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Using machine learning to model the three-way laryngeal contrast in Korean

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Introduction

- **Random Forest** models (a kind of Machine Learning (ML) tech.) were trained to learn the laryngeal contrast in Korean via acoustic measurements.
- Training data: from 7 acoustic measurements.
  - F0, VOT, spectral tilt, closure duration, frication duration, aspiration duration, release duration (frication + aspiration duration)
- Goal #1: To identify which measures form necessary & sufficient conditions for ML models with accuracy over 95%.
- Goal #2: To identify which measures are relatively more important for the models.

Background – Korean Obstruents

- Korean obstruent inventory:
  - By place, manner & laryngeal setting: **lenis** [p], **tense** [p’], **aspirated** [pʰ] (Kim, 1965; Kim & Duanmu, 2004).

Type	Labial	Coronal	Dorsal
Stops	p p’ pʰ	t t’ tʰ	k k’ kʰ
Affricates		t͡ʃ t͡ʃ’ t͡ʃʰ	
Fricatives		s’ s	

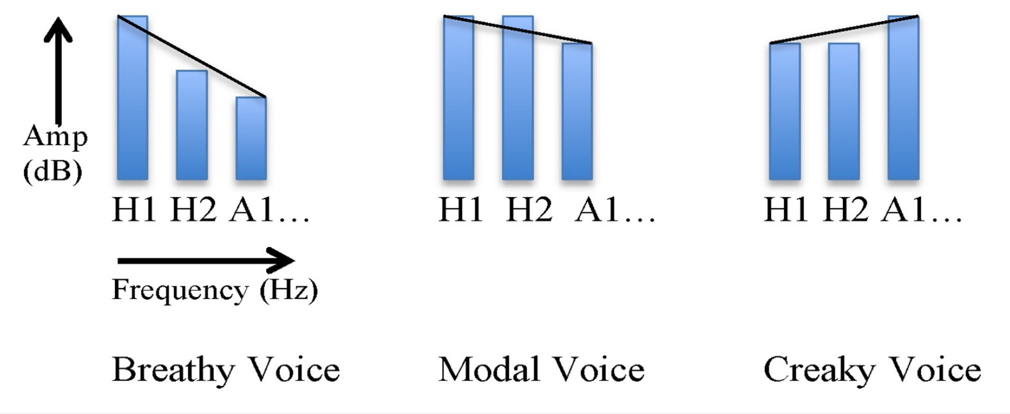
- In early work, laryngeal setting differences depended on VOT:
  - Tense: short positive VOT.
  - Lenis: intermediate VOT (Lisker & Abramson, 1964).
  - Aspirated: long positive VOT.

Background – Changing Phonetic Cues

- Aspirated & lenis **VOT** differences are no longer distinct.
  - F0 in a following vowel has replaced VOT as the primary difference between aspirated & lenis (Silva, 2006; Wright, 2007; Kang & Guion, 2008; Kang, 2010; Kang, 2014).
- Young speakers used **lowered f0**, not VOT to recognize lenis obstruents.
  - Tense & aspirated are recognized via a combination of f0, VOT and spectral tilt (Kim, Beddor & Horrocks, 2002; Kim, 2004; Schertz et al., 2015).

Background – Tense Obstruents

- Tense obstruents have laryngeal constriction - creaky phonation at the start of a following vowel (Cho et al., 2002).
- Measured via **spectral tilt**: At higher frequencies, intensity drops less in creaky voice than modal voice.
  - Tense obstruents have reduced values for H1*–H2* and H1*–A1* at following vowel onset.



Methods - Data Collection

- 24 Seoul Korean speakers (14 F, 10 M), aged 20-27.
- 66 bisyllabic **C**aCa words, most nonce (2 repetitions).
  - Target: C1, allowing all possible variations of laryngeal setting, manner & place.
  - C2: Lenis or Aspirated stop.
- Carrier sentence: 단어 X 는 무슨 뜻인가요
  - “What does the word X mean?”

Methods: Acoustic Measurements (1)

- F0 & spectral tilt in V1 extracted via VoiceSauce (Shue, 2010).
  - Formant-normalized:
    - H1*–H2*, H1*–A1*, H1*–A2*, H1*–A3*, H2*–H4*.
  - 1 measure chosen per model, to maximize accuracy.
- 1 measurement per word, closest to the vowel.
- Duration via Praat (Boersma & Weenink, 2022) segmentation of consonant closure, frication & aspiration.

