Robust Digital Bulbar Monitoring in ALS Using a Minimal, Interpretable Speech Feature Panel

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Introduction

Digital speech biomarkers provide a non-invasive window into progression of Amyotrophic lateral sclerosis (ALS), but their utility depends on clinical transparency. We present a robust, low-dimensional monitoring panel that is optimized for clinical interpretability over high-quantity data sets. This streamlined approach focuses on the most sensitive indicators of bulbar decline, offering a tool for (i) identifying ALS and (ii) tracking dysarthria progression in both research and clinical practice.

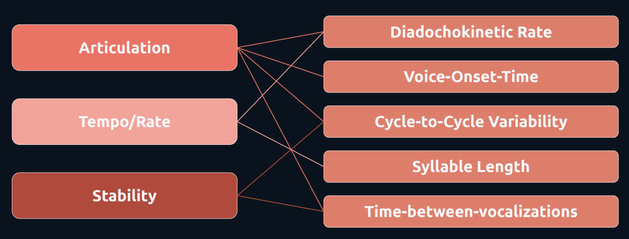
Methods

Data Collection

- In-clinic smartphone recordings (Vox4Health, SAND data set)
- 165 individuals with ALS and 107 healthy controls (HC)
- Speech tasks (taken from SAND data)
  - DDK (pa-pa-pa, ta-ta-ta, ka-ka-ka)
  - Sustained vowel phonation (i, a, u)

Data Processing

- Acoustic feature extraction via SIGMA, ki:elements' processing pipeline
  - Composite scores using DDK features



  - Vowel Formants F1 and F2 to calculate
    - Vowel Space Area (VSA)
    - Vowel Articulation Index (VAI)

Data Analysis

- Group differences were computed via Kruskal–Wallis tests
- Discriminative performance for i) group membership and ii) speech severity (indexed by ALSFRS-R speech score) were evaluated via ROC and Spearman correlation analyses

Group	Sex	Age	ALSFRS-R speech
HC (n = 107)	56 M, 51 F	64.2 (10.1)	
ALS (n = 165)	97 M, 68 F	63.0 (12.0)	3.2 (0.8)

Conclusion

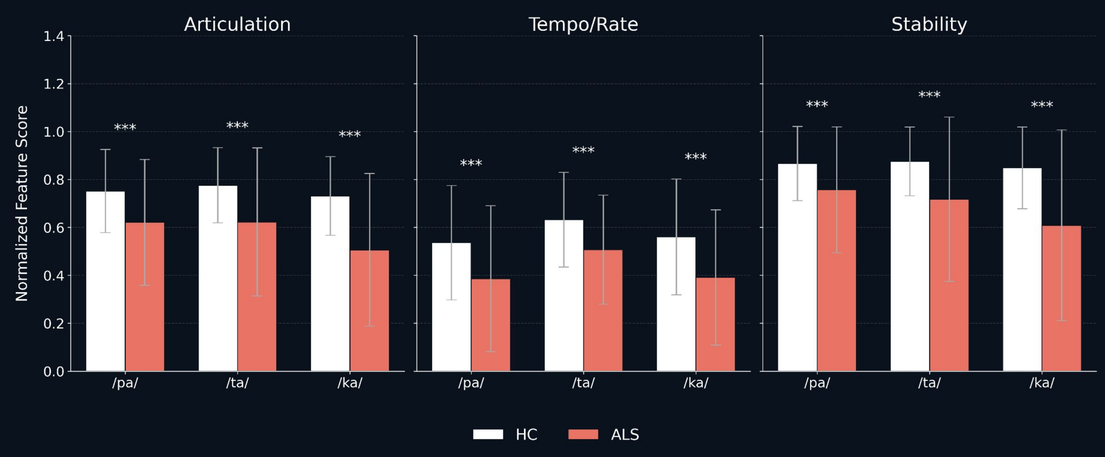
A minimal, interpretable feature set captures ALS bulbar impairment with high precision. Our findings reveal a critical functional split in task utility:

- **Early Detection:** The velar DDK task /ka/ is the most sensitive marker for identifying early bulbar involvement.
- **Progression Monitoring:** The alveolar DDK task /ta/, alongside vowel space reduction, serve as superior longitudinal markers of bulbar severity.

