Quantifying gradience of epilaryngeal constriction in Levantine Arabic "gutturals": *A Generalized Additive Modelling approach to ultrasound tongue contours*

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Retraction in Gutturals

- Gutturals in Arabic ⇒ Uvulars /χ ʁ q/, Pharyngealised /tˤ dˤ ðˤ sˤ/ and Pharyngeal or Epilaryngeal /ħ ʕ/ or /ʜ ʢ ʡ/; debate Glottals /ʔ h/

→ Assumed to form a natural class due to phonological patterning and use of *common* oro-sensory zone in the pharynx (McCarthy, 1994; Sylak-Glassman, 2014a,b)

- Articulatory differences ⇒ Uvulars → raised tongue dorsum; Pharyngealised → Tongue dorsum depression; backing to upper-mid/low pharynx Pharyngeal → retracted tongue root and tongue dorsum depression (e.g., Al-Tamimi, F. & Heselwood, 2011; Ghazeli, 1977; Heselwood & Al-Tamimi, F., 2011; Zeroual & Clements, 2015)

Laryngeal Articulator Model (LAM)

- Epilaryngeal constriction ⇒ **Raised/constricted larynx** causes **retracted tongue root**, due to constriction of the hyoglossus, in a *back and down* gesture
- However, **Dynamic nature of tongue movements, and of laryngeal constrictions** favour **gradient rather than categorical** epilaryngeal constriction
- **Epilaryngeals** predicted to have a maximal epilaryngeal constriction; partial in **Pharyngeals/Pharyngealised**, and least/nil in **Uvulars**; **glottals** no lingual change (e.g., Esling, 2005; Esling et al., 2019; Moisik, 2013; Moisik et al., 2012, 2019)

Aims

- Aim ⇒ Quantify **gradience of epilaryngeal constriction** in Levantine Arabic "gutturals"; Ultrasound data
- Static and dynamic analyses (AR1 GAMMs)
- Building on acoustic evidence of **partial epilaryngeal constriction** in pharyngealized stops in Jordanian and Moroccan Arabic (Al-Tamimi, J., 2017)
- Overarching ⇒ Empirical evidence of **guttural natural class** using synchronised Ultrasound, Electroglottography and acoustics

