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Laryngeal changes associated with Guttural consonants in Levantine Arabic

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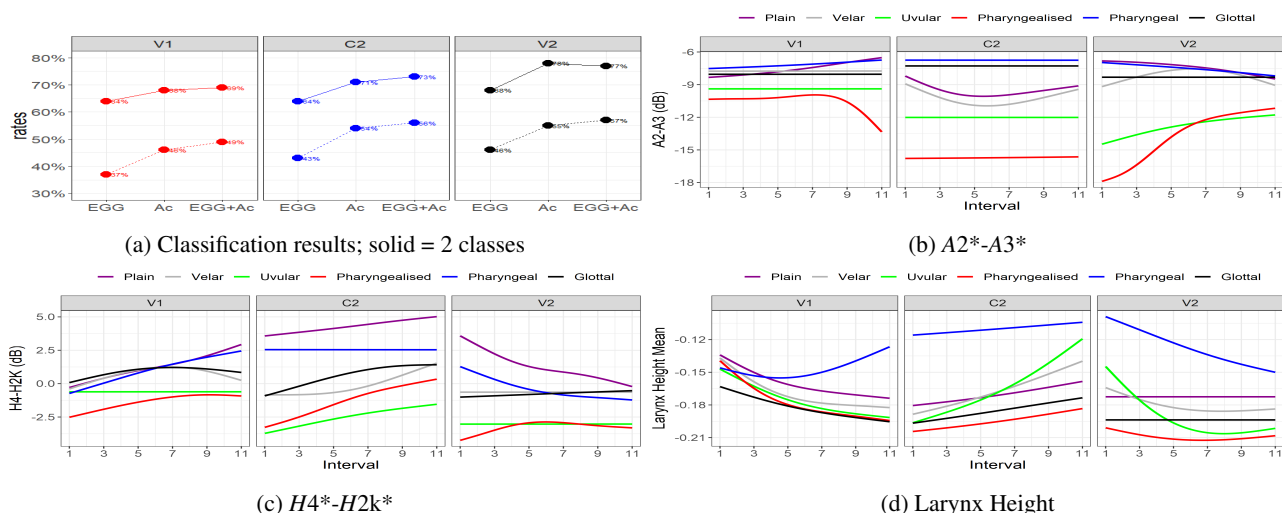
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Introduction. This study aims at evaluating the role of laryngeal changes associated with guttural consonants in Levantine Arabic. Laryngeal changes are reported in a handful of studies on Arabic guttural consonants; e.g., variable creaky voice using *H1-H2* measure for the variable types of /ʕ/ across Arabic dialects (Heselwood 2007); raised larynx in pharyngealised coronals via videofluoroscopy (F. Al-Tamimi and Heselwood 2011); raised larynx and creaky voice quantified via videofluoroscopy and *H1-H2* in pharyngeals (Heselwood and F. Al-Tamimi 2011); or more recently lower spectral tilt measures of Voice Quality quantifying the degree of tense voice in pharyngealised coronals (J. Al-Tamimi 2017).

Following these findings, we wanted to evaluate laryngeal changes in gutturals using non-invasive techniques. Gutturals are traditionally composed of uvulars /q ɣ ʁ/ and pharyngeals /ħ ʕ/ (McCarthy 1994) although pharyngealised consonants /tʕ dʕ ðʕ sʕ/ and glottals /ʔ h/ are also included due to the constriction location being somewhere in the lower vocal tract. Recently, J. Al-Tamimi and Palo (2023) provided an empirical evidence that gutturals share articulatory similarities in how they impact on the tongue contours quantified via Ultrasound Tongue Imaging (UTI). The results also suggested that gutturals (uvular, pharyngealised and pharyngeal) show a potential for a raised larynx posture due to a variable degree of tongue root retraction. However, and due to the difficulty in quantifying laryngeal changes from UTI alone, this study uses a combined acoustic and Electroglottography (EGG) measures to quantify the (dis-)similarities between gutturals with respect to systematic laryngeal changes. We ask the question whether gutturals show a systematic larynx raising, when compared to plain coronals (or velars and glottals) and whether there is a systematic spectral tilt lowering, which could be indicative of a more creaky or tense voice quality. Following the predictions of the Laryngeal Articulator Model; LAM (Esling et al. 2019) and the findings from J. Al-Tamimi and Palo (2023), we expect gutturals to show systematic differences to non-gutturals but to show a more gradient larynx height and constriction (quantified via Closed Quotient; CQ and Peak Increase in Contact; PIC). We also expect them to show a gradient spectral tilt decrease as quantified via the various acoustic measures of voice quality.