This task-specific approach enhances clinical transparency and provides a validated, low-burden pathway for integrating digital monitoring into multi-center ALS trials.

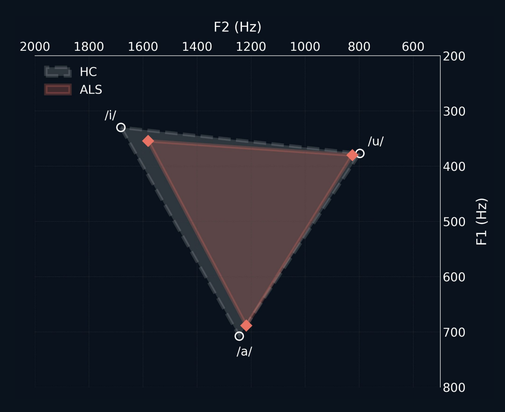
Results: Group Differences

All DDK composite scores showed significant group differences.



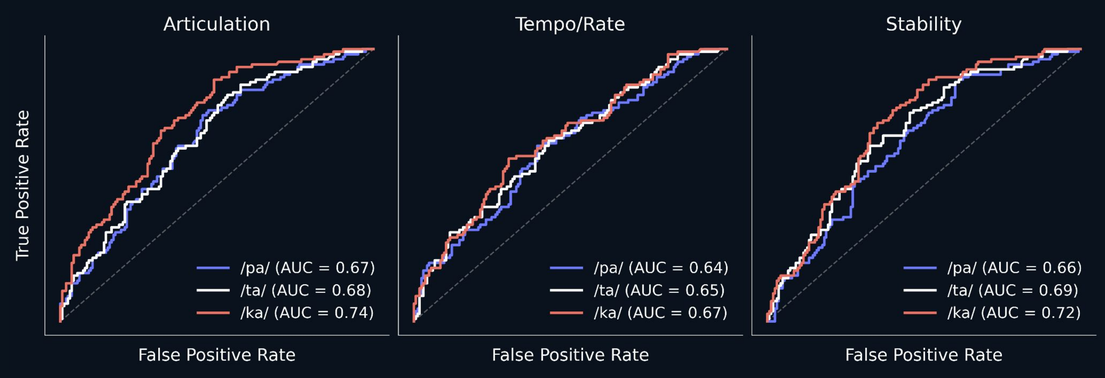
Both vowel space measures (VAI, VSA) were reduced in ALS, indicating a smaller articulatory working space in ALS which is depicted based on formants F1 and F2 of vowels /i/, /a/, and /u/.

	HC	ALS	Stats
VAI	0.876 (0.172)	0.826 (0.175)	H = 4.831 p = 0.028
VSA	159342 (86099)	130127 (88380)	H = 8.762 p = 0.003



Results: Identifying ALS

Composite scores taken from the velar DDK task /ka/ emerged as the most sensitive digital measure, significantly outperforming global vowel metrics (VAI: AUC = .58; VSA: AUC = .61). The highest discriminative power was achieved by Articulation (AUC = .74, Sens = .51, Spec = .89) and Stability (AUC = .72, Sens = .65, Sepc = .73) within this task.



Results: Determine Dysarthria Severity

Composite scores taken from the alveolar DDK task /ta/ were the most effective task, specifically Stability (AUC = .81, Sens = .97, Spec = 0.53) and Articulation (AUC = .79, Sens = .88, Spec = .65). Vowel space metrics demonstrated moderate capability to track progression of dysarthria severity (VAI: AUC = .72, Sens = .84, Spec = .50; VSA: AUC = .71, Sens = .78, Spec = .62).