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Weak Connections in Functional Brain Networks Contribute to the Classification of Anesthetic-Modulated States of Consciousness.

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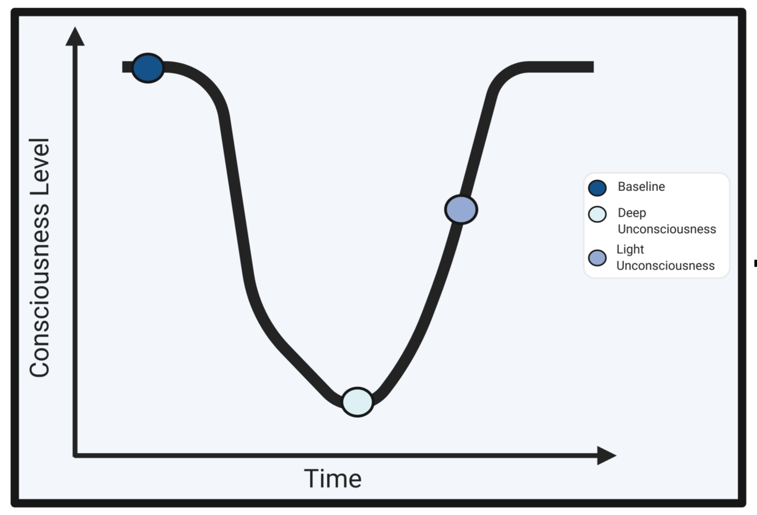
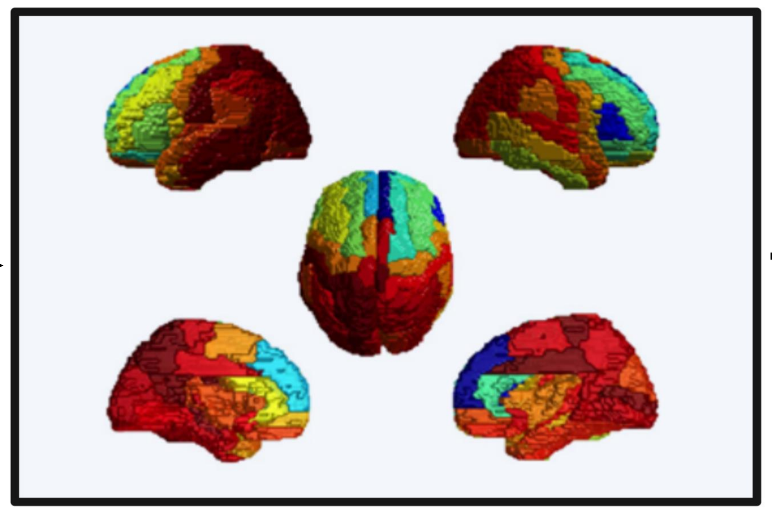
Machine Learning Pipeline

