MANDIBLE AS SYLLABLE ORGANIZER

N. Rhardissse and C. Abry
Institut de la Communication Parlée, INPG/Université Stendhal
BP 25 F-38040 Grenoble Cedex 9

ABSTRACT

A correlation between adherence of consonants to vowel nucleus and mandibular height has been proposed by Lindblom and colleagues [1-4]. To support this proposal [i,a] and [s,l] in VC(:)V items were recorded for 2 French and 2 Moroccan subjects. Results indicate a mandibular order increasing from low to high as follows [a]<[l]≤[i]<[s], and a perfect overall correlation between normalized *relative* coarticulability (σ/m) and mean height of the jaw.

1. INTRODUCTION

In his proposals arguing for economy of speech gestures, Lindblom [1] drew a hypothesis to explain the formation of complex syllables from VCV behaviour. Consonant propensity to cluster in syllables could depend on their jaw height that determines coarticulatory compatibility: what we call *coarticulability*. This relationship corresponds to the intuition that consonants are more assimilated by vowels than the reverse. At the same time it explains both propensity for consonants to settle more or less further apart from the vowel within the syllable (like *s* in *straight*) and their propensity to coarticulate maximally (*relatively*) enough when the same segments occur close to the vowel (in *sane*).

Results from Swedish [1] were reinterpreted by [2]. On the basis of English data, she pointed out that vowels *and some consonants* adopt jaw height to accommodate other consonants, typically [s] (to support an aerodynamic rationale for this behaviour, see [5]). Finally data from Swedish and English were examined [3] : jaw height measurements, depicted in percentage of maximum opening relative to clench (for absolute values, see [4]), are displayed on Fig. 1 for [f,b,t,d,s,n,l,r,k,h] realized in [a-a], [e-e] and [i-i] contexts. An overall correlation (r=.80) is clearly visible between height and coarticulability ranks. The latter is expressed by the coefficient of variability (σ/m), which compensates better for the fact that overall absolute variance for high segments like [s] is smaller than for low segments, say [a] (the «very high and invariant [*sic*]» jaw position, claimed for [s,ʃ] in Palestinian Arabic and French by [5] in token-to-token measurements, is not contradictory, since σ/m is not taken into account). In other words σ/m captures the overall accommodation of the consonant to the vowel in the opening scale.

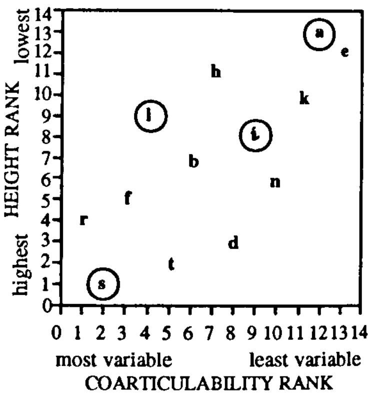

Fig.1– Ranks of mean height (m) and coarticulability (σ/m) for consonants and vowels (from % jaw opening, see text). English and Swedish combined (adapted from [3]). Test segments chosen hereafter are within circles.

In this investigation we will use Moroccan Arabic and French data to support Lindblom's hypothesis, portrayed in the frame of the [a]–[s] height scale, with a particular emphasis on the «meeting-point» of the nearest consonant to the highest vowel. Hence the test segments we chose according to previous results were [i,a] for extreme vowel magnitude in height, and [s,l] for the consonants, [l] being the closest consonant to [i] (following [4], opening values are in mm: [l]=5.50, [b]=4.86 and [i]=5.29). Arguments for comparing [l] and [i] or [j] heights can be taken from their proximity in the different proposals of sonority scales by phonologists [6, 7] and from the frequent confusion of [l] and [j] in language acquisition [8,9]. As concerns coarticulability, we will not consider the most coarticulable «guttural» [5] consonants [ʔ,h,ħ,ʁ,χ] and [q,k]. A recent study of jaw movements in 6 degrees of freedom [10] reports an interesting case of *pure translation* in a [li] syllable, with no rotation component as for [s] (and [ʃ,r,t,k,p,f]). But [l] is clearly among the consonants that resist to jaw lowering in the [a] context. Hence we will show that the correlation between coarticulability and height holds where it is not trivial, i.e. for consonants who display some coarticulation resistance of their own to vowel opening.

