Differential Motor Intent Decoding in ECoG: Hand vs Tongue Movements

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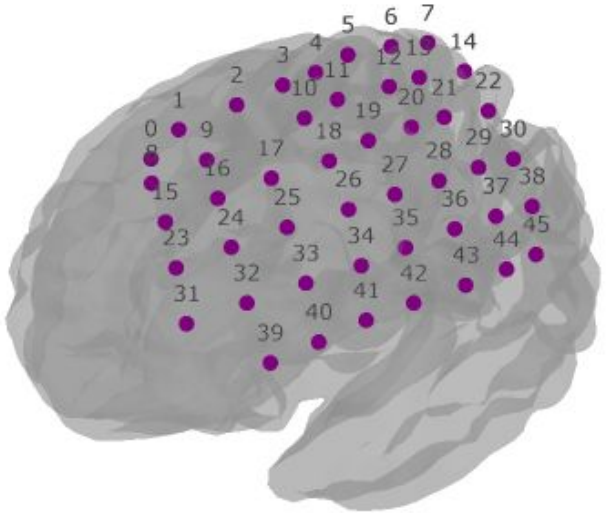
Introduction & Background

Introduction:

Electrocorticography (ECoG): A technique to record brain activity directly from the cortex, capturing high-frequency signals in the high gamma band (70–200 Hz).

Motor Execution Connection: High gamma activity is strongly associated with motor functions, reflecting neural processes during movement.

BCI Applications: ECoG enables brain-computer interfaces (BCIs) for neurorehabilitation, aiding patients with stroke, paralysis, or movement disorders.



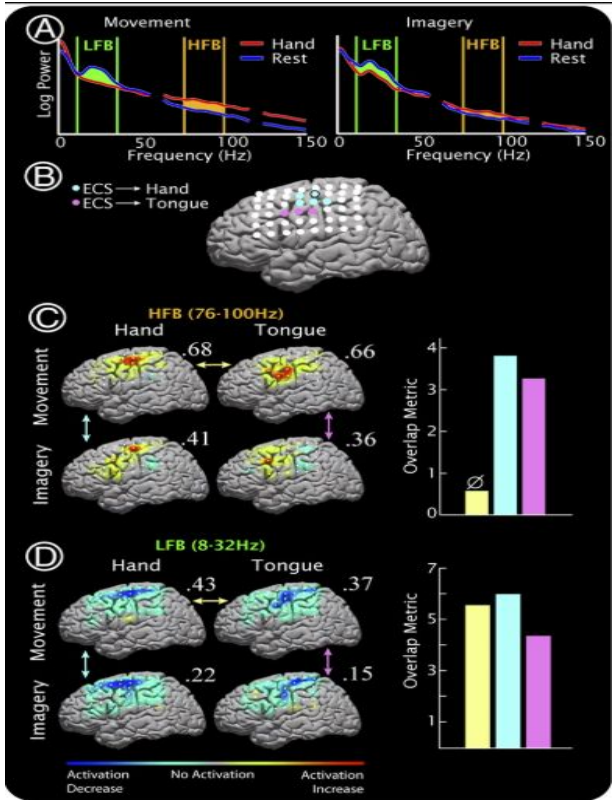
Background:

Key Challenge: Accurately distinguishing actual movement from imagined movement in single-trial ECoG data remains difficult.

Impact on BCIs: This limitation slows the development of reliable, personalized BCIs for clinical use in neurorehabilitation.

Study Objective: Investigate whether high gamma power can effectively differentiate executed versus imagined tongue and hand movements using human ECoG data.

The Kai Miller Datasets



What are these datasets?

Collection of high-resolution **electrocorticography (ECoG) recordings** acquired from patients performing motor and language tasks, offering a rare window into the dynamics of the human brain at the cortical surface.

Produced by Dr. Kai Miller, a neurosurgeon at Stanford along with his team to better understand the correlation between actual and imagery movements.

We used the 2019 Dataset, tracking ECog readings from 7 epilepsy patients

What data does it provide us?