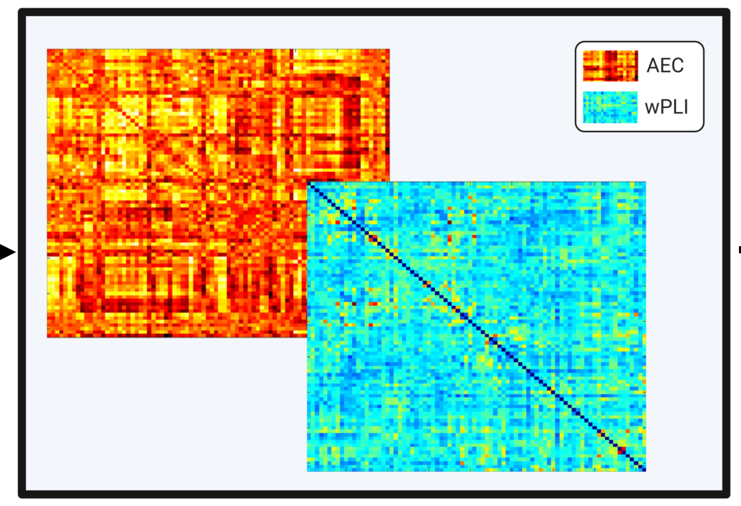
Experimental Point of Interest



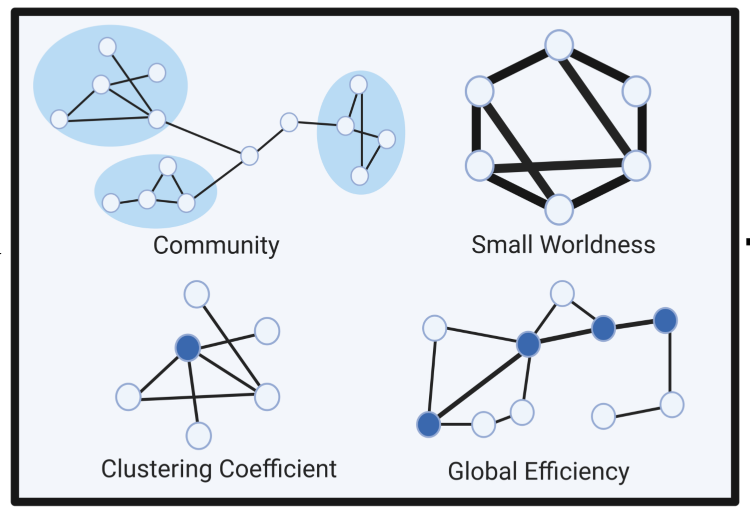
Source Localization



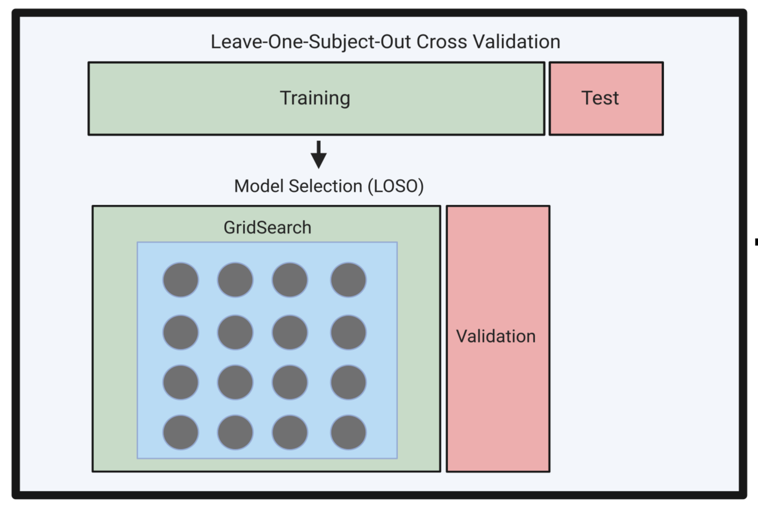
Functional Graph



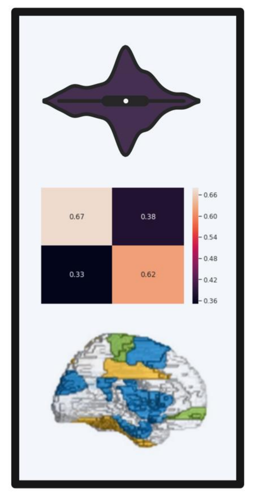
Feature Extraction



Cross-Validation Scheme



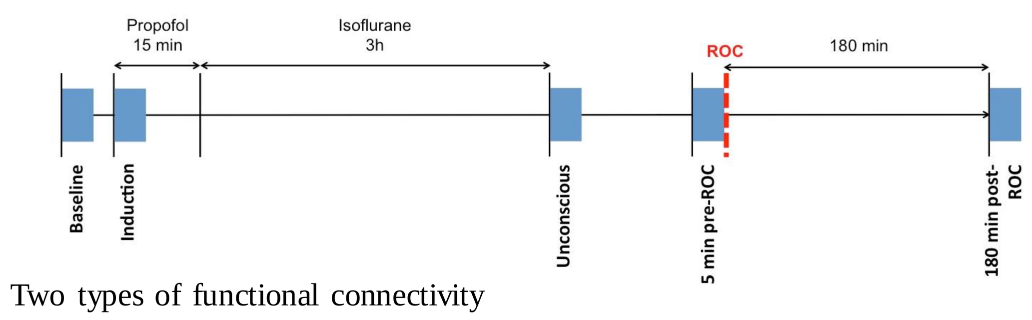
Results



Introduction

Graph theory analysis has been successfully used to capture differences in brain dynamics across various states of consciousness. For the most part, **graphs generated from functional connectivity data are often binarized to only include the strongest connections, excluding the weak, but significant, weights from the analysis**. The effects of