

TEMPORAL RESPIRATORY RHYTHM INSTABILITY AS A PORTABLE SCREENING BIOMARKER FOR EARLY PARKINSON’S DISEASE

A LIGHTWEIGHT RESPIRATORY SENSING SYSTEM CAN QUANTIFY TEMPORAL BREATHING INSTABILITY AND PROVIDE AN INTERPRETABLE SCREENING INDICATOR FOR EARLY PARKINSONIAN AUTONOMIC DYSFUNCTION.

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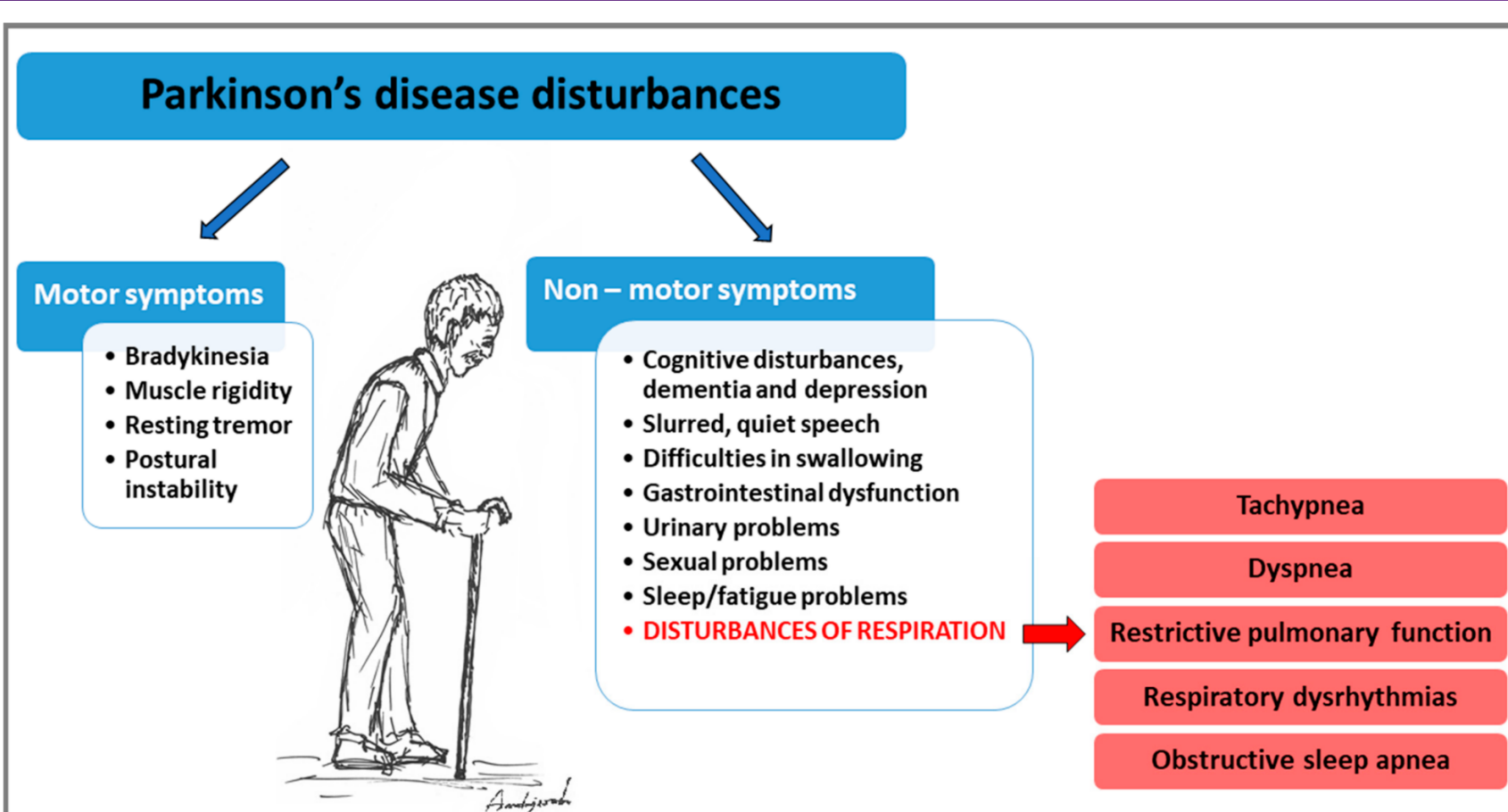
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1. INTRODUCTION