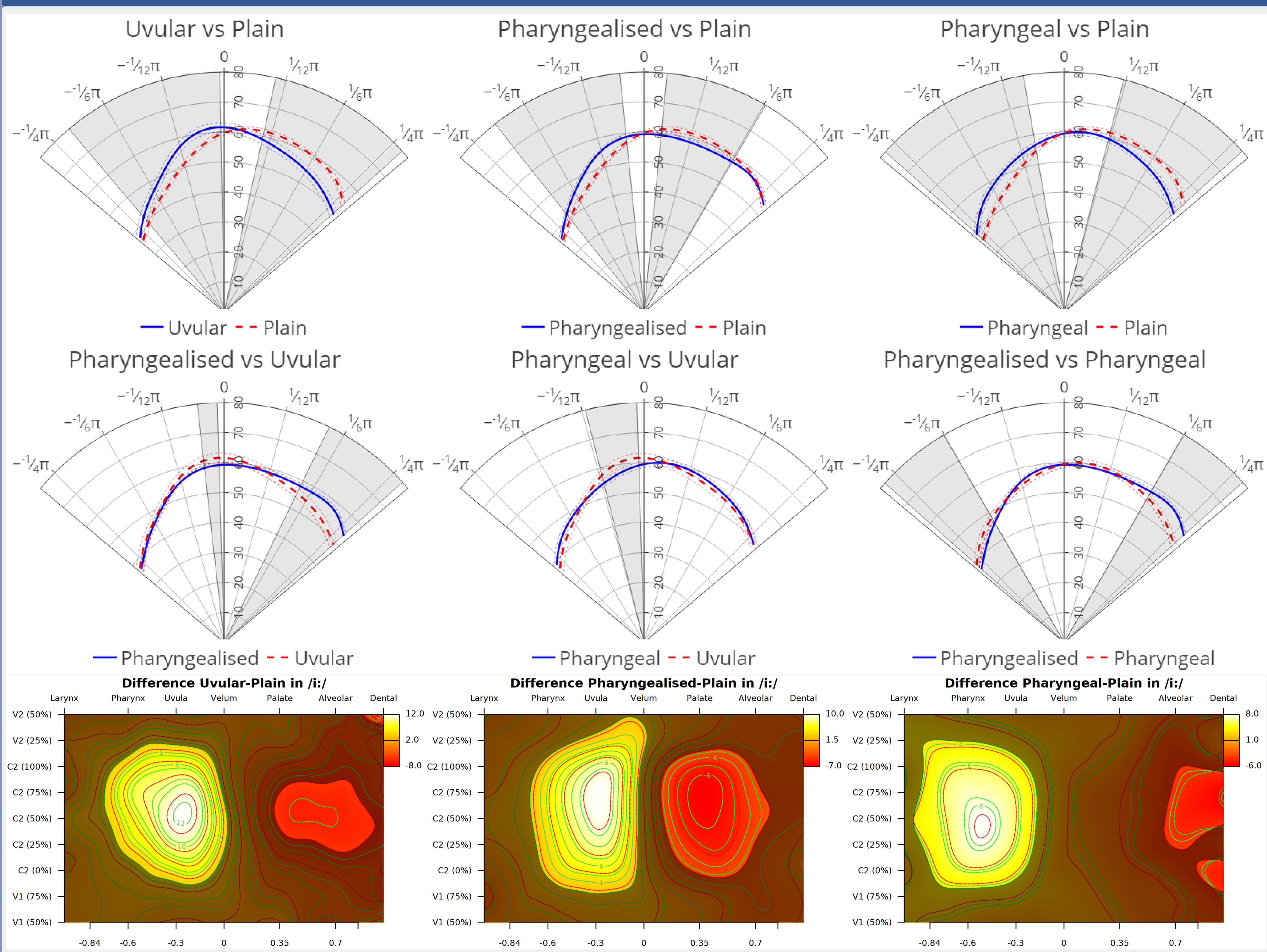
Material

- Ten Levantine Arabic Urban speakers (5 males; 5 females), aged 25-45
- Synchronised Ultrasound Tongue Imaging, Electroglottography, and high quality audio recordings through a multichannel breakout (Wrench & Scobbie, 2008);
  Ultrasound ⇒ Mindray DP-6600, NTSC video output at 30fps (60fps deinterlaced), depth = 7.55cm, Frequency 5MHz, with endocavity microconvex probe (10mm radius; 120°FOV) with a stabilisation headset
- Real and nonsense words (3 sequential repetitions) in **/ˈʔV:ˈCV:/** frame:
- V: ⇒ symmetric /iː aː uː/
- C ⇒ **Plain** ⇒ /t d ð s z l/, **Velar** ⇒ /k g x ɣ/, **Uvular** ⇒ /q/, **Pharyngealised** ⇒ /tˤ dˤ ðˤ sˤ zˤ lˤ/, **Pharyngeal** ⇒ /ħ ʕ/, and **Glottal** ⇒ /h ʔ/ (= 2034 items; /χ ʁ/ realised [x ɣ] in Levantine Arabic)

Data processing and Statistical design

- Data from 8 participants (4 males and 4 females); AAA (Wrench, 2018)
- Nine-Intervals: V1 at 50%, 75%; C2 at 0%, 25%, 50%, 75%, 100% and V2 at 25% and 50%
- 13698 tongue splines; automatic & hand corrected
- Polar coordinates (r, φ); 42 fanlines exported; first/last 4 hidden by hyoid and mandible bones discarded
- Auto-Regressive Generalised Additive Mixed-effects Modelling (AR1 GAMMs) ⇒
  - Fixed ⇒ Context by vowel interaction by gender; ordered
  - Smooths ⇒ Contour and Interval by Context*vowel
  - Tensor product interaction (ti) ⇒ Contour and Interval by Context*vowel and by gender
  - Factor smooths interactions ⇒ Contour and Interval by speaker by Context*vowel
  - Factor smooths interactions ⇒ Contour and Interval by word by gender
  - Outcome ⇒ Radius (height) value
  - 465732 data points (13698 splines * 34 fanlines); R^2 = 88.6%
- Within and between speaker and gender adjustments
- **Static** ⇒ 2-D Differences two tongue contours (following Heyne et al., 2019): `itsadug` and `plotly`
- **Dynamic** ⇒ 3-D Differences two tongue contours by Interval: `plot_diff2` in `itsadug` with estimated constriction location on secondary x axis (inspired Carignan et al., 2020)

Static - 2-D Contour (x) by Height (y); Dynamic - 3-D Contour (x), Interval (y), Height (z); 95% Confidence Intervals



- Static (tip right, root left; averaged VCV)

→ Uvular, pharyngealised and pharyngeal ⇒ "Retraction" and back tongue changes

→ Uvular ⇒ Raised

→ Pharyngealised ⇒ Mid-pharyngeal

→ Pharyngeal ⇒ Low-pharyngeal

→ Root differences ⇒ maximal in pharyngeal; minimal in uvular and pharyngealised

- Dynamic (3-D)

→ Throughout C2 and onset V2

→ Post-velar to mid/low-pharyngeal; "Retraction" and root differences

Discussion and Conclusion

- Empirical evidence compatible with legitimacy of guttural natural class
- Gutturals in Arabic show **gradient "retraction"**
  - **Uvular** ⇒ minimal "retraction" with **"raised"** and **"back"** gesture and minimal root differences.

  → Fronted in /iː/ context to post velar
  - **Pharyngealised** ⇒ partial "retraction" with **"mid"** and **"back"** gesture and minimal root differences

  → Back and mid-up gesture in /uː/ context to upper pharyngeal
  - **Pharyngeal** ⇒ near maximal "retraction" with **"down"** and **"back"** gesture and maximal root differences.

  → Fronted configuration compatible with an /æː/ context; true "pharyngeal" rather than epilaryngeal; possibly "double bunched" (see Esling et al. 2019; Moisik et al. 2019)
- Static ⇒ Overall changes in VCV; Dynamics ⇒ differences within C2 and onset of V2; progressive coarticulation
- Gutturals in Arabic show **gradient "retraction"**, contra to categorical predictions of LAM

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