An investigation of lingual coarticulation resistance using ultrasound

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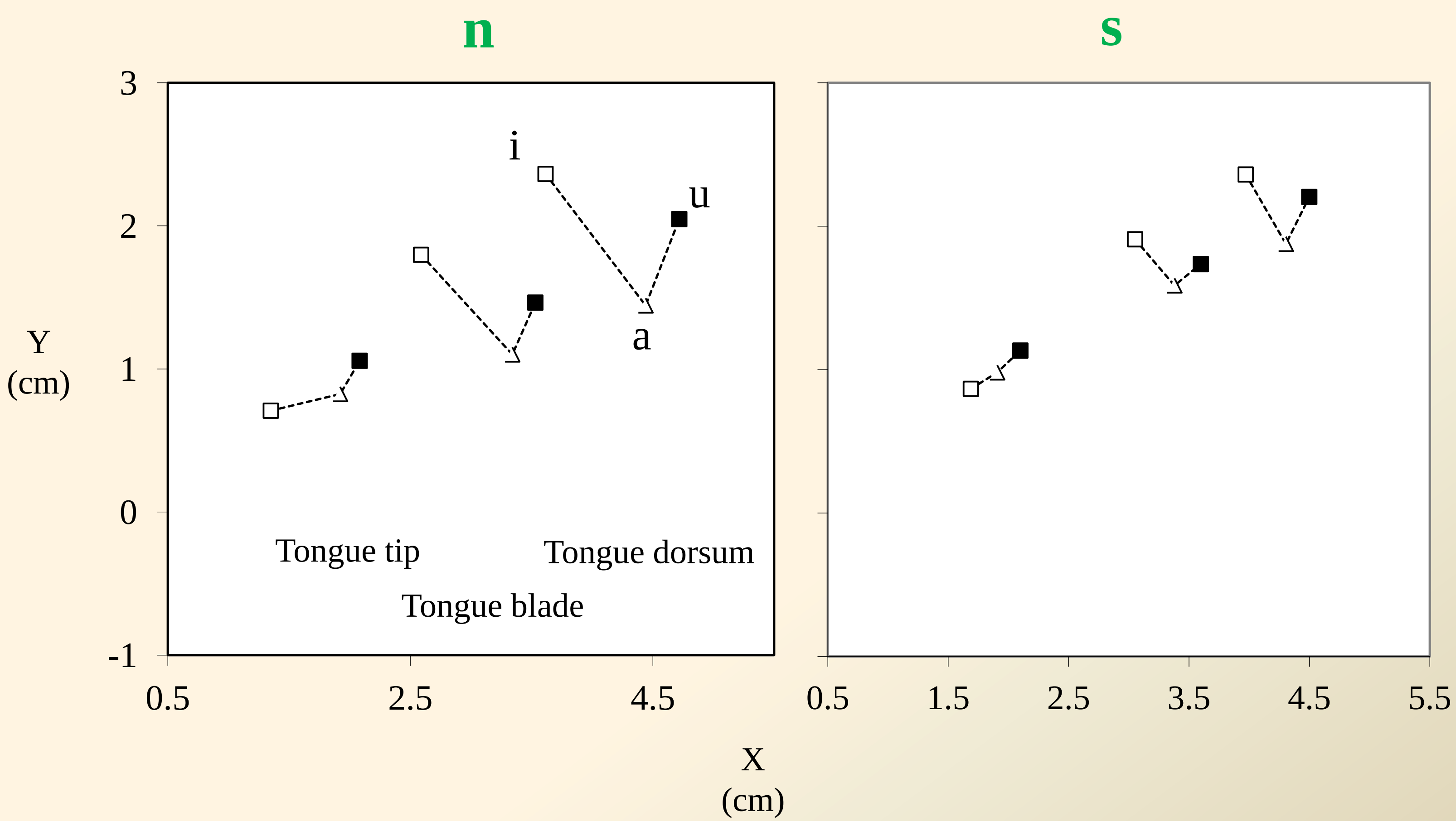
INTRODUCTION

The goal of the present investigation is to study **tongue body coarticulatory resistance (CR)** for Catalan **front lingual** consonants and vowels in **VCV sequences** using ultrasound.

Coarticulatory resistance for a given phonetic segment is a measure of degree of articulatory variability as a function of phonetic context such that

the less variable, the more resistant.



EMA data taken from Recasens & Espinosa (2009)

Ultrasound has advantages with respect to EPG and EMA in that it allows measuring lingual coarticulation not only at the palatal and alveolar zones but at the **velar and pharyngeal zones** as well.

Catalan consonants and vowels subject to analysis

Dentoalveolar Cs	/t/	
	/d/	(realized as [ð] intervocalically)
	/n/	
	/l/	(‘clear’ rather than ‘dark’)
	/s/	
	/ɾ/	(tap)
	/r/	(trill)
Alveolopalatal Cs	/ʃ/	
	/ɲ/	
	/ʎ/	
Vowels	/i, e, a, o, u/	

Testing hypothesis

Tongue body coarticulatory resistance should increase with

(1) The formation of a dorsopalatal closure or constriction

(Cs) **palatal > dentoalveolar**
(Vs) **front > low, back rounded.**

(2) Specific manner of articulation demands

(Cs) **trill, fricative > stop, nasal, clear /l/ > approximant**.

Maximal CR		Intermediate CR		Minimal CR
/ʃ, ɲ, ʎ, s, r/	>	**/t, n, ɾ, l/**	>	**/d/ ([ð])**
/i,e/	>			**/a, o, u/**

Are there CR differences

between **/ʃ, ɲ, ʎ/** and **/s, r/**?
among **/t, n, ɾ, l/**?
among **/ʃ, ɲ, ʎ/**?
between low **/a/** and back rounded **/o,u/**?

METHODOLOGY

Recording procedure

Recording material

Symmetrical VCV sequences with all combinations of consonants /t, d, n, l, s, ɾ, r, ʃ, ɲ, ʎ/ and vowels /i, e, a, o, u/ embedded in the Catalan carrier sentence ‘Sap__poc’ “He/she knows ___ little’.

Subjects

2 men (DR, MO) and 3 women (IM, MO, ES), of 30-60 years of age.
Subjects were asked to produce the two syllables with equal degrees of stress.

Sequence tokens

6, except for speaker DR (4).

Ultrasound

Probe attached to a transducer holder under the subject's chin in an Articulate Instruments stabilization device.

Sampling rate= 57 f/s (one ultrasound image every 17.5 ms). All consonants including the alveolar tap /ɾ/ were longer than 20 ms.

Synchronous audio signal sampled at 22050 Hz.

Palate traces were recorded by asking subjects to press the tongue against the palate.

Data analysis

1.Tongue contours at the midpoint of V1, C and V2 were tracked automatically, adjusted manually and exported using the Articulate Assistant Advanced program.

2. Spline points were converted from ***Cartesian coordinates*** into ***polar coordinates*** with origin at X= 86.7 mm/Y=0 mm so as to account for the fact that the tongue surface approximates an arc more closely than a horizontal line.

3. Smoothing spline SSANOVA computation was applied using the gss package with R to find a best fit curve (Gu, 2002, Davidson 2006).