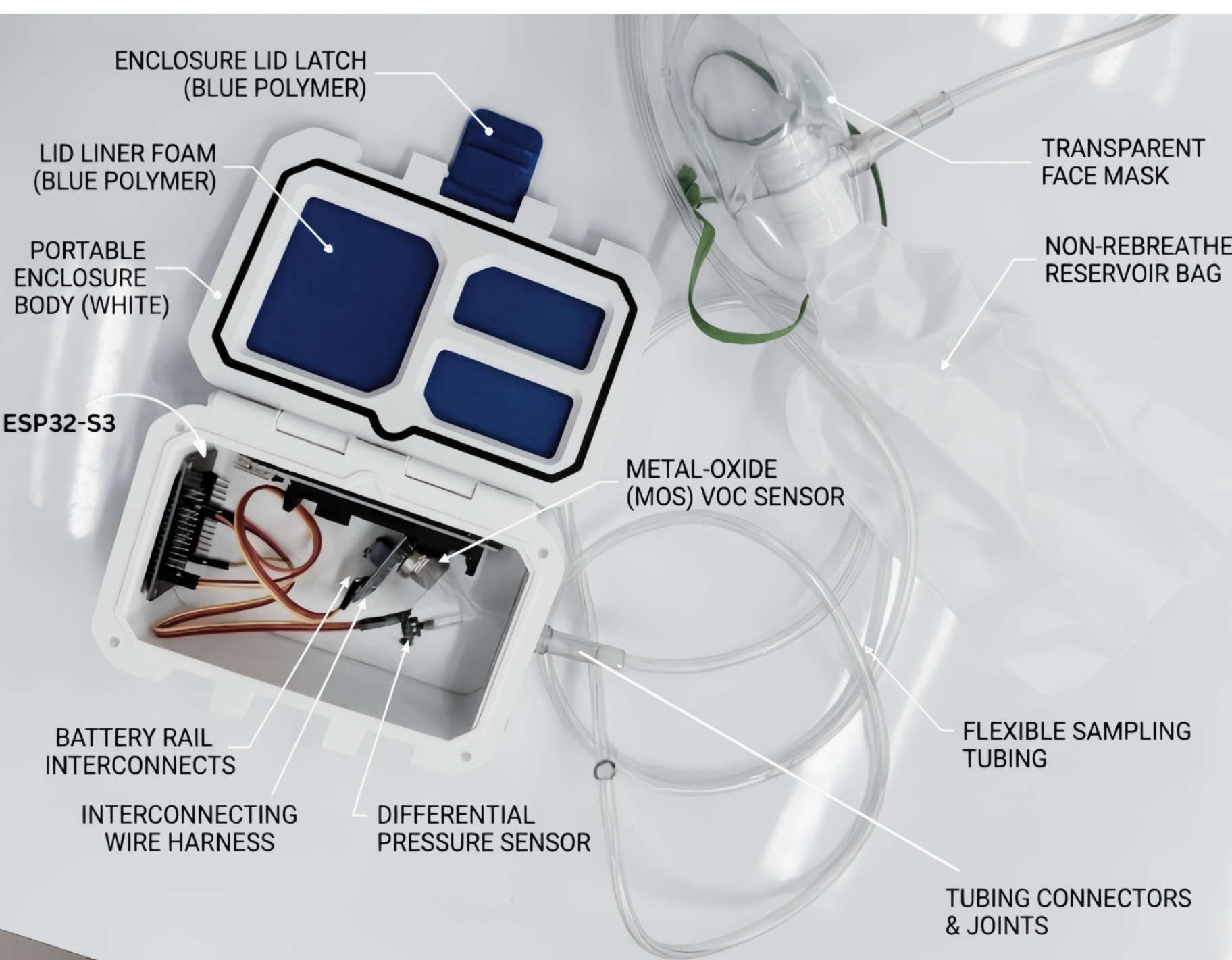
- **Parkinson’s disease** is a **progressive neurodegenerative disorder**.
- **Motor symptoms** often appear after **substantial neurodegeneration**.
- **Non-motor and autonomic symptoms** may appear **earlier**.
- **Respiratory dysfunction** is an **underexplored non-motor pathway**.
- **Portable screening tools** are **needed for early and community-based assessment**



