Studying pharyngealization using an articulograph

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Articulatory Data Acquisition

- Studying speech production from an articulatory point of view requires a lot of articulatory data.
- Traditional techniques:
  - Cineradiographic (X-ray) imaging dangerous ⚠️
  - Magnetic Resonance Imaging (MRI) slow acquisition rate
Articulatory Data Acquisition

• **Electromagnetography can help..**
  – Not too invasive a technique
  – Provides information about the tongue and the palate.
  – Almost unlimited quantity of articulatory data

• **But..**
  – Limited number of fleshpoints...

• *First, what is electromagnetography?*
How it works?

• A coil immersed into a magnetic field generates a current.
• Measuring the current provides the strength of the electromagnetic field.
• The magnetic field strength in a receiver is inversely proportional to the cube of its distance from a transmitter.
• → the sensor lies on a sphere
3D Electromagnetography

• Proposed by Zierdt (1993):
  – 5 dof sensors (3 coordinates and two angles)

• 6 transmitters:
  • S1, S3 and S5 parallel to X, Y and Z axis
  • S2, S4 and S6 in XY, YZ and XZ planes pointing the positions of S6, S2 and S1
  • Operating at different frequencies.

Calculating the sensor position

• The magnetic field is approximated by B-splines functions on nodes covering the region where the subject’s head is.

• Cause of errors:
  – Two sensors becoming too close (and thus modify the magnetic field).
  – Local minima capturing the solution.

• The good news:
  – Errors can be easily detected (sensor trajectory becomes discontinuous)
  – Measurements and computations are separated.
  – Several scientists are working on computation improvements.

Existing systems

- Carstens AG 500 (designed mainly for speech):
  - 12 sensors (5 dof), 200 Hz (sampling frequency)
  - A good knowledge about the technology

- NDI Aurora system (designed for surgery)
  - 8 sensors (5 dof), 40 Hz (sampling frequency)
  - should be faster in the future.
  - No calibration required
Carstens - AG500

• Growing community among speech scientists
• Sensors are better adapted to tongue gluing than NDI sensors.
• Good accuracy (Yunusova 2008):
  – median error 0.5 mm
  – Maximum error between 1 to 2mm
  – Accuracy depends on the region of the cube
  – Best accuracy at the center of the cube.

• Y. Yunusova, J. R. Green, and A. Mefferd (2008). Accuracy Assessment for AG500, Electromagnetic Articulograph
• Christian Kroos (2008). Measurement Accuracy in 3D Electromagnetic Articulography (Carstens AG500), International Seminar on
  Speech Production, Strasbourg
Acquisition of data
The sensors are located at the midsagittal plane, approximately 1.6, 3.6, 5.2 and 7 cm, respectively from the tongue tip.

Plus...
• 4 sensors on the lips
• 1 sensor on the jaw
• 3 reference sensors

The further, the better: providing information about the back of the tongue.
It is possible to predict tongue contour between sensors from their positions (Kaburagi and Honda, 1994, Toutios, Ouni & Laprie, 2008)

Tongue contour from 4 sensors

It is possible to predict tongue contour between sensors from their positions (Kaburagi and Honda, 1994, Toutios, Ouni & Laprie, 2008)

Pharyngealized Phonemes
Pharyngeals

- Recording using the articulograph
- A list of Arabic words covering a variety of phonemes was recorded
- Speaker: Native Arabic, from Tunisia
- Results related only to pharyngealized and pharyngeal phonemes.
Pharyngealized phonemes are commonly described as having the same place of articulation as their non-pharyngealized cognates, but differ by the presence of a secondary articulation involving mainly the back of the tongue.
Pharyngealized phonemes

• Arabic has four pharyngealized phonemes: /tˤ/, /dˤ/, /sˤ/, and /ðˤ/, which are pharyngealized cognates of the oral consonants /t/, /d/, /s/, and /ð/.

• Pharyngealized phonemes are present in almost all the Arabic regions.

• Tunisian speakers do not pronounce /dˤ/. This sound is replaced by /ðˤ/. 
Definition of the Palate

Soft Palate

Hard Palate
The shape of the soft palate changes during phonation, breathing, etc.

[Rubesin et al. 1988]

Presentation of results
\[ V_1 C^\ddagger V_2 / V_1 C V_2 \]

Sensor positions over time
$V_1C^\delta V_2 / V_1CV_2$

- **V2 non-phary.**
- **V2 phary.**
- **$C^\delta$**
- **C**

![Diagram](image-url)
$V_1 C^\phi V_2 / V_1 CV_2$

\[ a[s/s^\phi]a \]

\[ a[s/s^\phi]u \]
$V_1C^fV_2 / V_1CV_2$

$V_2 \text{ non-phary.}$

$V_2 \text{ phary.}$

$C^f$

$C$

$a[t/t^f]i$

$u[t/t^f]u$
$V_1C^\delta V_2 / V_1CV_2$

\[u[\tilde{\delta}/\tilde{\delta}^\delta]u\]

\[a[\tilde{\delta}/\tilde{\delta}^\delta]i\]
$V_1 C^f V_2 / V_1 CV_2$

V2 non-phary.
V2 phary.
$C^f$
C

a[s/s^f]i

u[s/s^f]u
Horizontal displacement of the four sensors.
Coarticulatory effect of the pharyngealized phoneme on the surrounding phonemes
Back consonants : Pharyngeals

• There are two pharyngeal fricatives (/ħ/ and /ʕ/).

• We consider also the velars (/χ/, /ʁ/) and the uvular (/q/) as pharyngeals as they are back phonemes and present similar characteristics as pharyngeals (important backing of the tongue).

⇒ This classification is highly dependent on the region of the speaker
Velars /x/ (unvoiced) and /ʁ/ (voiced)

Constriction formed between the tongue and the upper pharynx for /x/ and /ʁ/: no differences
Pharyngeal fricatives /\textipa{h}/ (unvoiced) and /\textipa{f}/ (voiced)

→ Important constriction at the pharynx for /\textipa{f}/ (narrower than for /\textipa{h}/)
Uvular /q/

Complete closure for /q/ at the velum

Comparison between two examples of articulography data with x-ray tracings obtained by (Ghazali, 1977).
Discussion and conclusion
Pharyngealisation and vowels

/a/

/i/

/u/
Pharyngealisation and vowels: /a/

- a very wide articulatory domain allowed
- requires a narrow or very narrow back cavity
  - Accepts pharyngealization easily
Pharyngealisation and vowels: /i/

- requires a very narrow front cavity for acoustical reasons

- does not accept pharyngealization without changing acoustical properties (formants)
Pharyngealisation and vowels: /u/

- requires a very precise place of articulation
- hypothesis (to be validated): speakers use the second place of articulation for /u/
- does not accept pharyngealization without changing acoustical properties (formants) or the articulatory strategy.
Pharyngealisation and vowels: /u/
To conclude...

- Dynamic aspects are essential:
  - Strong anticipation
  - Design of a corpus that isolates better pharyngealization effects

- Compromise between articulatory and acoustic constraints

- Articulography allows studying pharyngealization:
  - Should be coupled with an articulatory model to get the shape of the pharynx
  - Exploit existing X-ray data on Arabic to derive a model better adapted than that of Maeda derived from French data.