- Preprocessed and raw ECoG signals
- Task onset annotations
- Subject demographics
- Electrode locations (registered to cortical surfaces)

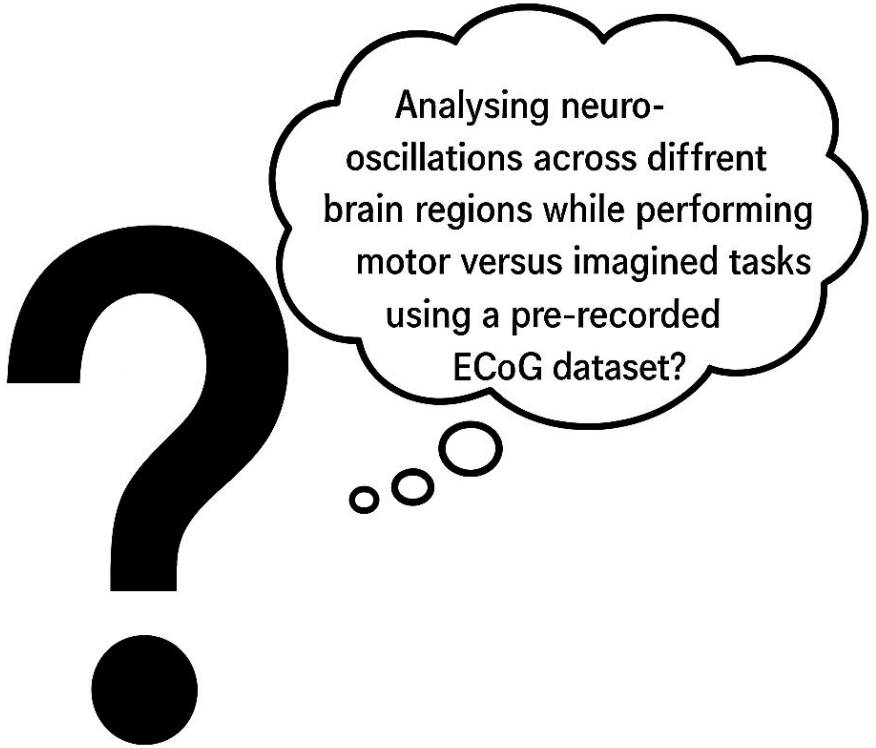
But why this specific dataset?

It contains finely sampled electrocorticography (ECoG) recordings from patients performing **hand and tongue movements**, with a clear distinction between **overt actions and motor imagery**. This makes it particularly well-suited to investigate the neural signatures of movement intention versus execution.

Research Question

The significance

- Personalized BCIs
- Neurophysiological Insights
- Enhanced Rehabilitation
- Neural Prosthesis Design



Methodology

Preprocessing:

- Voltage data were extracted from **Brodmann Areas:** 2, 3, 4, 6, 9, 43, 45 (closely linked to **motor control** and **sensory processing**)

Feature Extraction:

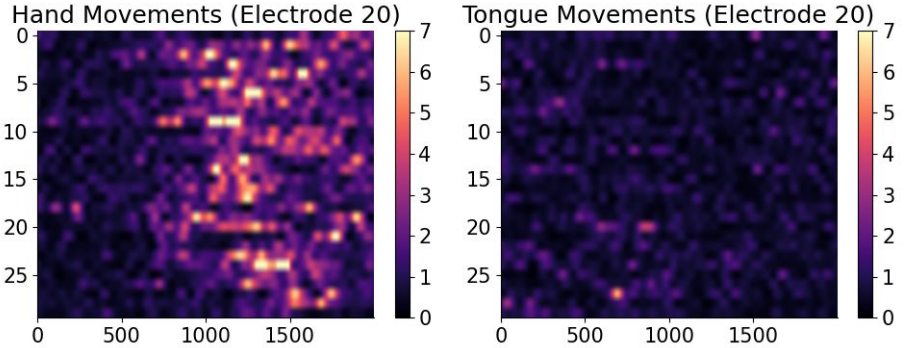
- Compute **Power Spectral Density (PSD)** for each trial and electrode using **Welch's method**
- **Flatten** the PSD (frequency × channels) into a 1D vector
- Apply **Principal Component Analysis (PCA)** to reduce to 11 key features
- Extract **labels** for each trial: 0 = hand movement, 1 = tongue movement

Classifiers:

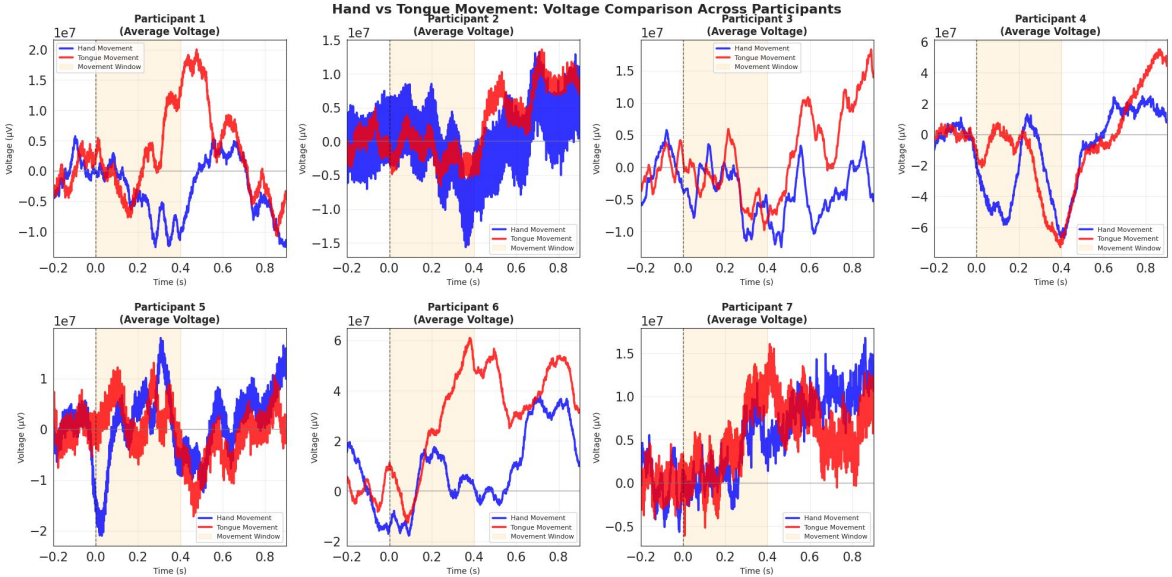
- **Logistic Regression**: A linear classifier using regularization
- **SVM**: Finds a separating hyperplane; good for high-dimensional data
- **Random Forest**: Ensemble of decision trees; captures complex feature interactions