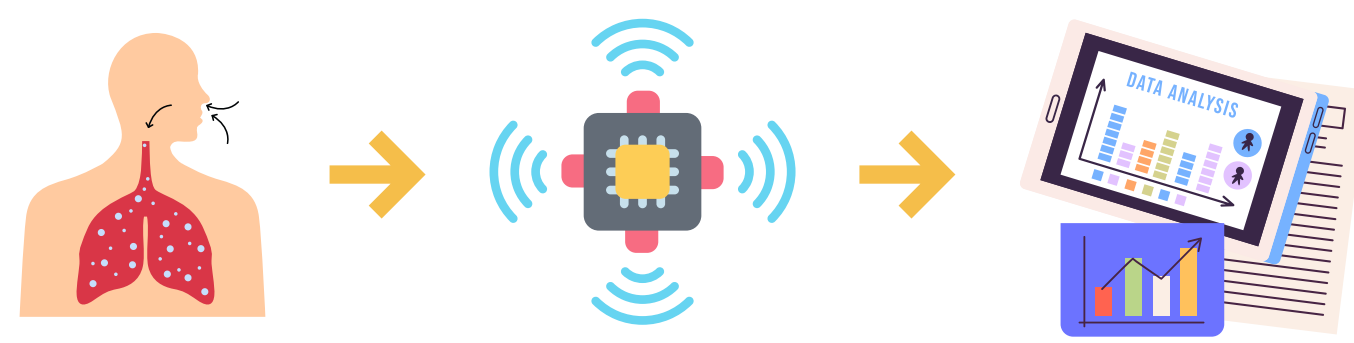
2. MOTIVATION & RESEARCH GAP

- **Clinical motor assessment**
 - Symptoms often appear late
 - Need earlier physiological indicators
- **Chemical breathing profiling**
 - Requires complex analysis
 - Not ideal for large-scale screening
- **High-dimensional AI models**
 - Limited interpretability
 - Need more explainable features
- **Our approach**
 - Simple and portable
 - Analyzes temporal respiratory instability

3. METHODOLOGY



- **Wearable or mask-based breath acquisition interface.**
- **Differential pressure sensing for airflow-related respiratory dynamics.**
- **MOS VOC sensor for dynamic breath context signal**
- **ESP32-S3 microcontroller for synchronized acquisition.**
- **Battery-powered portable operation.**



3.1 Signal Acquisition

$$x(t) = [p(t), v(t)] \quad (1)$$

- $p(t)$: differential pressure signal.
- $v(t)$: VOC sensor voltage signal.
- T_{warm} : sensor stabilization period.
- T_{rec} : 3-5 minute resting recording window.

- **Participants breathe normally** near the **sensing chamber** while **seated** in a **relaxed position**.
- **MQ138** captures **VOC-related gas response**; the **pressure sensor** captures **breathing pressure variation**.

- **ESP32** records **timestamped MQ138** and **pressure values** and **exports them for machine learning analysis**.
- **Each session lasts approximately 1 to 3 minutes** depending on the **experimental setup**.

3.2 Preprocessing

Raw pressure and VOC signals are preprocessed to improve robustness and preserve breath patterns.