Methods. Ten Levantine Arabic Urban speakers (5 males, 5 females), aged 25-45 were recorded using synchronised UTI, 2-channel EGG system, and audio recordings through a multichannel breakout. They were instructed to produce a list of items in a /ʔV:CV:/ frame, with all possible consonants in Levantine Arabic and the three symmetric long vowels /i: a: u:/; see more details of corpus and data collection in J. Al-Tamimi and Palo (2023). After transcribing and force-aligning the data using Arabic WebMUS (J. Al-Tamimi, Schiel, et al. 2022), the data were processed. Larynx Height (LH) was extracted from the 2nd channel and contact measures were automatically quantified using EGGWorks. EGG and acoustic measures of voice quality were obtained at 11-intervals from VoiceSauce, with *f0* and formant measures being speaker-adapted using Praat settings. For the EGG measures, we obtained LH, CQ (using the Hybrid method); the PIC and PDC (Peak Decrease in Contact); the Closing and opening slopes and ratio (Kuang and Keating 2014). For acoustic measures, we extracted all measures described in the psychoacoustic model of voice quality (Garellek et al. 2016) in addition to the three high-frequency amplitude measures used in J. Al-Tamimi (2017) to quantify the impact of an epilaryngeal constriction on the voice source. We used Random Forest (RF), a Machine Learning classifier, and dynamic information to evaluate the impact of gutturals on the VCV sequence. We look next at the classification results and the patterns observed for the top three measures identified by the various RFs we ran.

Results. Figure 1a shows classification results. When combining EGG and acoustic measures (EGG+Ac), an overall improvement in classification accuracy is observed especially within V2. This is indicative of a progressive coarticulatory impact of voice quality. When comparing gutturals to non-gutturals (2 classes; solid lines), the rates are around 78%; when looking at the six classes (dashed lines), the rates are much lower and are close to the 60%. The relatively low rates



are indicative of a secondary role for voice quality. Figures 1b, 1c and 1d show the top three predictors used by most of the RF. Dynamic changes throughout the VCV sequence show values to have an overall \downarrow in V1, \uparrow/\downarrow in C2 and \uparrow in V2. Interestingly, uvular and pharyngealised consonants show $\downarrow A2^*-A3^*$ and $\downarrow H4^*-H2k^*$ indicative of a steeper and an abrupt change in the Slope around 2kHz and 3kHz, which can be correlated with a more constricted glottis; pharyngeal consonants show the highest values indicating a potential for a more constricted epilarynx. Pharyngeal consonants have a clear $\uparrow LH$, throughout the VCV sequence, which is more marked at the C2; pharyngealised consonants show a pattern of \downarrow in V1, \uparrow in C2 and \downarrow in V2, while uvular consonant follows a similar pattern, but shows a $\uparrow LH$ within the release.

Discussion. These results confirm that gutturals share specific common laryngeal components. Pharyngeal consonants are inherently produced with a \uparrow Larynx, which yields a constricted epilarynx, following LAM. Pharyngealised consonants on the other hand show \downarrow Larynx, which increases towards the release, but with a more abrupt and constricted glottis. Uvular consonant seems to share a \uparrow Larynx *and* abrupt and constricted glottis similar to pharyngealised. The results of this study provide an empirical evidence that gutturals show systematic laryngeal changes not often quantified in the literature.

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