4. Splines for all consonants and vowels for a given subject were rendered ***equally long*** by adjusting their edges.

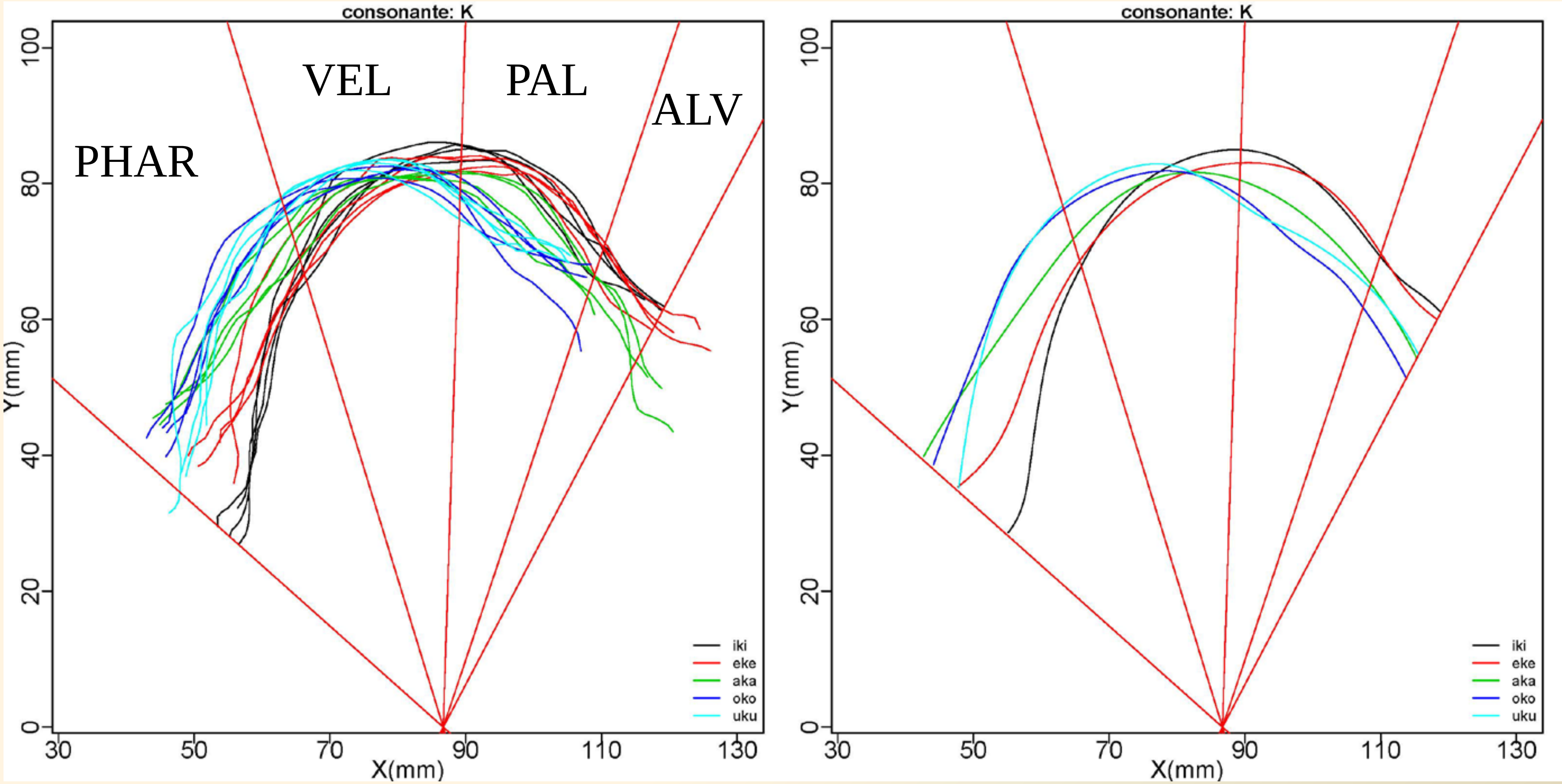
(Procedure: for each spline, we measured the angles whose sides connected the origin of the ultrasound field-of-view to the right and left edges of the spline; of all angles measured, we chose the largest angle at the right edge and the smallest one at the left edge).

5. The splines were subdivided into four portions which corresponded to the ***alveolar (Alv), palatal (Pal), velar (Vel) and pharyngeal (Phar) articulatory zones*** as follows:

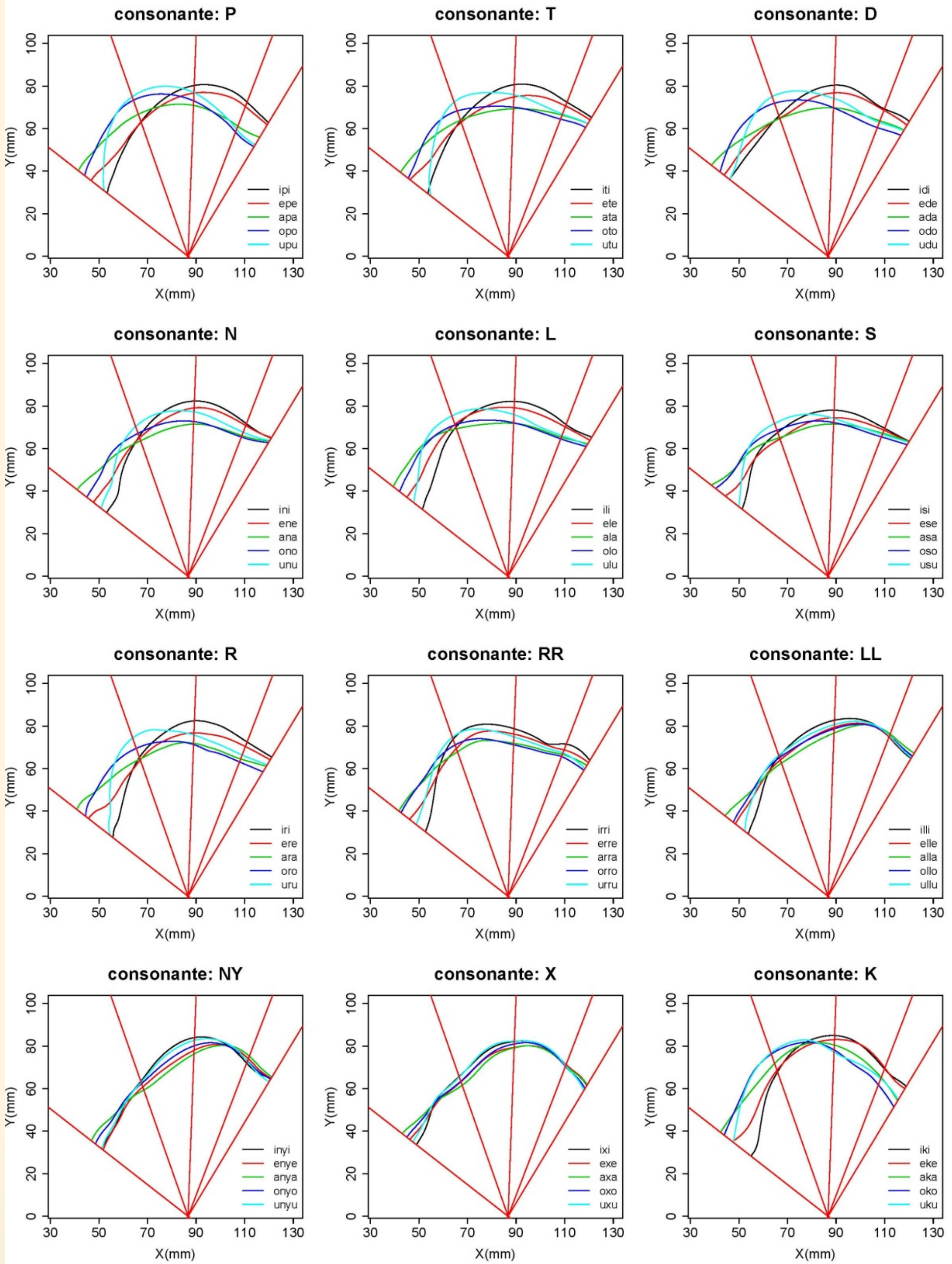
(Alv/Pal boundary) At a spline inflection point located at about the place of articulation for the trill /r/, which is postalveolar in Catalan.

