

Robust phoneme classification under adverse conditions using MEG

In non-invasive speech decoding, phoneme-level classification remains a central challenge due to the inherently low signal-to-noise ratio of magnetoencephalography (MEG) data. While invasive brain–computer interfaces have achieved remarkable accuracy, their clinical applicability is constrained by surgical risks, underscoring the importance of advancing robust non-invasive approaches. Despite recent progress in applying supervised and self-supervised methods to neural data, these techniques are rarely evaluated under realistic conditions where sensor noise, artefacts, and signal variability significantly impact performance. Moreover, current benchmarks often prioritize clean accuracy, overlooking robustness as a key property for models intended for practical use in neuroscience and neuroprosthetics.

This study provides a systematic exploration of phoneme classification robustness, leveraging LibriBrain, the most extensive open-source MEG dataset to date, which comprises over 50 hours of within-subject recordings aligned to naturalistic speech. The design of adverse conditions that emulate common challenges such as sensor dropout, baseline drift, and ambient interference, and propose training strategies that combine augmentation-driven objectives with self-supervised representation learning. By situating robustness as a primary evaluation criterion, our approach aims to identify stable neural representations of phonemes that generalize across noisy and degraded conditions.

The evaluation of models within a standardized experimental framework using balanced metrics enables a comprehensive comparison between baseline and robustness-enhanced methods. The study emphasizes realistic protocols that mirror the constraints of non-invasive neural decoding, to inform both methodological innovation in machine learning and theoretical understanding of phoneme encoding in the human brain. The contributions of this paper not only establish benchmarks for robust MEG-based speech decoding but also provide insights relevant to the long-term development of safe and reliable non-invasive neuroprosthetic systems.

This work ultimately positions robustness-oriented training on large-scale single-subject MEG data as a stepping stone toward models that generalise across subjects and modalities, advancing the broader goal of reliable, non-invasive speech decoding at scale.

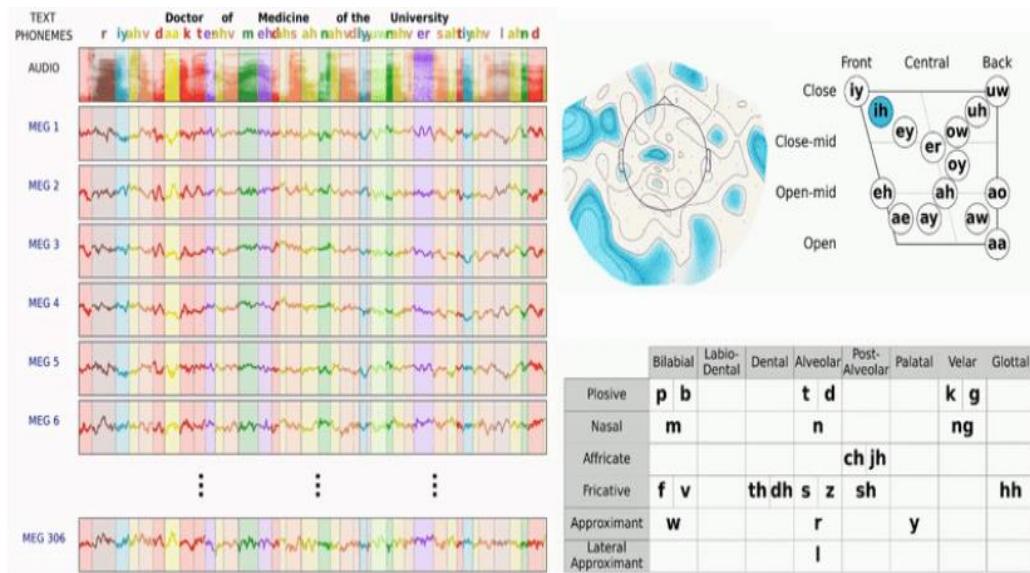


Figure: The proposal workflow of a classifier map for MEG data to the specific phonemes being heard.