Methods – RF Model Training Method

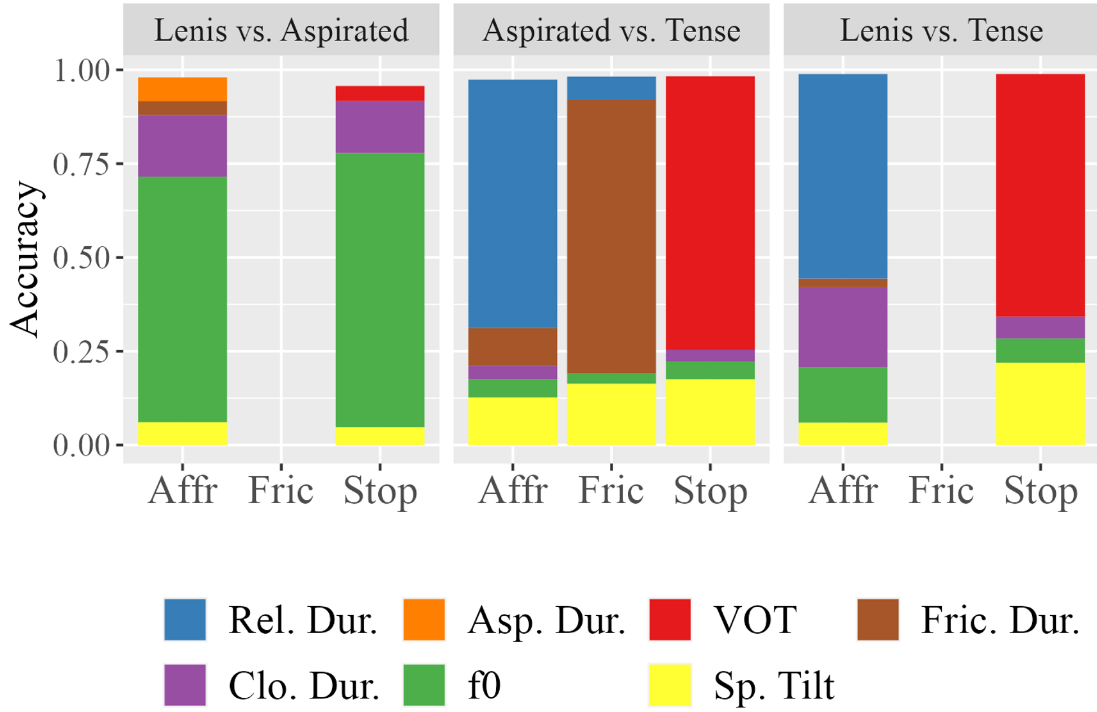
- RF models trained by separate data partitions defined by pairs of laryngeal features & by manner:
  - (1) aspirated & lenis; (2) aspirated & tense; (3) lenis & tense.
  - (A) stops; (B) affricates; (C) fricatives.
  - 7 total data partitions (3 for stops, 3 for affricates, 1 for fricatives).
- Training data: 1 of 2 repetitions randomly selected per word & speaker.
- Therefore, data partitions for testing/training were fully balanced by word & speaker.

Methods – RF Model Interpretation

- Models were built containing all possible combinations of the measures for each data partition (Xue & Zhao 2008).
  - A **successful** model: overall accuracy ≥ 95%.
- A measure or group of measures was **sufficient** if all models containing those measures were successful.
- A measure or group of measures was **necessary** if the only models that were successful contained those measures.
- Relative **importance** values (summing to 1) quantify each measurement's relative contribution to a model.

Results (1)

- Fully-loaded RFs ≥ 95% acc.
- Lenis vs. Aspirated: mostly f0
- Aspirated/Lenis vs. Tense:
  - Affricates: Rel. duration
  - Fricatives: Fric. Duration
  - Stops: VOT



Importance values are plotted.

