepoint of peak velocity (PV), and Target in the closing phase of the lower lip movement made for one token of [b] in *sabga* 'to be ahead of', Speaker 1.



Stiffness was calculated [13] for the closing phase of each articulator movement as in (1).

(1) $$\text{Stiffness} = \frac{\text{peak velocity (cm/sec)}}{\text{maximum displacement (cm)}}$$

Two sets of consonants were analyzed: stops grouped by articulator (LL [b], TT [d, t], TB [g, k]), thereby holding manner constant; and tongue tip consonants grouped by manner (liquids [ɾ, l], stops [d, t], fricatives [s, z, ʃ]), thereby holding articulator constant. The liquid [ɾ] is a rhotic flap in this language. Within each data set each token was classified as belonging to one of two phonetic contexts, word-initial or word-internal after [a]. The number of stimuli in each analysis are shown in the relevant figures in the Results section below.

2.5. Results

2.5.1. Primary oral articulator

The results of the analyses of stiffness by primary oral articulator for Speaker 1 are shown in Figure 2. Univariate ANOVAs were performed separately for each speaker with articulator and phonetic context as independent variables and stiffness as the dependent variable. There was a main effect of articulator on stiffness [$F(2, 275)=4.685$, $p<0.01$] and no effect of context [$F(1, 275)=2.030$, $p=0.155$]. The interaction of articulator and context was not significant ($p=0.350$). Tukey HSD post hoc analyses showed that the effect of articulator was attributable to TB having significantly lower stiffness (mean=1.44, SD=0.47) than both TT (mean=2.21, SD=2.48, $p<0.001$) and LL (mean=2.06, SD=0.39, $p<0.05$). The stiffness of

Figure 2: Stiffness of closing phase movements for stops, by primary oral articulator for Speaker 1.

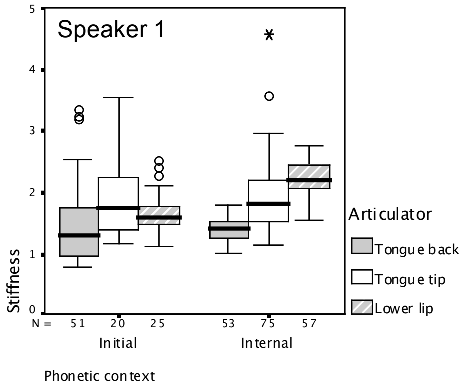
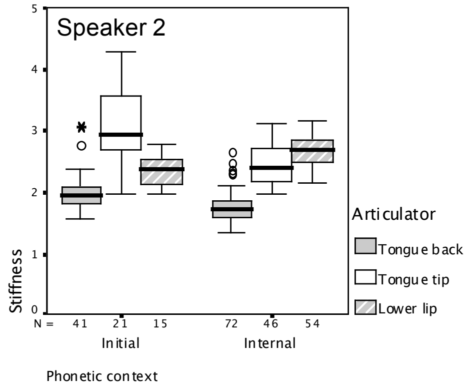


Figure 3: Stiffness of closing phase movements for stops, by primary oral articulator for Speaker 2.



TT and LL were not significantly different from each other (*p*=0.764).

The results for Speaker 2 were similar to those for Speaker 1, as shown in Figure 3. There was a main effect of articulator on stiffness [$F(2, 243)= 25.873$, $p<0.001$] and no effect of context ($F<1$). The interaction of articulator and context was not significant ($p=0.220$). Post hoc analyses showed that TB had significantly lower stiffness (mean= 1.85, SD=0.31) than both TT (mean=3.15, SD=2.00; $p<0.001$) and LL (mean=2.61, SD=0.27; $p<0.001$). Unlike Speaker 1, TT had significantly higher stiffness than LL ($p<0.01$).

2.5.2. Manner of articulation

The effects of manner on stiffness for Speaker 1 and 2 are shown in Figures 4 and 5, respectively. Absence of data for certain cells reflects stimuli adjustments made for the larger study between recording sessions. Univariate ANOVAs were performed separately for each speaker, with manner of articulation and phonetic context as independent variables, and stiffness as the dependent variable. For Speaker 1 there was no main effect of manner on stiffness ($F<1$) nor of context ($F<1$). There was no interaction of manner and context ($p=0.462$).

For Speaker 2, however, there was a main effect of manner on stiffness [$F(2, 134)=6.213$, $p<0.005$]. There was no main effect of context [$F(1, 134)= 0.002$, $p=0.967$]. There was no significant interaction between manner and phonetic context ($p=0.853$). Tukey HSD post hoc analysis showed that the main effect of manner was due to fricatives having higher stiffness (mean=5.61, SD=4.72) than both stops (mean=3.15, SD=1.99; $p < 0.001$) and liquids (mean=3.58, SD=0.61; $p<0.005$). Liquids were not significantly different from stops.

It should be noted that the fricatives for this speaker show much more variability in stiffness than the other manners, as can be seen in Figure 5. Comparison of the individual fricatives shows that [ʃ] had much higher and more variable stiffness than [s, z]. Given the more posterior place of articulation for [ʃ] (postalveolar, not alveolar) it

Figure 4: Stiffness of tongue-tip closing phase movements by manner of articulation for Speaker 1.