(Pal/Vel boundary) At the Y maximum value for /k/ in the sequence /iki/, which is postpalatal in Catalan.

(Vel/Phar boundary) The velar zone was taken to be 1.26 and 1.51 times longer than the palatal zone for males and females, respectively (Fitch & Giedd, 1999).



For four speakers, the size of the articulatory zones turn out to decrease in the progression pharygeal > velar, palatal > alveolar.



consonante: P
ipi
epe
apa
opo
upu
consonante: T
iti
ete
ata
oto
utu
consonante: D
idi
ede
ada
odo
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consonante: N
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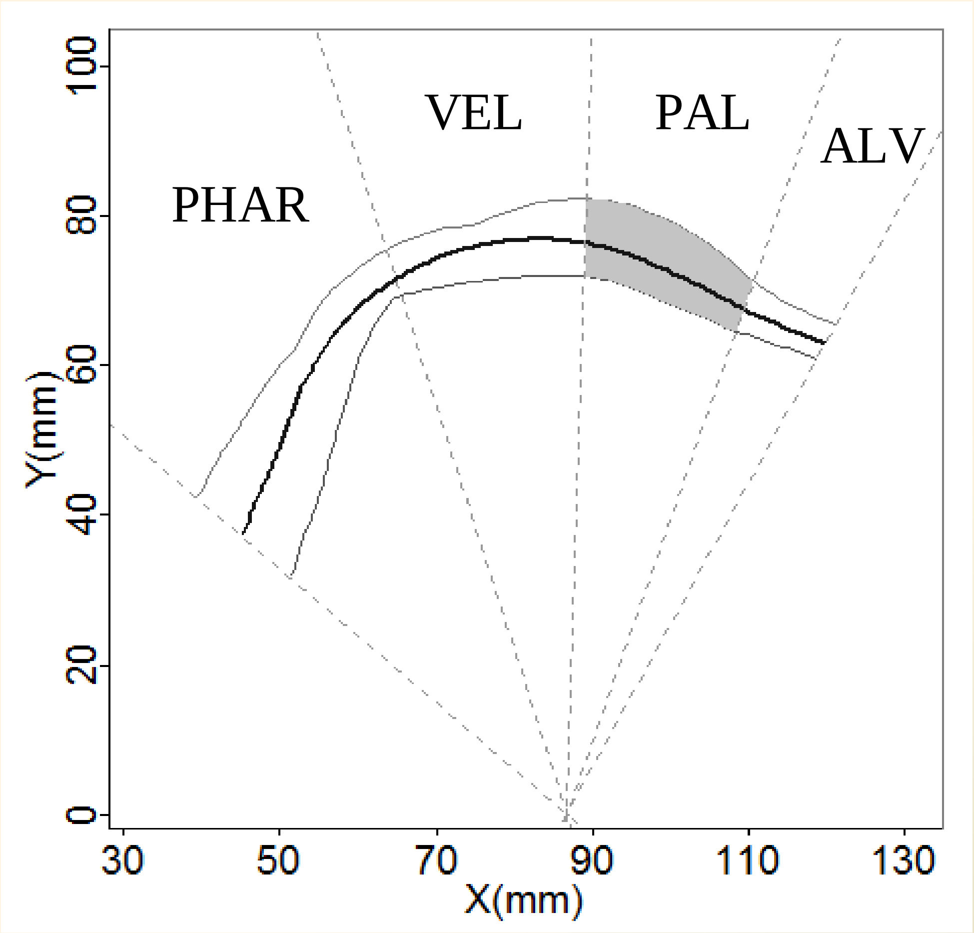
consonante: NY
inyi
enye
anya
onyo
unyu
consonante: X
ixi
exe
axa
oxo
uxu
consonante: K
iki
eke
aka
oko
uku
Y(mm)
X(mm)

6. Coarticulatory resistance was measured

- for each consonant as a function of all 5 vowels at C midpoint,
- for each vowel as a function of all 10 consonants at the midpoint of V1 and V2.

Gauss algorithm was used to compute **the area of the polygons embracing all contextual splines at each articulatory zone**, as determined by the maximal and minimal Y values at each point along the X axis.

The smaller the area of the polygon at a given zone, the more coarticulation resistant the consonant or the vowel is taken to be at that zone.

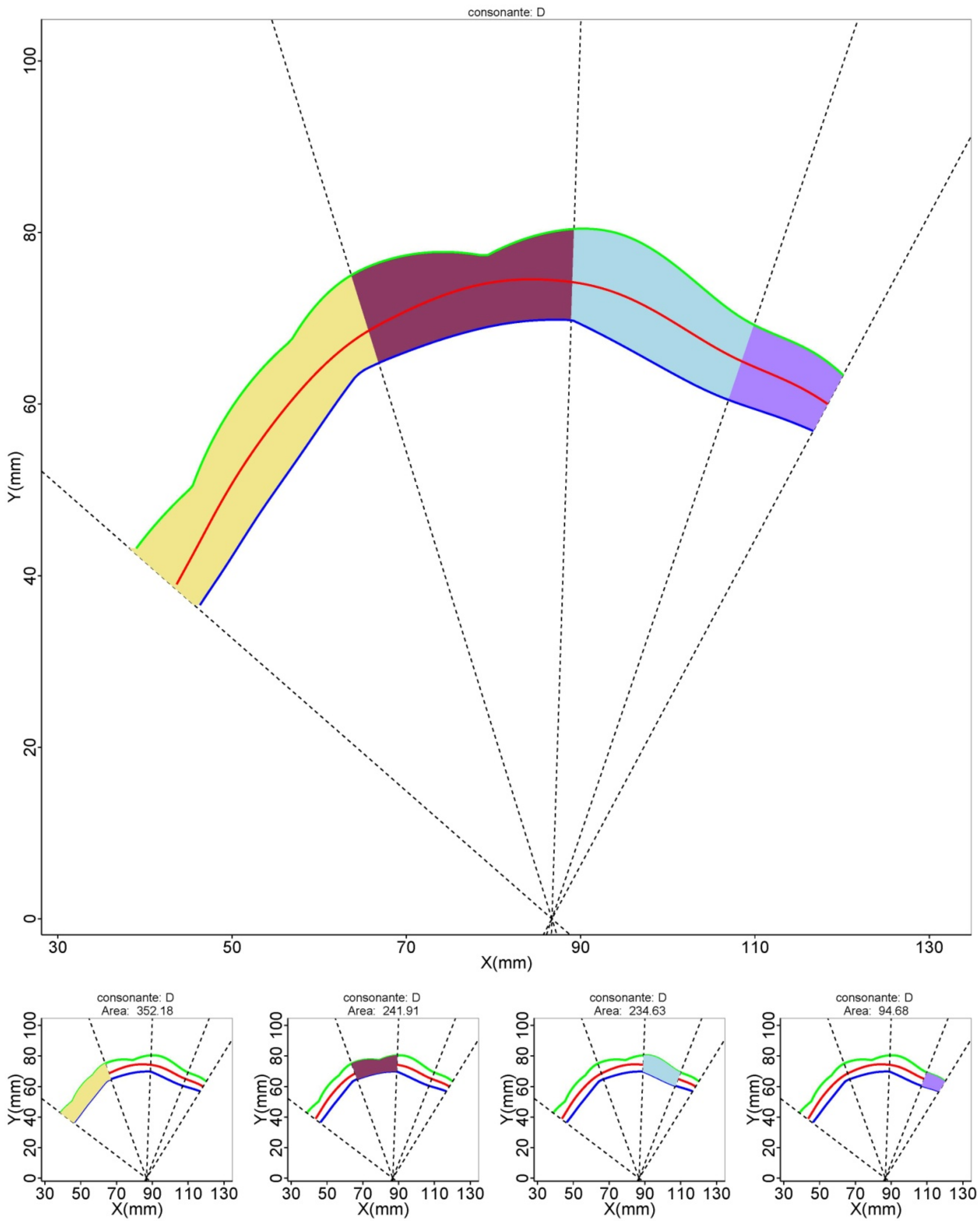


Polygons for the consonant /l/ encompassing the splines for /ili, ele, ala, olo, ulu/.