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Results (2)

- Necessary and sufficient acoustic measures for learning:

Lar. Contrast	Manner	Necessary Measures	Sufficient Measures
Lenis-Aspirated	Affr.	f0	f0
	Stops	f0	f0, closure duration
			f0, spectral tilt, VOT
Aspirated-Tense	Affricates	release duration	release duration, any other
	Fricatives	frication duration	frication duration, release duration
			frication duration, spectral tilt
	Stops	VOT	VOT
Lenis-Tense	Affricates	**none**	release duration
			F0, spectral tilt, closure duration, frication duration
	Stops	**none**	VOT
			F0, spectral tilt, closure duration

Conclusions

- ML models can get relative weights of acoustic cues.
  - Separate perception research is needed to confirm a cue.
- Previous findings were confirmed by RF modelling:
  - The aspirated-lenis contrast is primarily distinguished via f0.
  - Tense obstruents are primarily distinguished via VOT among stops.
  - No single acoustic measure is necessary for Tense vs. Lenis.
- Affricates & fricatives: release duration and frication duration substitute for VOT in distinguishing tense obstruents.

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Random Forest (RF)

- RF is an ML procedure used to develop prediction models.
  - In the RF settings, many classification and regression trees are constructed using randomly selected training datasets and random subsets of predictor variables for modelling outcomes.
  - Results from each tree are aggregated to give a prediction for each observation.
- In this study, the basic parameter settings of all of the RF models are: {number of estimators: 200, random state: shuffle}

Background – Psychoacoustic Roughness

- Tense obstruents have laryngeal constriction.
- Leads to creaky phonation at the start of a following vowel, traditionally measured via spectral tilt (Cho et al., 2002).
- Psychoacoustic roughness: Used to measure creaky phonation in Burmese (Villegas et al. 2020).
    - Roughness extracted via a Matlab routine in Villegas et al., 2020.
    - Research question 2: How do roughness & spectral tilt compare in identification of Tense obstruents?

Measurements of Laryngealization (1)

- Research Question 2: Which of the various spectral tilt & roughness measures are optimal for learning the laryngeal contrast?
- Minimally sufficient models with one measure of laryngealization are compared for model accuracy:

Measure	Lenis-Aspirated		Aspirated-Tense			Lenis-Tense	
	Affricates	Stops	Affricates	Fricatives	Stops	Affricates	Stops
Roughness	.967	**.960**	**.965**	.942	**.982**	.944	.907
H1*–H2*	.967	.959	.944	.942	.976	.946	.923
H2*–H4*	.967	.952	.958	.942	.964	.953	.915
H1*–A1*	.951	.952	.963	**.971**	.973	.946	**.958**
H1*–A2*	**.972**	.950	.963	.942	.970	.944	.925
H1*–A3*	.967	.949	.963	.947	.972	**.958**	.931

Measurements of Laryngealization (2)

- Minimally sufficient models with one measure of laryngealization are compared for relative importance of that measure:

Measure	Lenis-Aspirated		Aspirated-Tense			Lenis-Tense	
	Affricates	Stops	Affricates	Fricatives	Stops	Affricates	Stops
Roughness	**.135**	**.116**	.160	.178	.152	.060	.142
H1*–H2*	.135	.085	.141	.211	.159	.073	.182
H2*–H4*	.133	.103	.177	.187	.114	.117	.193
H1*–A1*	.101	.085	.218	**.257**	**.278**	**.184**	**.398**
H1*–A2*	.096	.068	.218	.202	.250	.131	.328
H1*–A3*	.096	.074	**.235**	.218	.189	.182	.277

Measurements of Laryngealization (3)

- Tense contrasts: spectral tilt measures had higher importance values than roughness.
  - H1*–A1* was most important in 5/6 models.
- Lenis-aspirated contrast, roughness had higher importance values than spectral tilt.
  - Roughness inversely correlates with f0 (in Thai; Perkins, 2021), so that roughness is raised following lenis obstruents (low tone).

Measurements of Laryngealization (4)

- Spectral tilt correlates with creakiness & breathiness.
  - Lenis are breathy, (raised spectral tilt) (Cho et al, 2002).
  - Spectral tilt diverges for lenis (raised) and tense (lowered).
  - Roughness converges for lenis and tense (both raised).
- Therefore, aspirated-tense contrast is most informative.
  - Accuracy: Higher roughness for affr. & stops (not fricatives).
  - Importance: Higher spectral tilt in all three models.
    - Reason: Correlation between roughness and f0.