thresholding functional connectivity brain networks to generate graphs have not been systematically investigated.

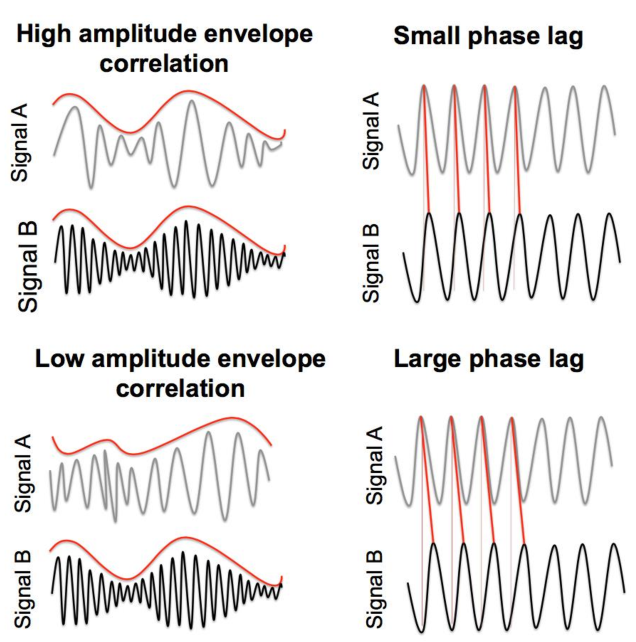
Nine participants underwent an anesthetic protocol while 128-channel EEG was recorded before (Baseline), during anesthetic-induced unconsciousness (**Unconsciousness**), and immediately prior to the recovery of consciousness (**Pre-Recovery**). The signal was source localized and averaged onto 82 regions which correspond to the cortical regions in the AAL brain atlas.



Two types of functional connectivity - **Amplitude Envelope Correlation (AEC) and weighted Phase Lag Index (wPLI)** – were calculated across all combinations of brain regions.