2. METHOD

To show up [l] and [s] jaw heights, in contact with high [i] and low [a], and their mutual coarticulation resistance, three factors were manipulated: consonantal gemination (simple *vs.* double consonants), rate (conversational *vs.* fast) and context ([i-a],[a-i],[a-a],[i-i], for consonants,[-l-],[-ll-],[-s-],[-ss-], for vowels). Arabic stimuli (9 words, 7 logatemes) were inserted in the carrier interrogative sentences [a:l —] (he says). French sequences are preceded by first name «Al» and contained significant combinations to obtain comparable sequences. Arabic stimuli were preceded by a little glottalization. Note that Moroccan Arabic gemination is tautomorphemic and French heteromorphemic.

Two native speakers of Fez Arabic (sisters A and N, present author) and two French (C woman and F man) recorded sequences in an anechoic room, in random order, producing 12 repetitions by item at two speaking rates (conversational and fast).

The tracking system was a mandibular kinesiograph (Myotronics K5AR) with a magnet fixed to the lower incisors, moving in the linear portion of the kinesiograph [11]. Vertical displacement was recorded on an FM tape. Analyses are based on 9 (out of 12) correctly produced utterances.

Jaw vertical position and audio signals were digitized in stereo at 8 kHz with Audiomedia (Macintosh). Then edited and measured using Signalyze™. Mandibular signal was undersampled at 500 Hz. Numerical signal values were converted in mm (owing to the calibration carried out by bite blocks when recording). Jaw height was measured for each segment at about its acoustic centre, relative to the minimum minimorum mandibular opening of each subject. A total of 3,456 values were thus obtained.

3. RESULTS

We will examine here only a global description for each subject, based on mean values and standard deviation to portray his/her height and coarticulability scales, without regrouping segments on the basis of the results of ANOVA for main effects (gemination, rate, context). This in order to compare our results with the overall correlation given in Fig. 1 by [3]. For all subjects mean values and standard deviations were normalized which gives us the general trend for Arabic and French. Our results will be annotated progressively in relation to English and Swedish ones.

3.1. Height and coarticulability: individual strategies

	a	l	i	s
A	7.17 *0.150*	4.62 *0.227*	3.74 *0.172*	2.50 *0.262*
N	11.96 *0.159*	9.32 *0.122*	7.51 *0.177*	5.05 *0.188*
C	10.33 *0.198*	9.18 *0.136*	6.73 *0.308*	2.45 *0.475*
F	8.95 *0.231*	6.18 *0.251*	5.86 *0.233*	3.56 *0.333*

Table 1– Mean jaw opening (mm) and *coefficient of variability* (σ/m) for test consonants and vowels. Arabic (A and N) and French (C and F) subjects.

Table 1 shows that mean jaw opening range is clearly subject-dependent (from 4.67 mm for A to 7.88 mm for C), but that on the mandibular height scale all subjects get the same ranking increasing from low to high: [a]<[l]<[i]<[s]. Thus this order is the same for Arabic, French and Swedish. Separate results taken from [3] show that velarized English [ɫ] is slightly higher than [i] (i.e. in mm: [a]=9.25, [ɫ]=4.53, [i]=5.33, [s]=2.50). In summary, an ordering [a]<[l]≤[i]<[s] corresponds to the proximity of [l] et [i], in Arabic (for A more than for N) and in French (only for F).

Coarticulability displays two different behaviours, which are not language-dependent since N (Arabic) and C (French) display the same ranking *vs.* A and F (Fig. 2), who show the same pattern as English and Swedish combined (Fig. 1). In fact the overall correlation found by [3] is fairly well reproduced, since segments are set not farther from one rank off the positive diagonal (r=0.80). [s] has the most stable coarticulability rank *vs.* [l], which changes most, [i] and [a] being in between.