The polygon for the palatal zone is highlighted for exemplification.

Polygons for [ð] highlighted

in different colours



7. The area values of the polygons were **normalized** at each articulatory zone.

(Procedure: the mean area value across all consonants or vowels was subtracted from the area value for each individual consonant or vowel, and the resulting outcome was divided by the standard deviation of that mean. All resulting values were rendered positive.)

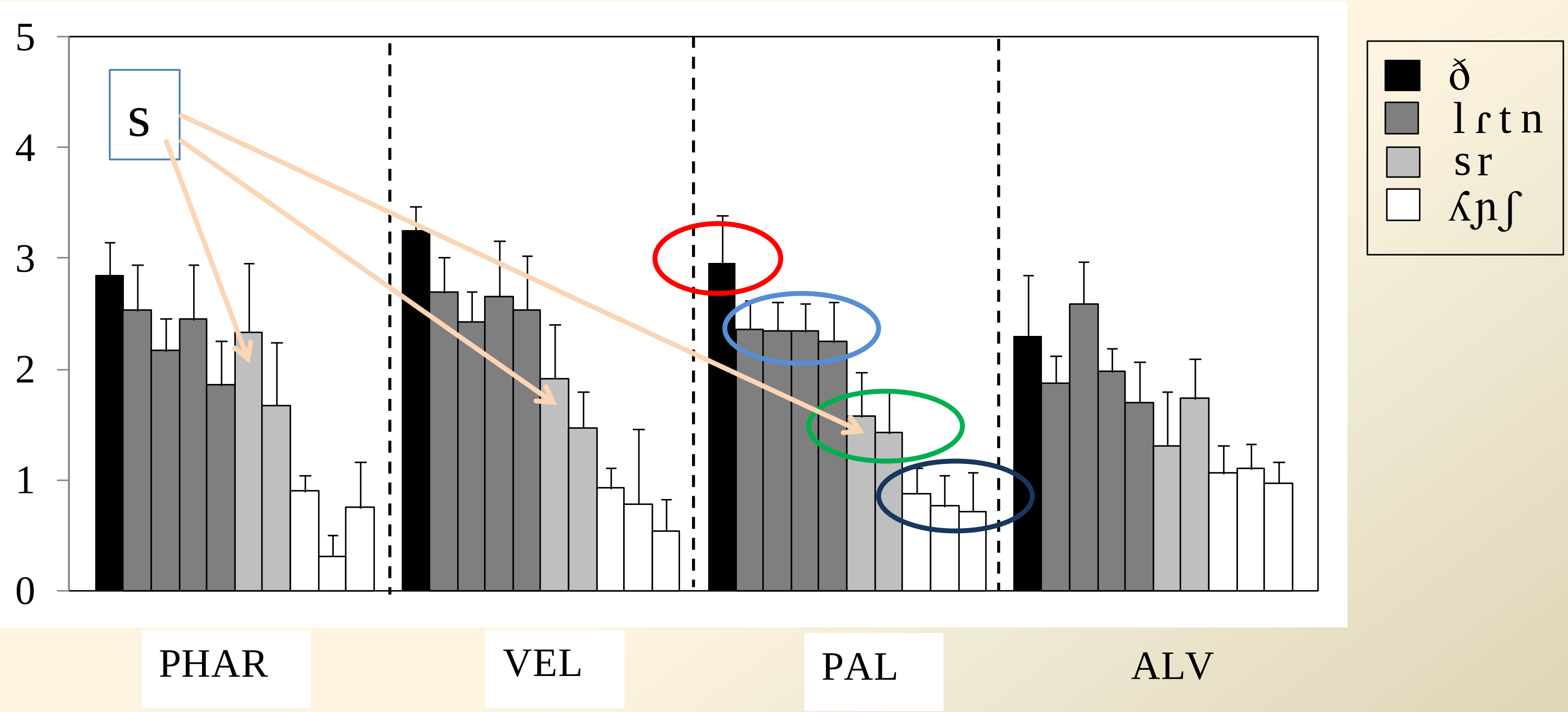
8. ANOVAs were run on the normalized area values with ‘Consonant’ or ‘Vowel’ and ‘Zone’ as fixed factors and ‘Speaker’ as a random factor. ‘Position’ was also a fixed factor for the ANOVAs performed on the vowel data (V1, V2).

(Significance level $p < 0.05$; Tuckey post-hocs; simple effects tests).

The statistical results will not be interpreted for the ‘Zone’ main effect since the normalization procedure happened to level out the differences in area size among the polygons located at different articulatory zones.

