Ordinal-Pattern-Based Analysis of Human Brain States from EEG Phase Dynamics

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Human brain is a complex system. Understanding the relationship between brain states and the statistical properties of electroencephalography (EEG) signals is important. In this study, we investigate whether permutation entropy (PE) [1], an ordinal-pattern-based measure robust to noise, can serve as a robust biomarker of human brain states. We analyze EEG recordings obtained during a general anesthesia protocol comprising seven states, namely, eyes-closed (EC), propofol injection (P), loss of consciousness (LOC), burst (B), suppression (S), post-burst/suppression (PBS), and recovery (ROC). Following preprocessing, we compute relative phases and extract the dominant phase mode , which captures macroscopic anterior-posterior information flow [2,3]. We then compute the normalized PE, , from its ordinal pattern distribution. To assess its discriminative capability, we employ decision-tree-based classifiers using as a single feature. Our results [4] show a clear dependence of PE on brain state. Unconscious states (LOC, B and S) show significantly higher mean entropy and lower standard deviation than conscious states (EC, ROC) and boundary states (P and PBS). We also find a negative correlation between mean PE and the inverse participation ratio, supporting a link between entropy and consciousness depth. Using PE alone, the classifier distinguishes consciousness levels with an accuracy of 77-81%. We also examine the effects of embedding delay and data resolution on PE. Further, we investigate irreversibility across these brain states.

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