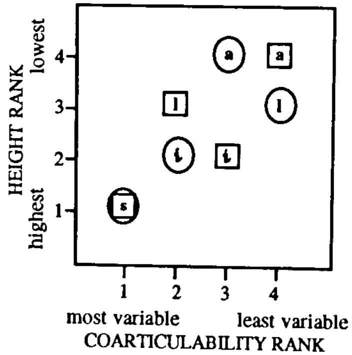

Fig.2– Height and coarticulability ranks for subjects A and F (squares) and N and C (circles).

3.2. Height and coarticulability: general trend

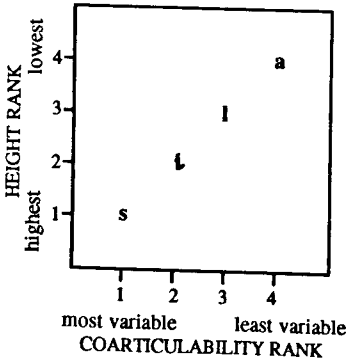

Fig.3– Ranks of normalized (see text) height and coarticulability for the four test segments. Arabic and French combined.

To get the general behaviour of the four test segments [a,l,i,s], we normalized mean height for each speaker with the following formula: $m_{norm}\%=100(m-m_{min})/(m_{max}-m_{min})$. σ/m is normalized in two steps : $\sigma_{norm}\%=\sigma/(m_{max}-m_{min})$; then $\sigma_{norm}\%/m_{norm}\%$. (Note that the convention of an origin normalized at 0% for [s] gives corresponding coefficients of variability tending towards ∞).

The means $m_{norm}\%$ and $\sigma_{norm}\%/m_{norm}\%$ across the four subjects are displayed on Fig. 3, showing a perfect correlation between normalized height and coarticulability for both languages combined. Our results support Lindblom's hypothesis, for whom scales of mandibular position and variability can be used as indexes to account for the economy of the syllable.

4. DISCUSSION

Jaw height scale, [a]<[l]≤[i]<[s], resists to language and speaker difference – and, just to mention results to be published, resists also to metrical ([l] *vs.* [ll]; [s] *vs.* [ss]) and speech rate changes.

The correlation between mandibular height and coarticulability scales, that globally holds for speakers of languages as dissimilar as Arabic, English, French and Swedish can meet optimization principles. In motor control for large and small targets (like Fitt's law). But also in the articulatory-to-acoustics mapping [12], knowing that acoustics is fairly well related to log-area ratios [13], a sensitivity in which the mandible takes part, synergetically, even if it is not the end effector of the constriction [5].

More generally, such an approach could renew the question of the constituency of the syllable, provided that it is reconsidered at the control level for the production of the opening-closing modulation of the basic cycle of speech, for which the mandible is the carrier articulator.

In this frame, questions addressed by phonologists concerning the sonority scales and syllable structure could be reformulated. So the highest mandibular position for [s], makes [s]+plosive clusters not so weird. Processed both by Germanic metric [14] and French pig Latin (*verlan* [15]), they are too recurrent to be confined to borrowings from elite languages [16]. Thus, in mandibular height terms they don't need extrasyllabicity [7] or contextual processing by harmony phonology [17].

As concerns the proximity of [l] and [i] or [j], one can ask whether there is some empirical rationale to such a refined scale as the one proposed for Meknes Arabic [18]: [a]<[j]<[r]<[ʕ]<[l,n,w]<[d,s]<[t]; knowing that [l] and [i] are so closed in the mandibular scale (not to speak of other sonority proposals from De Brosses [16] to [6], and not to mention acquisition data again [8,9]). More necessary: the traditional paucity in degrees in the vowel sonority scale has been repaired up to a point following [19] in Berber.