1. **Baseline Compensation** - To remove slow pressure drift
$$\hat{p}[n] = p[n] - \hat{p}_{\text{trend}}[n] \quad \text{Find } \hat{p}_{\text{trend}}[n] \text{ using moving-median filter low-pass smoothing}$$
2. **Noise Reduction** - Low-pass filter is applied to suppress high frequency electronic noise while preserving intra-breath variation
3. **Z-score normalization** - Each signal channel was normalized per recording
$$\hat{x}_i[n] = \frac{x_i[n] - \mu_i}{\sigma_i}, \quad i \in \{p, v\} \quad \mu_i \text{ and } \sigma_i \text{ are estimated from the stabilized signal segment}$$
4. **Windowed feature extraction**
$$\{\Delta P, \sigma_P, E, BI, \bar{R}_V, f\}$$
 Overlapping windows were used to computer temporal descriptors

3.3 Feature Extraction

- **Breathing Instability Index (BI):**
Measures how much a person's breathing changes over a short period of time.
- **Pressure Standard Deviation:**
Measures how much breathing effort varies.
- **Energy Dispersion:**
Shows how stable or unstable the breathing rhythm is.
- **Frequency Variability (σf):**
Measures changes in breathing rate over time.
- **VOC Rate-of-Change ($\bar{R}_V$):**
Measures how quickly the VOC signal changes over time.

3.4 Composite Risk Score

$$S = w_1 BI + w_2 \sigma_f + w_3 \bar{R}_V \quad (2)$$

The score combines **respiratory instability**, **breathing frequency variability**, and **VOC temporal fluctuation** into an **interpretable neuro-respiratory screening score**. A **higher score** indicates **greater PD-related respiratory rhythm instability**.

4. RESULTS

4.1 Experimental Setup

- **Resting spontaneous breathing condition.**
- **Recording duration: approximately 3-5 minutes after sensor warm-up.**
- **Pilot cohort: 20 participants.**
- **10 early-stage Parkinson’s disease participants.**
- **10 age-matched healthy controls.**

4.4 Classification Performance

- **Accuracy (~85%) - Overall performance**
Indicates that the model correctly classified most participants overall.
- **Sensitivity (~88%) - Ability to identify PD-risk participants**
Shows a strong ability to identify participants with Parkinson's disease.
- **Specificity (~82%) - Ability to identify healthy controls**
Demonstrates reliable identification of healthy control participants.
- **AUC (0.89) - Indicates excellent discrimination between groups**
Suggests good separation between Parkinson's disease and healthy groups in the pilot dataset.