RESULTS

Normalized area size for consonants

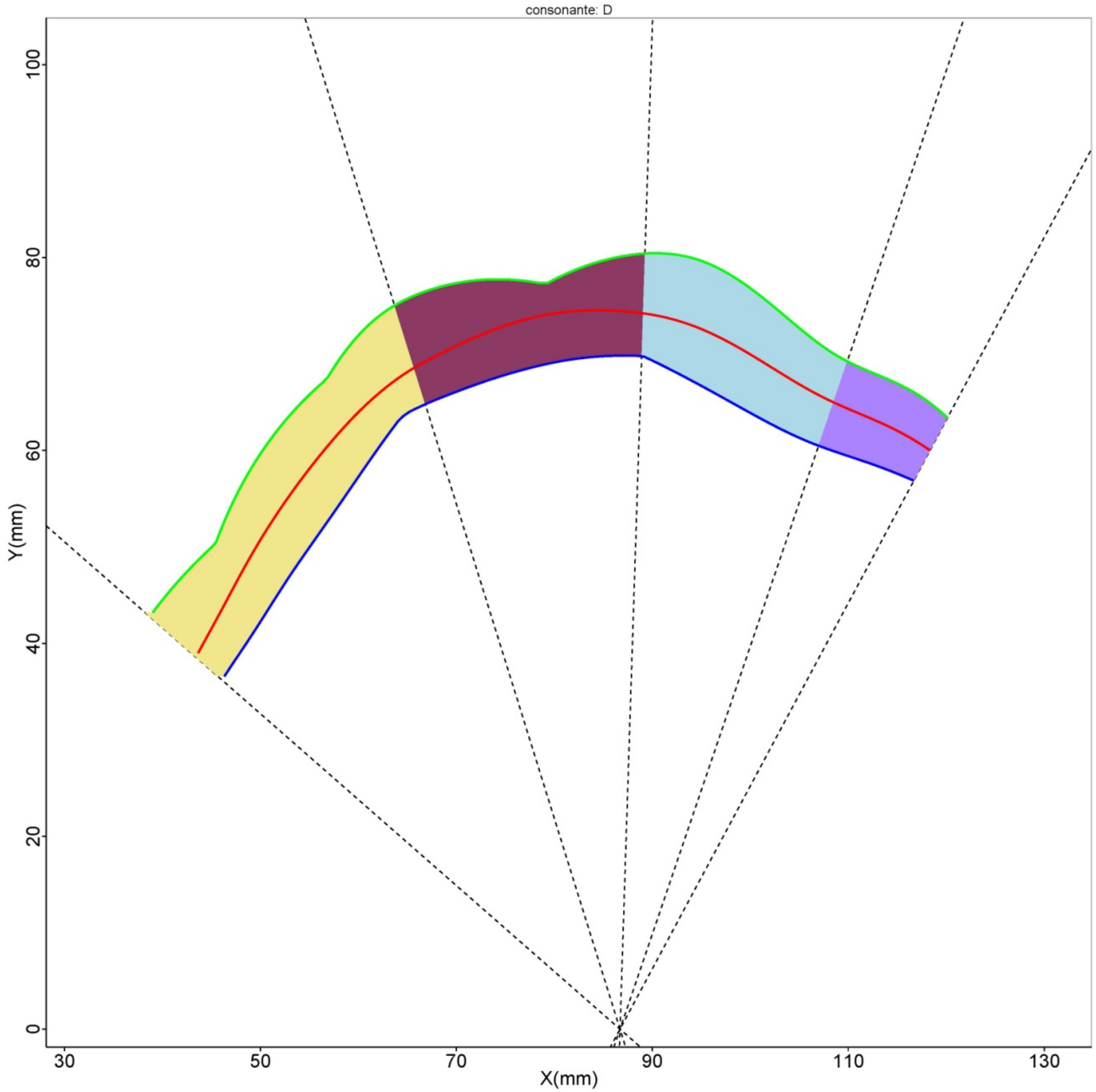


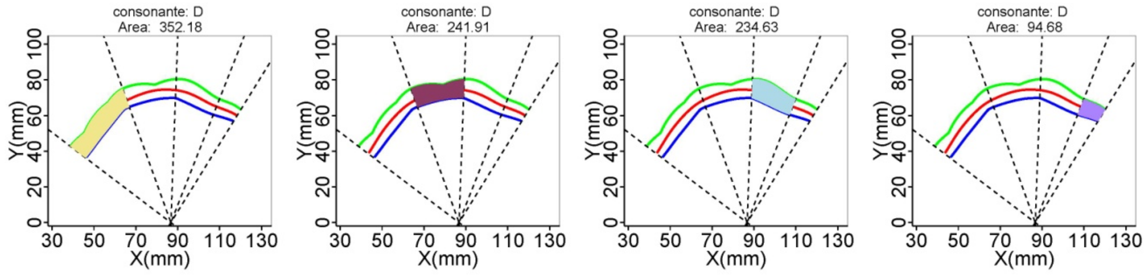
-Area size varies in the progression **[ð]** > **[l, ɾ, t, n]** > **[s, r]** > **[ʎ, ɲ, ʃ]**
(‘Consonant’ main effect, F(9, 160)=80.39, p< 0.001)

-**This hierarchy holds at the PAL, VEL and PHAR zones** except for /s/ (and to a lesser extent /r/) which happens to be most variable at the tongue back.
(‘Consonant’ x ‘Zone’ interaction, F(27, 160)=3.09, p< 0.001).

