Exploring the Role of Fricatives in Classifying Healthy Subjects and Patients with Amyotrophic Lateral Sclerosis and Parkinson's Disease

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ALS and PD

- **Amyotrophic Lateral Sclerosis (ALS)** and **Parkinson's Disease (PD)** are **incurable** and **progressive neuro-degenerative** diseases affecting **muscle movements**.
- **Dysarthria** is prevalent in both diseases.
- Speech functions including **phonation**, **articulation**, and **respiration**, are reported to get affected.

Sustained Phoneme Production (SPP) Task

- **SPP tasks** are commonly used in **clinical assessment of dysarthria**.
  - Simple and easy to administer
  - Can assess all the required sub-systems of speech
  - Different types of phonemes are examined, e.g., **vowels** and **fricatives**
- Can be a **potential task** for speech-based **automatic diagnosis** of ALS & PD.

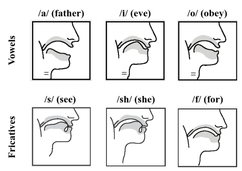
Our Objective

To analyze the relative utility of sustained fricatives (SFs), w.r.t. sustained vowels (SVs), in SPP task based classification of ALS/PD vs. Healthy (HC)

Motivation

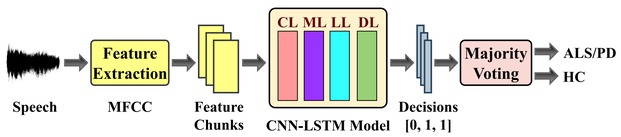
Physiological mechanisms of uttering vowels and fricatives are different.

- **Vowels:** Open vocal tract acting as a resonance chamber
- **Fricatives:** Narrow constrictions in the vocal tract leading to frication



The impacts of dysarthria on vowels and fricatives may differ significantly.

Classification Approach



CL: 1D-CNN layer
ML: Maxpooling layer
LL: LSTM layer
DL: Dense layer

Experimental Details

- **Dataset**
  - **Place of data collection:** NIMHANS, Bengaluru, India
  - **Subjects:** 35 (25M + 10F) from each of ALS, PD and HC groups (Every subject gave an informed consent.)
  - **Speech task:** Sustained utterances of vowels /a/, /i/, /o/ and fricatives /s/, /sh/, /f/
  - **Total #utterances:** 526 (ALS), 528 (PD), 507 (HC)
  - **Mean (SD) of utterance length (sec):** 3.30 (2.36) (ALS), 4.09 (2.53) (PD), 5.06 (2.04) (HC)
  - **Recording device:** Zoom H6 with XYH-6 capsule
  - **Sampling frequency:** 44.1 kHz (downsampled to 16 kHz)
- **Validation Protocol:** 5-fold cross-validation at subject level

Performance of Fricatives vs. Vowels

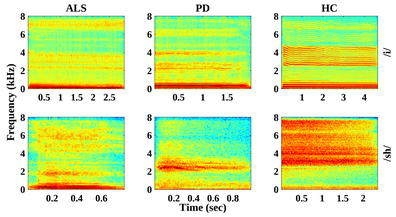
Mean classification accuracies in % (SD in bracket) obtained using different sustained phonemes

	Phonemes	ALS vs. HC	PD vs. HC
Vowels	/a/	62.88 (7.91)	55.97 (9.89)
	/i/	**78.42 (10.03)**	**72.85 (12.04)**
	/o/	68.40 (5.47)	51.78 (8.73)
	Overall	**69.90**	**60.20**
Fricatives	/s/	76.90 (7.86)	65.37 (7.84)
	/sh/	77.47 (7.56)	66.66 (9.40)
	/f/	72.44 (6.24)	64.70 (10.43)
	Overall	**75.60**	**65.58**

- Fricatives achieve higher mean classification accuracies than /a/ and /o/, though /i/ outperforms all.
- /sh/ achieves the highest mean performance among the fricatives.
- Patients seem to find it difficult to form constrictions while producing fricatives, or to proximally position the tongue and palate while uttering /i/.