Of course one could state, with Ohala that: "'Sonority' [does] not exist" [16]; and of course our interest for proposals [1] that consider the mandible as a *syllable organizer* accounts for the modulation principle in speech. But before giving up phonological constructs, more knowledge has to be gathered on the dynamic behaviour of the jaw, at least in our test segments, especially the nearest ones, [i] and [l], following emerging pioneering work on the control of *the* carrier articulator [10].

Acknowledgement: To T. Lallouache, R. Kies and A. Arnal, for the time they took to assess our signals ; to C. Smith and C. Stoel-Gammon, for their relevant references; to A. Diana for English.

5. REFERENCES

[1] Lindblom, B. (1983), "Economy of speech gestures", In P. F. MacNeilage (Ed.), *The production of speech*, (pp. 217-245), N.-Y.-Heidelberg: Springer Verlag.

[2] Keating, P. (1983), "Comments on the jaw and syllable structure", *J. Phonetics*, vol. 11, pp. 401-406.

[3] Keating, P., Lindblom, B., Lubker, J., & Kreiman, J. (1990), "Jaw position in English and Swedish VCVs", *U.C.L.A. W.P.*, vol. 74, pp. 77-95.

[4] Keating, P., Lindblom, B. Lubker, J., & Kreiman, J. (1994), "Variability in jaw height for segments in English and Swedish VCVs", *J. Phonetics*, vol. 22, pp. 407-422.

[5] Lee, S., Beckman, M., & Jackson, M. (1994), "Jaw targets for strident fricatives", *I.C.S.L.P.*, pp. 37-40.

[6] Van Coetsem, F. (1979), "The features 'vocalic' and 'syllabic'", in I. Rauch and G. F. Carr (Eds.), *Linguistic Method: Essays in Honor of Herbert Penzl*, (pp. 547-556), The Hague: Mouton.

[7] Clements, G. (1989), "The role of the sonority cycle in core syllabification", in J. Kingston, & M. E. Beckman (Eds.), *Between the Grammar and Physics of Speech*, Papers in Laboratory Phonology 1, (pp. 283-333), Cambridge: Cambridge University Press.

[8] Lappin, K. (1981), "Analyse de variation : les liquides chez des enfants bilingues", *Recherches linguistiques à Montréal*, vol. 17, pp. 75-87.

[9] Studdert-Kennedy, M., & Goodell, W. (1992), "Gestures, features and segments in early child speech", *Haskins SR*, vol. 111/112, pp. 89-102.

[10] Bateson, E., & Ostry, D. (in press), "An analysis of the dimensionality of jaw movement in speech", *J. Phonetics*.

[11] Kies, R. (1992), *Étude des signaux mandibulaires. Plan de phase dans les occlusives*, Rapport Interne I.C.P., Grenoble.

[12] Stevens, K. (1989), "On the quantal nature of speech", *J. Phonetics*, vol. 17, pp. 3-45.

[13] Fant, G. (1960), *Acoustic theory of speech production*, The Hague: Mouton.

[14] Kuryłowicz, J. (1971), "A problem of Germanic alliteration". In M. Barahmer, S. Helsztyński and J. Kryżanowski (Eds.), *Studies in language and literature in Honour of Margaret Schlauch*, New York : Russell & Russell.

[15] Azra, J.-L., & Cheneau, V. (in press), "Jeux de langage et théorie phonologique. Verlan et structure syllabique du français", *Journal of French Language Studies*.

[16] Ohala, J. (1992), "Alternatives to the sonority hierarchy for explaining segmental sequential constraints", *Papers from the Parasession on the Syllable*. Chicago: Chicago Linguistic Society, pp. 319-338.

[17] Laks, B. (in press), "A connectionist account of French syllabification", *Lingua*.

[18] Heath, J. (1987), *Ablaut and ambiguity : phonology of a Moroccan Arabic dialect*, New York: State University of New York Press.

[19] Dell, F., & Elmedlaoui, M. (1985), "Syllabic consonants and syllabification in Imdl'wn Tashlhiyt Berber", *Journal of African Languages and Linguistics*, vol. 7, pp. 105-130.