ð

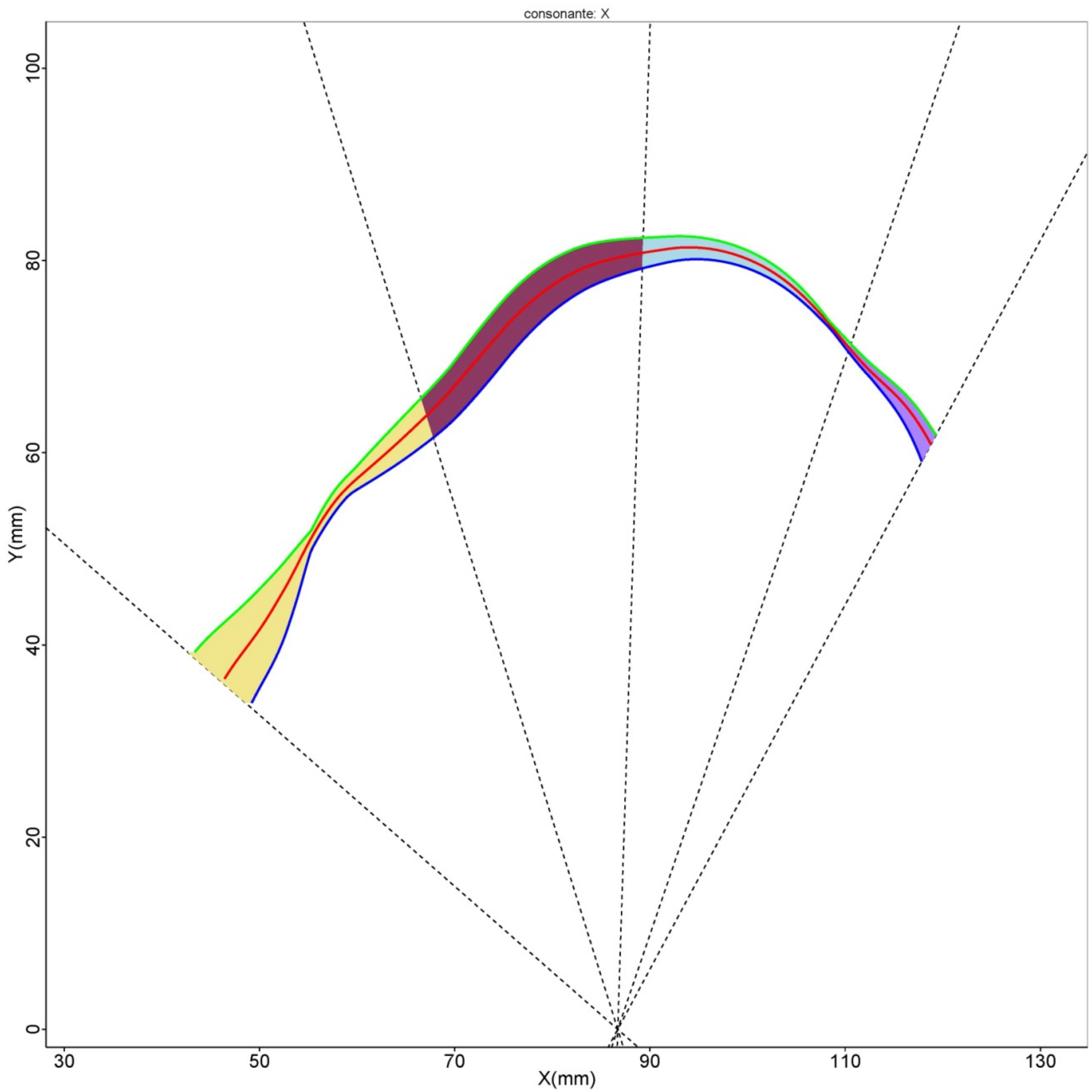
Most variable

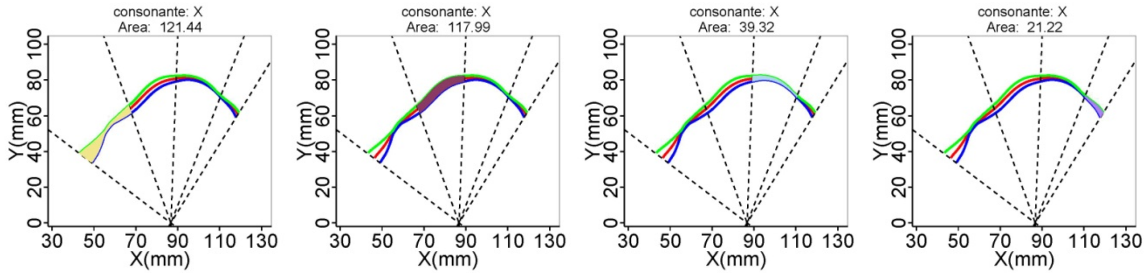




∫

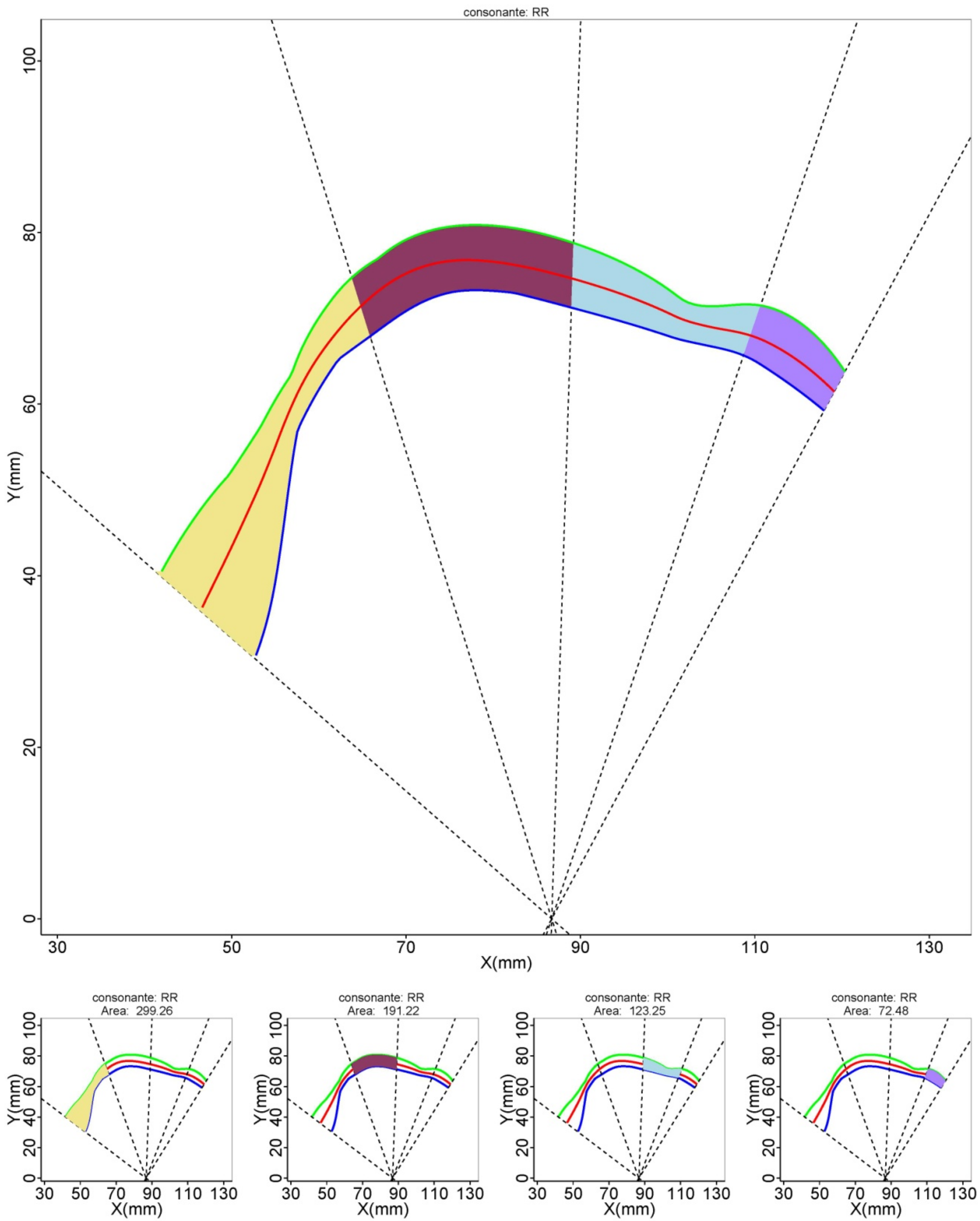
Least variable

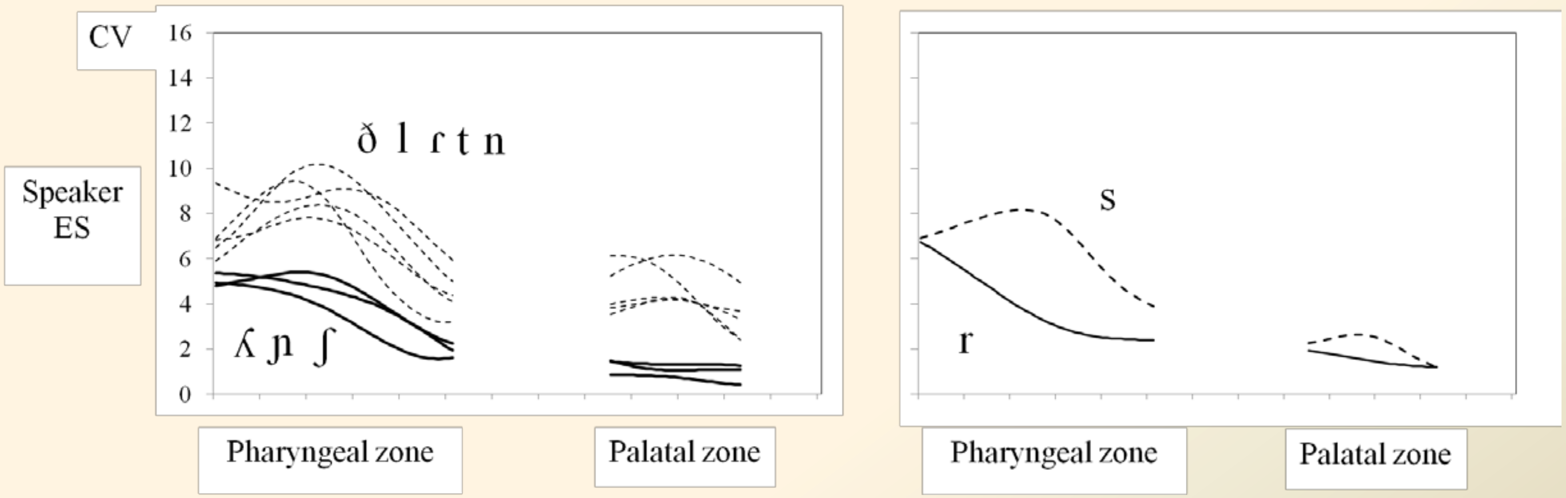




r

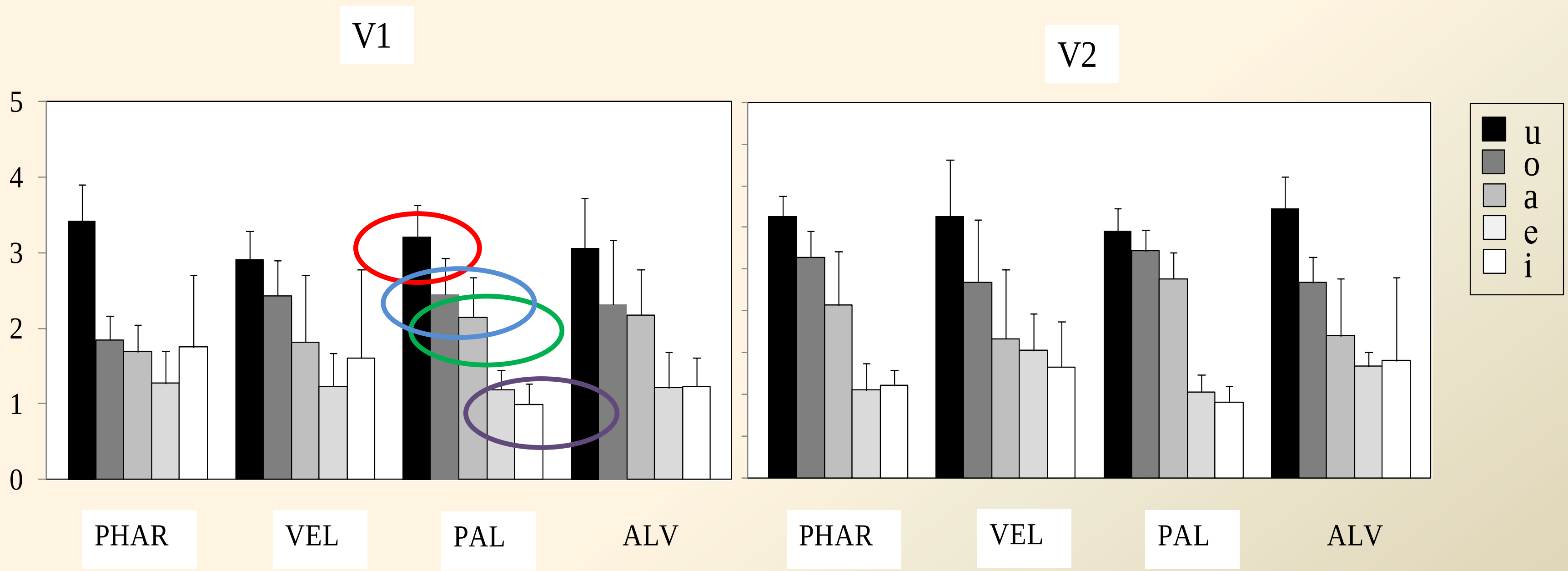
(alveolar trill)





Cross-vocalic variation coefficients for consonants computed at all spline points along the pharyngeal and palatal zones.