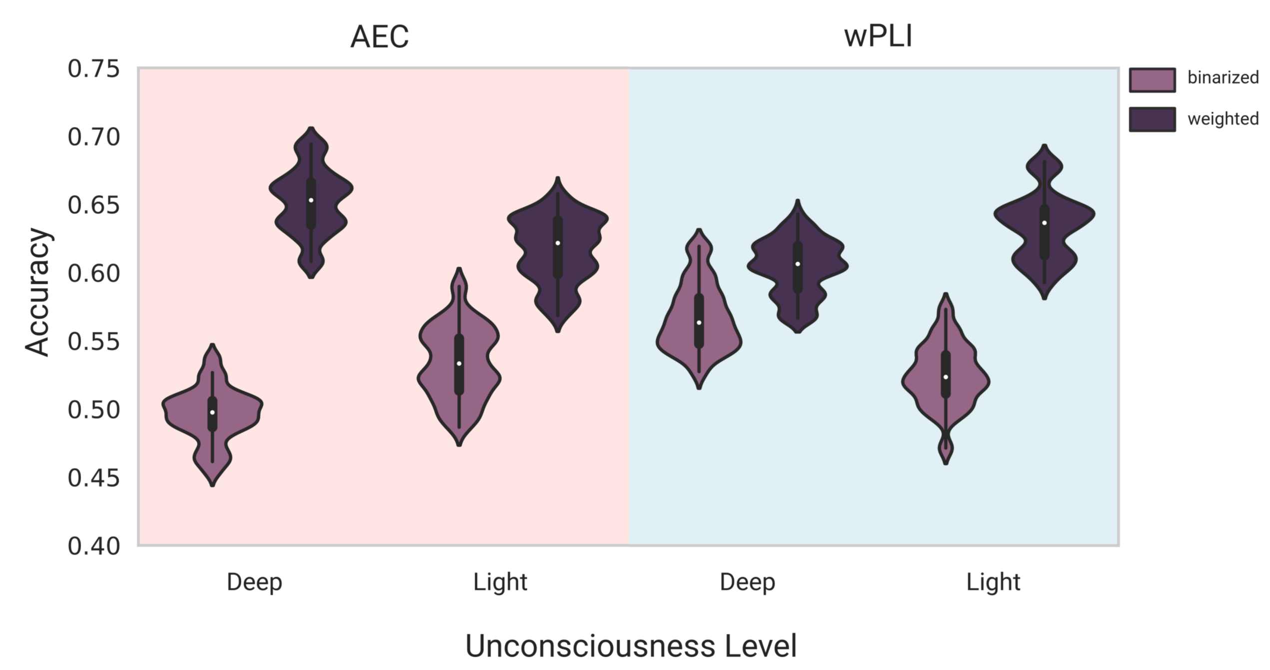
The resulting functional connectivity matrices were then either binarized (e.g. setting the top 10% percent of the connections to 1, and all others to 0) or kept weighted.

Graph theory metrics were calculated across both sets of matrices, and input to machine learning classification algorithms to predict 2 states of consciousness: Baseline vs. Unconsciousness, or Baseline vs. Pre-Recovery