4.2 Temporal Energy Fluctuation

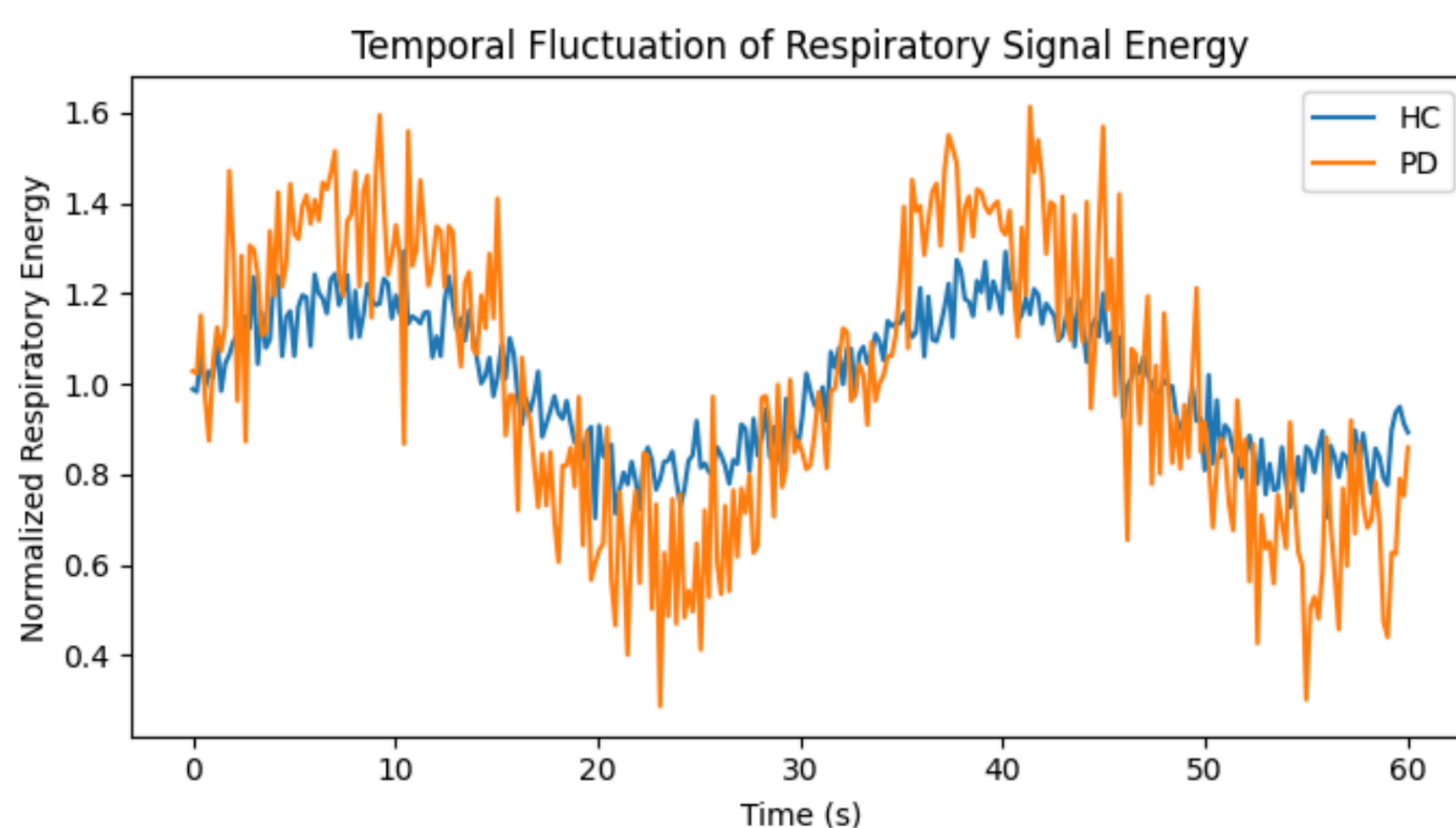
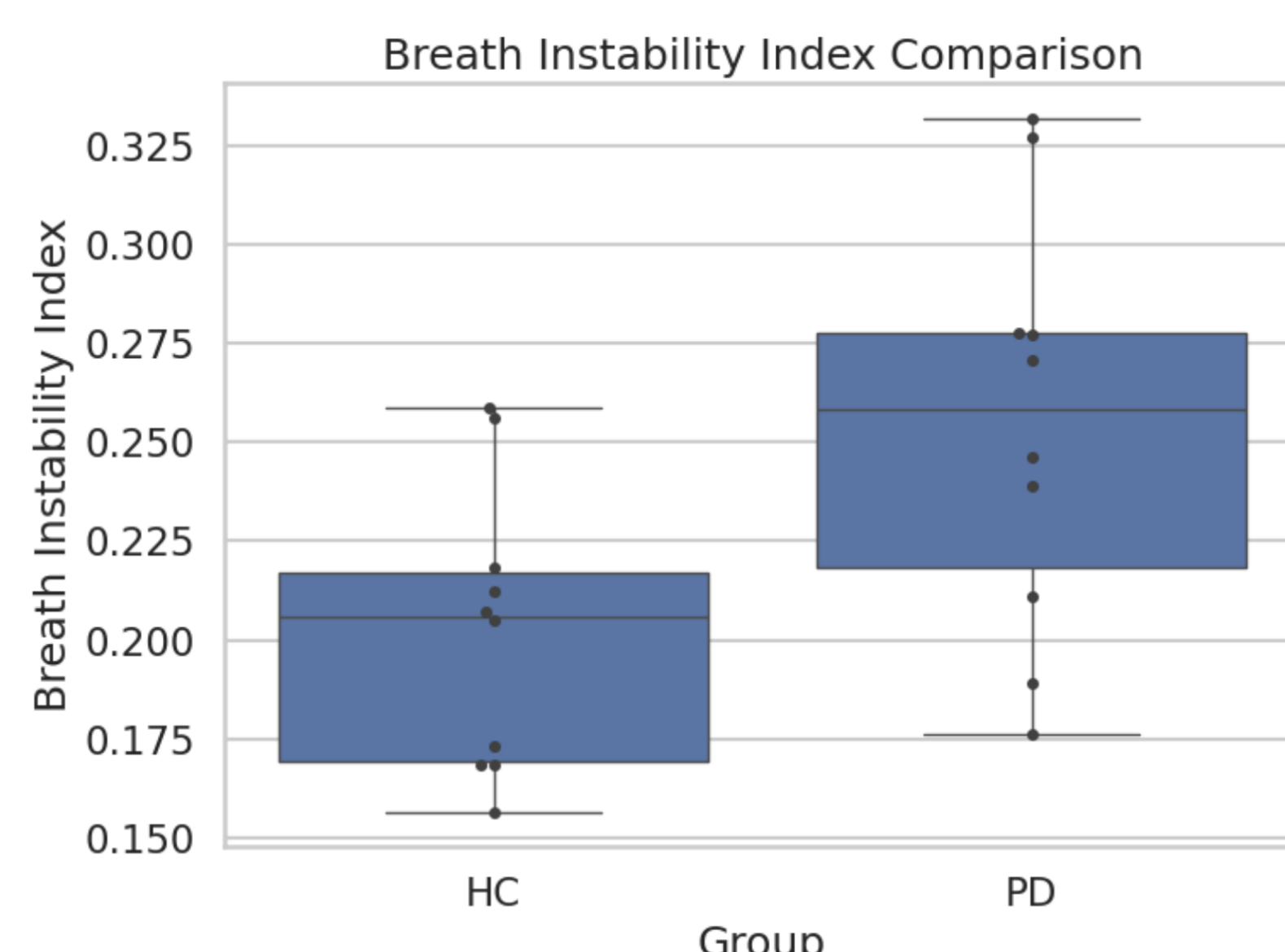