Normalized area size for vowels



Area size varies in the progression **[u]** > **[o]** > **[a]** > **[i, e]**

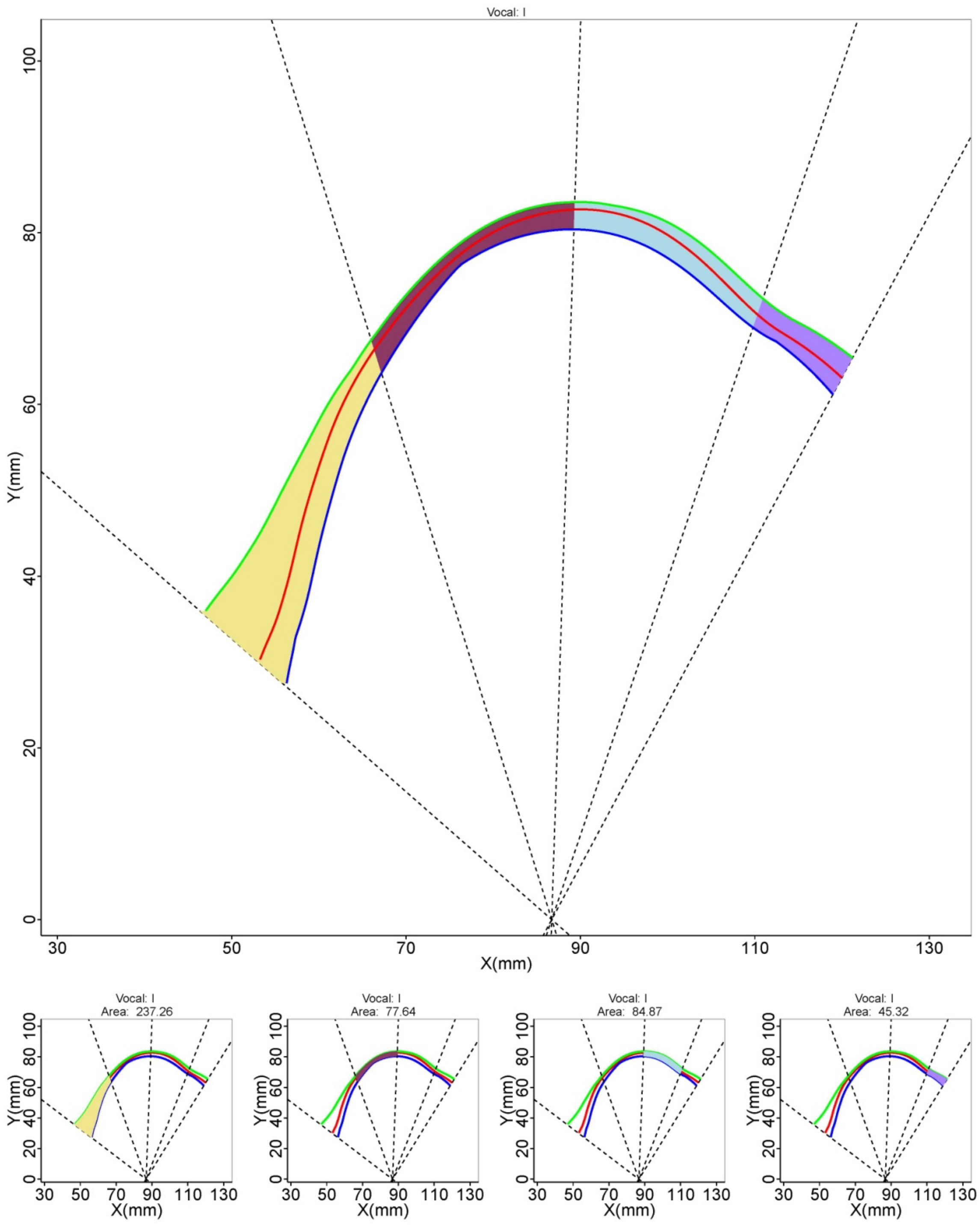
(‘Vowel’ main effect, $F(4, 160)=82.65$, $p< 0.001$).

Vowel-dependent differences in area size are roughly the same at all articulatory zones.

(‘Position’ and ‘Vowel’ x ‘Zone’ interaction did not achieve significance).