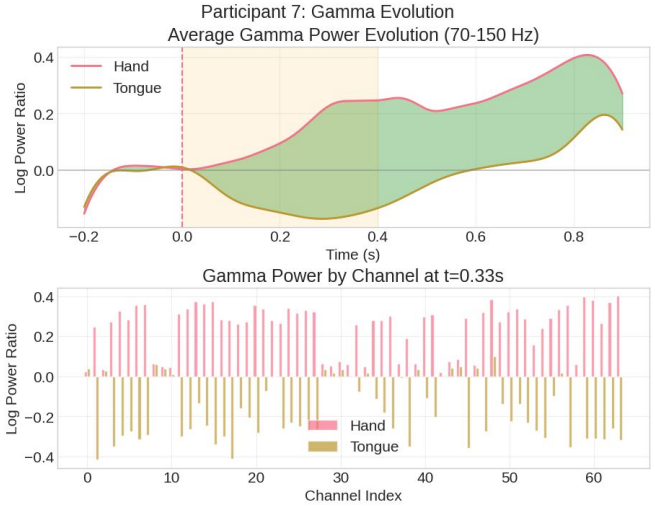
Results

Comparison of hand and tongue movement for electrode 20

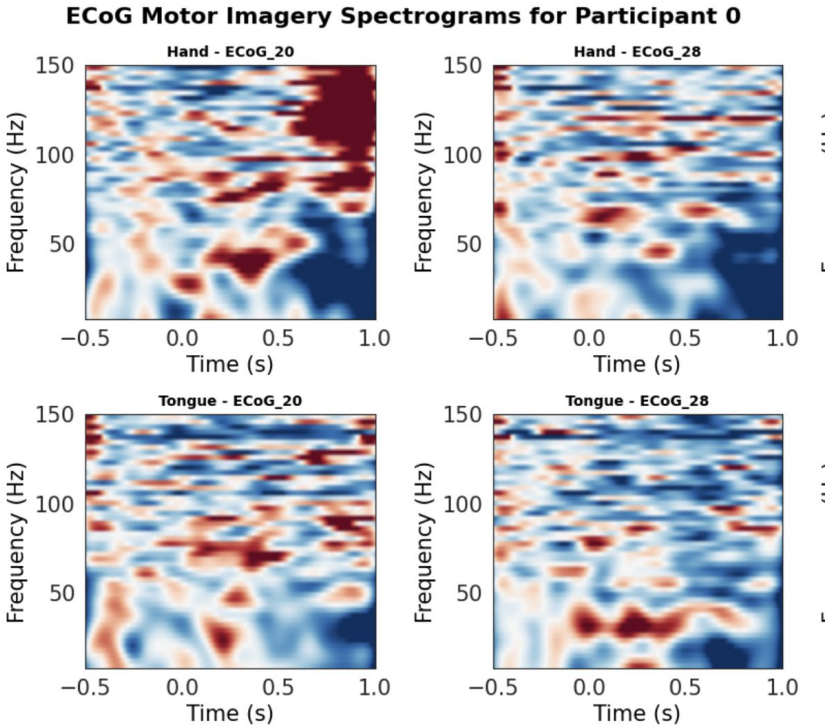


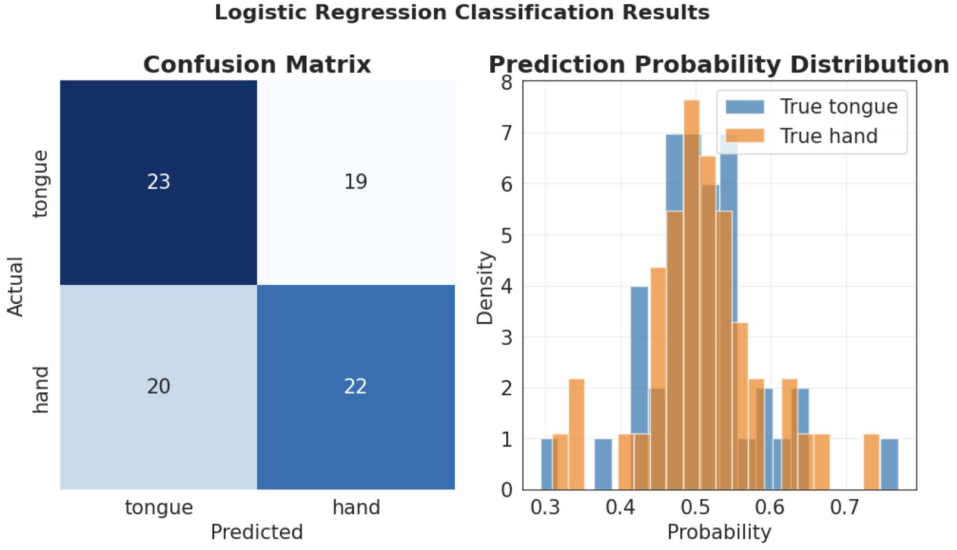
Mean voltage comparison for tongue and hand movements for selected Brodmann areas





Results





SUMMARY:

Model	Train Acc	Test Acc	CV Mean
Logistic Regression	0.562	0.536	0.467
SVM	0.708	0.560	0.462
Random Forest	1.000	0.429	0.474

Conclusion

1. **Temporal dynamics**
    - Executed hand movements produced rapid, high-amplitude gamma surges peaking within ~0.3–0.5 s of stimulus onset.
    - Imagined tongue movements elicited smaller, delayed gamma increases within the same window.
2. **Spatial localization**
    - Hand execution: high-gamma enhancements localized predominantly to primary motor cortex (Brodmann 4, 6).
    - Tongue imagery: comparatively greater (though weaker) activity in ventral regions (Brodmann 43, 45).
3. **Single-trial specificity**
    - Channel-wise comparisons at peak response times confirmed these region-specific patterns on a per-trial basis.

Future directions

Real-time Closed-looped Feedback and Adaptive BCIs

- Data Augmentation, regularization methods or implementing more complex models
- Range of electrode selections in different regions and different dynamic behaviors (Mustile *et al*., 2024)

Neuropathological Implication and Clinical Translation

- Stroke and Neurodegenerative Diseases Rehabilitation (Cunningham *et al*., 2021)


THANK YOU