Some Spectral Differences

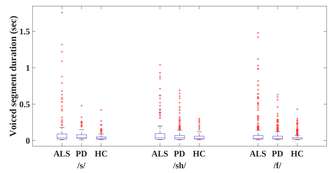
- For vowels (e.g., /i/),
  - **Less evident harmonic structure** of fundamental frequency in dysarthric utterances than HC utterances
  - **Lower formant energies** in dysarthric utterances than healthy ones
- For voiceless fricatives (e.g., /sh/),
  - **Less prominent high frequency content** in dysarthric spectrograms than HC ones
  - **Unwanted voicing** in dysarthric utterances



Illustrative narrowband spectrograms

Unwanted Voicing of Voiceless Fricatives

- Plot shows the distributions of the durations of voiced segments in fricative utterances.
- **Dysarthric fricatives have longer voiced segments** (at 1% significance level as per Wilcoxon ranksum test) than those produced by HCs.



Effect of Fusion

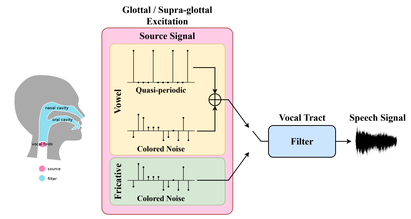
Mean (SD) of classification accuracies in % obtained using intra- and inter- phoneme decision-level fusion

	Fusion scheme	ALS vs. HC	PD vs. HC
Intra	/i/+/i/+/i/	81.83 (13.35)	**80.03 (11.96)**
	/s/+/s/+/s/	80.04 (8.58)	70.05 (13.19)
	/sh/+/sh/+/sh/	79.95 (8.90)	66.15 (11.36)
Inter	/i/+/s/+/sh/ (Distinct model)	82.02 (8.31)	75.67 (7.58)
	/i/+/s/+/sh/ (Pooled model)	**83.35 (5.93)**	72.65 (9.63)

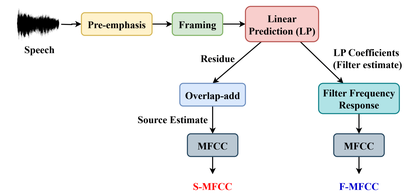
- Intra-phoneme fusion outperforms the single utterances in most cases.
  - Nature of cues vary in different utterances of a single phoneme.
- Inter-phoneme fusion using the pooled model achieves the highest mean ALS vs. HC classification accuracy.
  - Cues present in different phoneme utterances are complementary in nature.
- However, inter-phoneme fusion could not outperform intra-phoneme fusion of /i/ for PD vs. HC classification.

Source - Filter Analysis

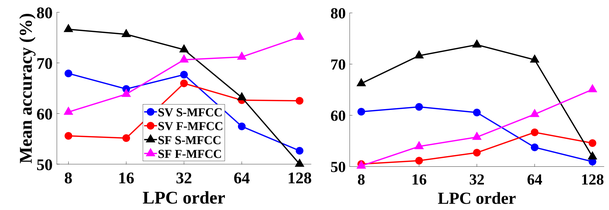
Source - Filter Model



Estimation Method



Relative Performance



(a) ALS vs. HC (b) PD vs. HC

Mean classification accuracies (in %) over all SVs and those over all SFs obtained using S-MFCC and F-MFCC estimated with varying LPC orders

- S-MFCC and F-MFCC of SFs outperform those of SVs at most LPC orders.
- At lower LPC orders, S-MFCC outperforms F-MFCC, while F-MFCC achieves better performance at higher LPC orders.
- At high LPC orders, more detailed structures are captured in the filter estimate and the source estimate becomes nearly white.

Conclusion

- **Key Takeaways:**
  - Phonemes involving constrictions in the vocal tract (fricatives) or even close placement of tongue and palate (/i/) are found to be better differentiators than the relatively more open ones.
  - Different phonemes are observed to capture complementary cues making inter-phoneme fusion the best choice for ALS vs. HC classification.
  - However, the same is not empirically true for PD vs. HC case.
- **Future Work:**
  - To derive some quantifying measures of proximity of pairs of articulators from the speech signals
  - To use those measures directly for performing ALS/PD vs. HC classifications

References

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