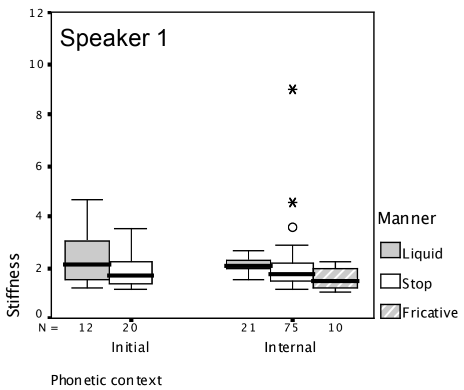
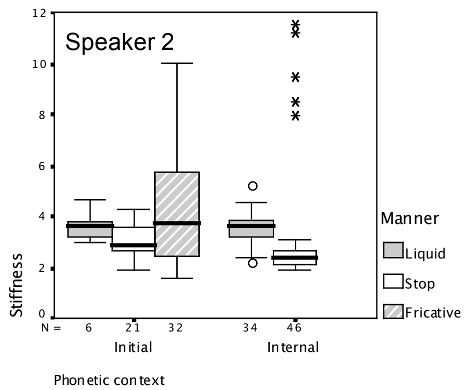


Figure 5: Stiffness of tongue-tip closing phase movements by manner of articulation for Speaker 2.



may be that the tongue blade rather than the tongue tip should be considered the primary oral articulator, which may make the results for [ʃ] not directly comparable to [s, z].

3. DISCUSSION

Two strong generalizations can be drawn from these results. The first is that the stiffness associated with TB movements is significantly lower than either of the other two articulators, regardless of context and speaker. This lower stiffness corresponds with the greater mass of the tongue back compared to the other articulators. For Speaker 2, the TT had the highest stiffness of all three articulators. Lack of a reliable difference in stiffness between consonants LL and TT across speakers is consistent with another study [10] that found no stiffness differences between the closing gestures of [p] and [t] for nine speakers producing nonsense syllables. The lower stiffness of the TB compared to other articulators may be a factor in patterns of place assimilation [12], as well as the observed pattern that velar consonants are the least likely to change their place of articulation [6].

The second generalization is that there is little evidence in these data for a relation between stiffness and manner of articulation.

These results raise questions as to how else stiffness may be involved in linguistic processes. Stiffness manipulation may be the basis of lexical durational contrasts (singletons vs. geminates). While the present data do not contain such stimuli, this question can be further investigated Moroccan Arabic since it has consonantal durational contrasts. We are currently investigating laryngeal and oral articulations from this point of view.

It is also worth noting that phonetic context was never a significant factor in any of these analyses. Stiffness is intended to be a context-independent measure of the speed of an articulatory movement. These results provide evidence that stiffness is a successful measure for this purpose.

4. CONCLUSIONS

Stop consonants with the tongue back as primary oral articulator were shown to have reliably lower stiffness than stops with primary oral articulators of lower lip or tongue tip. These results may support a phonetic grounding for some patterns of assimilation, most notably the resistance of velars to being targets of place assimilation [6], [12]. Stiffness is not reliably associated with differences in manner of articulation in these data. Stiffness does seem to be a good context-independent measurement of the "velocity profile" of articulator movement. Models of speech production that incorporate stiffness (or velocity profiles in general) need to factor in an influence of primary oral articulator, but not of manner. Differences in stiffness between consonants in a cluster, especially due to different articulators, may partially account for regular differences in overlap.

5. REFERENCES

[1] Beckman, M.E., Edwards, J. 1992. Intonational categories and the articulatory control of duration. In: Tohkura, Y., Vatikiotis-Bateson, E., Sagisaka, Y. (eds), *Speech Perception, Production and Linguistic Structure*. Tokyo: OHM Publishing Co., 356-375.

[2] Browman, C.P., Goldstein, L. 1986. Towards an articulatory phonology. *Phonology Yearbook* 3, 219-252.

[3] Browman, C.P., Goldstein, L. 1989. Articulatory gestures as phonological units. *Phonology* 6, 201-251.

[4] Browman, C.P., Goldstein, L. 1990. Gestural specification using dynamically-defined articulatory structures. *J. Phonetics* 18, 299-320.

[5] Byrd, D., Saltzman, E.L. 1998. Intragestural dynamics of multiple prosodic boundaries. *J. Phonetics* 26, 173-199.

[6] de Lacy, P. 2002. The formal expression of markedness. PhD dissertation. Dept Linguistics, U Mass, Amherst.

[7] Cooke, J. D. (1980). "The organization of simple, skilled movements," in Tutorials in motor behavior, edited by G. E. Stelmach, and J. Requin (North-Holland, Amsterdam).

[8] Edwards, J., Beckman, M.E., Fletcher, J. 1991. The articulatory kinematics of final lengthening. *J. Acoust. Soc. Am.* 89, 369-382.

[9] Guenther, F.H. 1995. Speech sound acquisition, coarticulation, and rate effects in a neural network model of speech production. *Psych. Review* 102, 594-621.

[10] Hertrich, I., Ackermann, H. 2000. Lip-jaw and tongue-jaw coordination during rate-controlled syllable repetitions. *J. Acoust. Soc. Am.* 107, 2236-2247.

[11] Hoole, P., Zierdt, A., Geng, C. 2003. Beyond 2D in articulatory data acquisition and analysis. *Proc. 15th ICPhS* Barcelona. p. 265-268.

[12] Jun, J. 2004. Place assimilation. In: Hayes, B., Kirchner, R., Steriade, D. (eds), *Phonetically Based Phonology*. Cambridge: Cambridge University Press, 58-86.

[13] Munhall, K.G., Ostry, D.J., Parush, A. 1985. Characteristics of velocity profiles of speech movements. *Journal of Experimental Psychology: Human Perception and Performance* 11, 457-474.

[14] Ostry, D.J., Munhall, K.G. 1985. Control of rate and duration of speech movements. *J. Acoust. Soc. Am.* 77, 640-648.

[15] Recasens, D., Pallarès, M.D., Fontdevila, J. 1997. A model of lingual coarticulation based on articulatory constraints. *J. Acoust. Soc. Am* 102, 544-561.