PHASE PRECISION LIMITS AND FAILURE MECHANISMS OF PHASE-AMPLITUDE COUPLING DETECTION

Poster

Neurofisiología - Neurophysiology

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Background: Phase-Amplitude Coupling (PAC), where the phase of a low-frequency oscillation modulates the amplitude of a higher-frequency oscillation, is vital for memory reconsolidation and neural communication. Although various methodologies measure PAC, the conditions under which it becomes undetectable remain poorly understood.

Objective: This study investigates the measurability limits of PAC using simulations of theta-gamma coupling.

Methods: Signals were generated via theta (6 Hz)-gamma (60 Hz) PAC in RStudio while systematically varying phase diffusion, preferred-phase stability, and measurement noise. PAC was estimated using the modulation index, mean vector length, and generalized linear model methods. These estimates were compared against ground-truth coupling to determine the precise conditions under which true coupling becomes undetectable.

Results: PAC metrics collapse when the estimated phase error reaches approximately 1.75 rad, which corresponds to a timing uncertainty of roughly 47 ms at 6 Hz, largely independent of noise levels. This defines a "dark zone" of PAC detectability where genuine coupling exists but methods fail due to phase estimation limits. Additionally, simulations revealed two biological mechanisms that eliminate observable PAC: preferred-phase drift across oscillatory cycles and stochastic

switching between coupling modes.

Conclusion: PAC disappearance can stem from three distinct mechanisms: estimator failure, preferred-phase drift, and preferred-phase switching. This establishes a fundamental phase-precision limit governing PAC detectability, highlighting the need to interpret absent PAC cautiously in future neural oscillatory coupling studies.

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