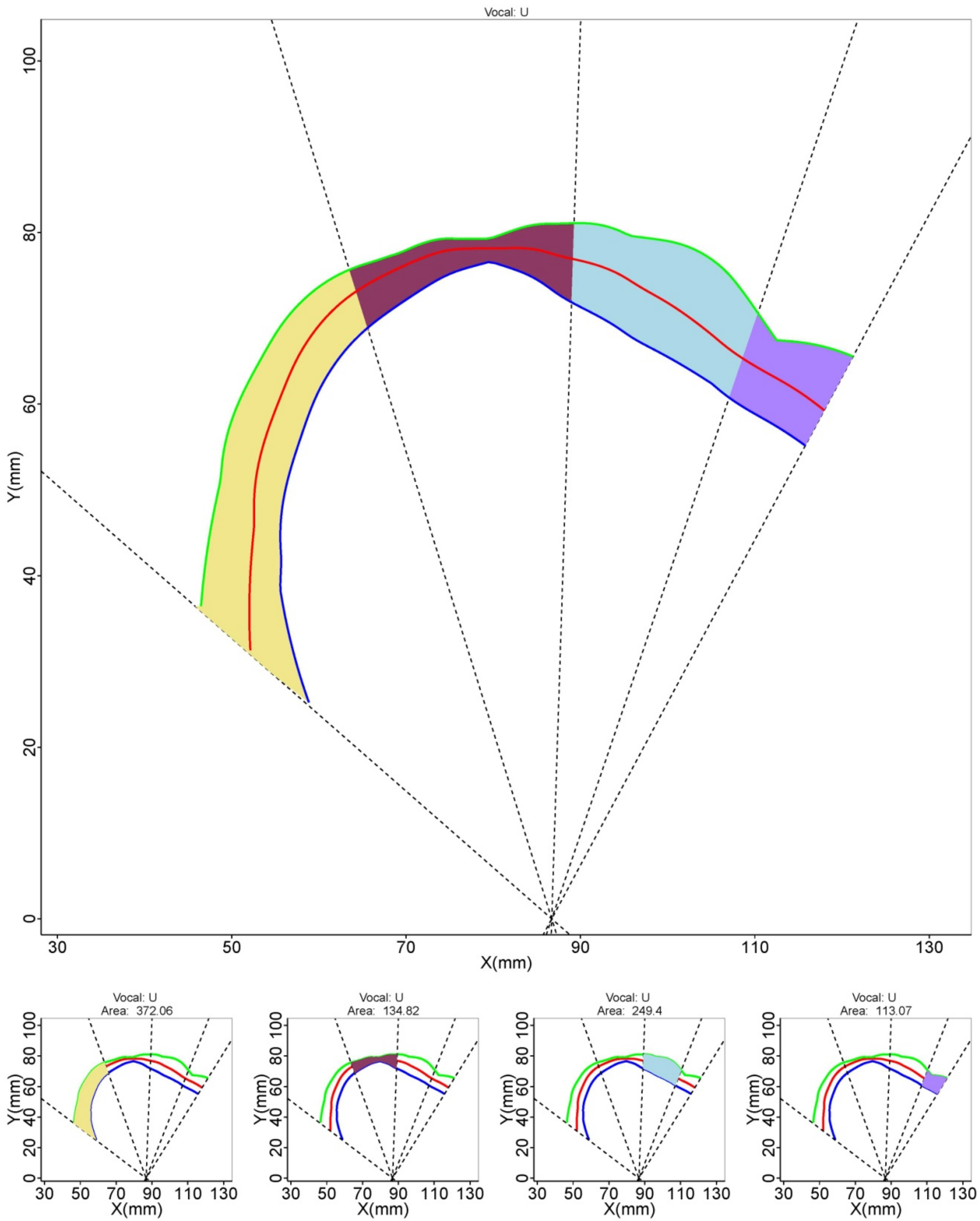
i

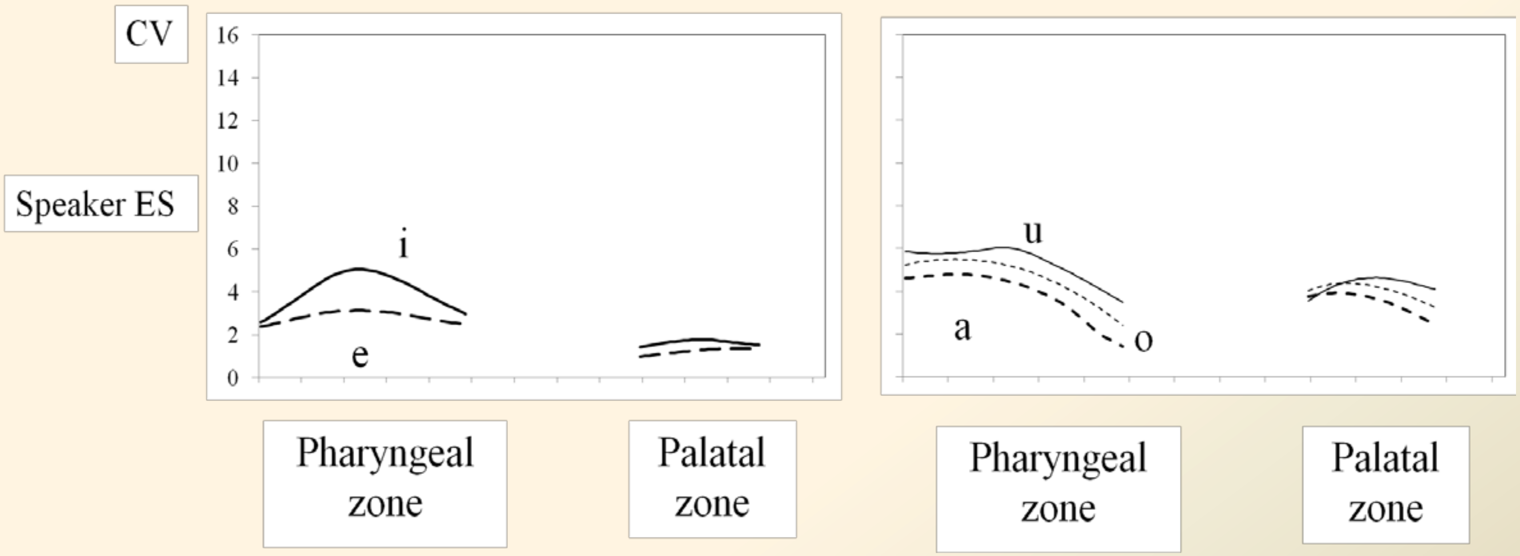
Least variable



u

Most variable





Cross-consonantal variation coefficients for vowels computed at all spline points along the pharyngeal and palatal zones.

SUMMARY AND DISCUSSION

Ultrasound data reported in this study show that coarticulatory resistance varies in the progression

Consonants

/ʃ, ɲ, ʎ/ > /s, r/ > /t, n, ɾ, l/ > /d/ ([ð])

palatals **dentoalveolars**

Vowels

/i, e/ > /a/ > /o/ > /u/

palatal **low** **back rounded**

Generally speaking, this hierarchy holds at the **palatal, velar and pharyngeal zones** and not only at the (alveolo)palatal zone as reported by EPG and EMA studies.

Little contextual variability for **palatal consonants and vowels** at all articulatory zones indicates that **the entire tongue body is highly controlled** during the production of these segmental units.

In any case, palatal vowels may exhibit some vowel-dependent changes in tongue fronting at the pharynx.

/s/ and the trill /r/ are highly constrained but less so than palatal consonants.

Coarticulatory variability for /s/ is somewhat greater at the back of the vocal tract than at about constriction location.

The **dentoalveolars /d, t, n, ɾ, l/** and **non-palatal vowels** show relatively low degrees of coarticulatory resistance at all articulatory zones.

The **approximant [ð]** is the least constrained of all consonants since it is produced with a wide lingual constriction.

Differences in coarticulatory resistance among **non-palatal vowels** (/a/>/o/>/u/) appear to be associated with differents demands imposed by the tongue postdorsum (for /o, u/) and by the tongue root (for /a/) on the front dorsum.

These results are in support of the **degree of articulatory constraint (DAC) model of coarticulation** in that the extent to which a portion of the tongue body is more or less resistant to coarticulation depends both

- **on its involvement in the formation of a closure or constriction,**

- **on the severity of the manner of articulation requirements**.

References

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Fitch, W. & Giedd, J. (1999). Morphology and development of the human vocal tract: A study using magnetic resonance imaging, JASA, 106,1511–1522.

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