Results

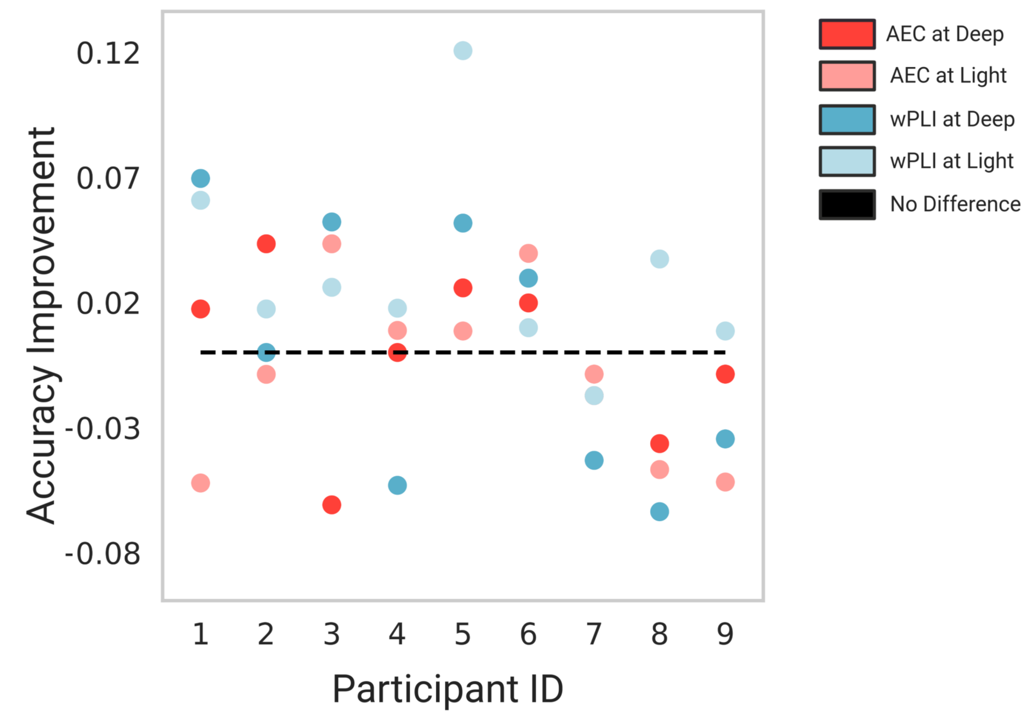
Graph Feature Performance



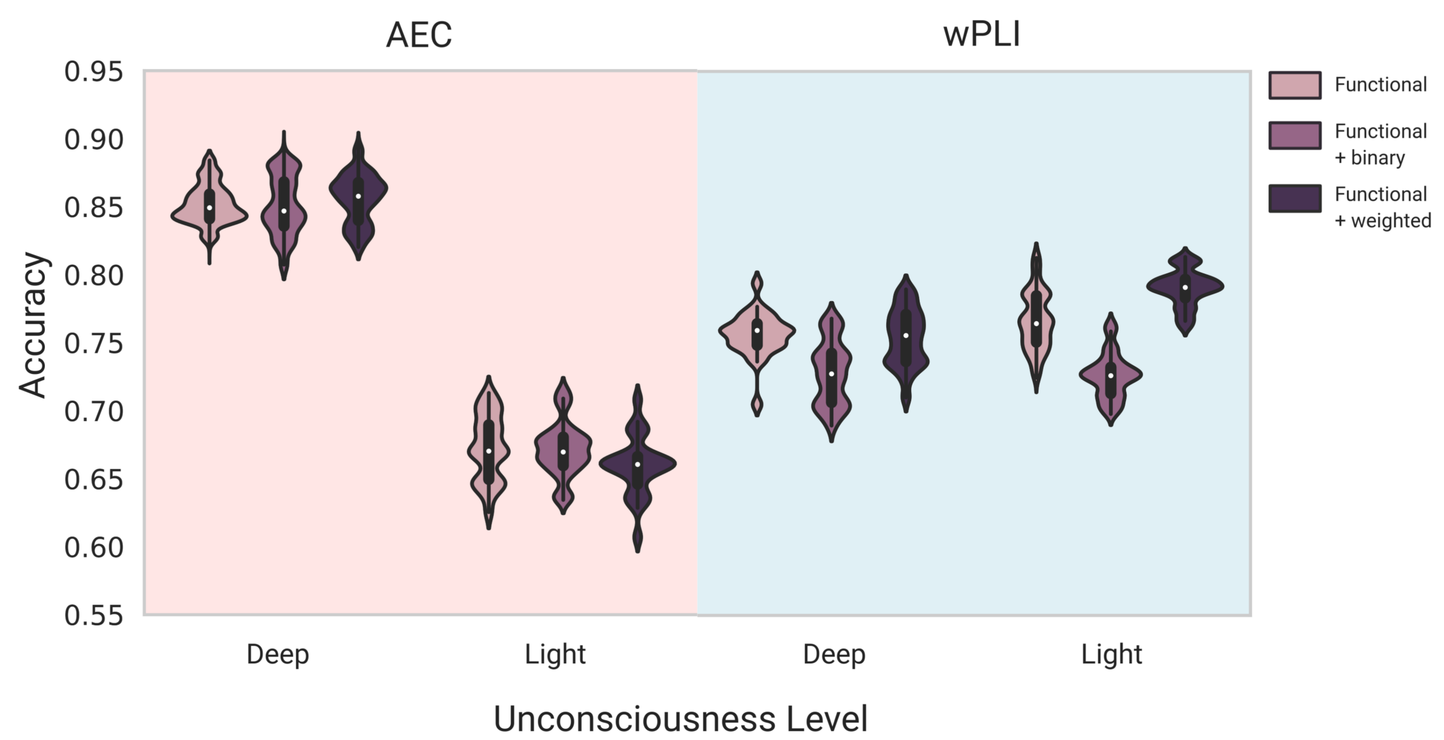
Graphs built from **weighted AEC networks increased predictive power by approximately 7-16%** in comparison to binary AEC networks (Unconscious: 49.55% (binary) to 65.22% (weighted); pre-recovery: 53.37% (binary) to 61.66% (weighted)). Graphs built from **weighted wPLI networks also increased their predictive power by approximately 3-10% in comparison to binary wPLI networks** (Unconscious: 56.73% (binary) to 60.40% (weighted); pre-recovery: 52.45% (binary) to 63.43% (weighted).