Fig. 5. Sliding-window respiratory signal energy (E) illustrates greater temporal fluctuation in PD recordings.

Sliding-window respiratory energy shows broader and more irregular fluctuation in PD recordings than in healthy controls, supporting the presence of reduced rhythm stability.

4.3 Breath Instability Index



Distribution of Breath Instability Index (BI) across groups (boxplots with median and IQR).

Parkinson's disease group showed greater breathing instability than healthy controls.

5. DISCUSSION

- **Increased BI and frequency variability** may reflect **altered autonomic and brainstem respiratory regulation**.
- The **proposed framework is interpretable** because it uses **physical signal descriptors** rather than **black-box features only**.
- **Pressure-derived features** are especially useful for capturing **natural rhythm instability**.
- **VOC dynamics** may provide **complementary information** but require **environmental compensation** in future work.

6. LIMITATION

- **Small pilot cohort.**
- **Controlled indoor recording condition.**
- **MOS VOC sensor** is sensitive to **humidity, airflow turbulence, and drift**.
- **No large-scale longitudinal validation yet.**
- Needs **comparison against other autonomic or neurodegenerative disorders**.

7. CONCLUSION

- A **portable respiratory sensing framework** was proposed for **early PD screening**
- **Temporal respiratory instability** can be quantified using **interpretable physical descriptors**.
- **Pilot results show higher instability** in **early-stage PD participants**.
- The **composite risk score** achieved **promising screening performance**.
- **Larger multicenter and longitudinal studies** are needed before **clinical translation**.