Envelope-based and phase-based functional connectivity had differential predictive power for different conscious states. AEC predicted deep unconsciousness with an accuracy of 85.81% and pre-recovery with an accuracy of 68.73%; wPLI predicted deep unconsciousness with an accuracy of 78.91% and pre-recovery with an accuracy of 77.72%. Notably, the inclusion of low-weight connections in network graphs differentially **improved the classification accuracy by 2% of pre-recovery for phase-based connectivity.**

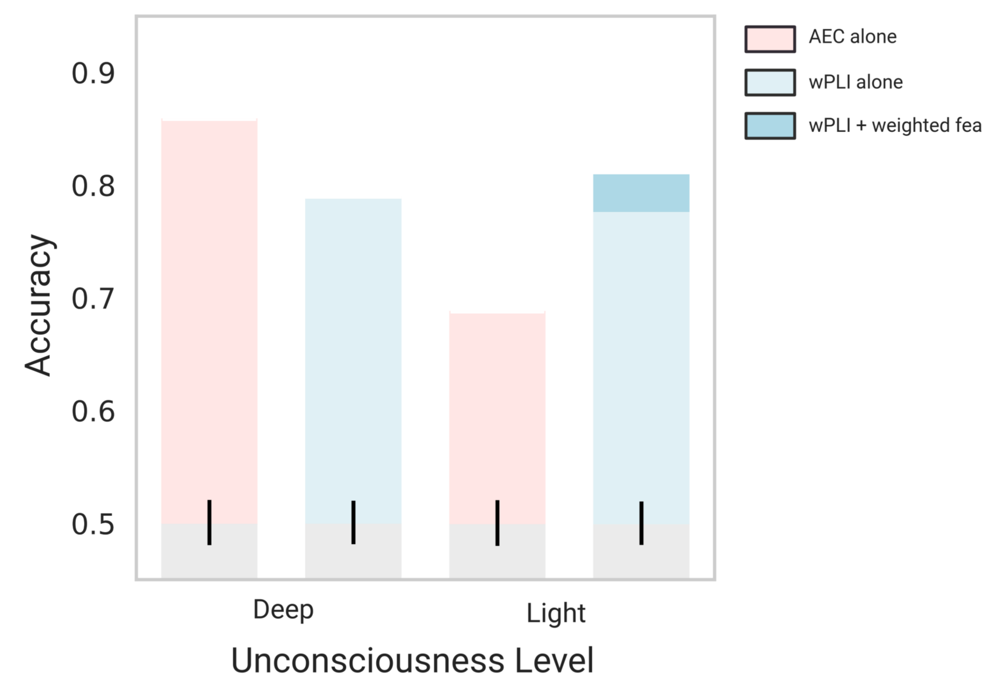
Per Participant Weighted Graph Feature Improvement



Functional Connectivity with Graph Feature Performance



Average Improvement with Weighted Graph Features



Conclusion

The majority of graph theory analyses for the characterization of states of consciousness are currently done using only the strongest-weighted functional connectivity between nodes. Our results suggest low-weight connections contain information that is significantly predictive of state of consciousness. Even though it didn't improve the classification of the amplitude-based graph, we can see in the "Per Participant Weighted Graph Feature Improvement" that some participants did benefit from adding weighted graph feature into the classifier. More participant or more data per participant might help the classifier leverage this source of information. Future consciousness studies should consider weighted and un-thresholded functional connectivity patterns to include this significant source of information.