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Electrovascular Phase-Amplitude Coupling During an Auditory Task

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Introduction: Although noninvasive multimodal neuroimaging approaches relying on electroencephalography (EEG) and functional near-infrared spectroscopy (fNIRS) have shown great promise in open and closed-loop brain-computer interface (BCI) applications, the underlying neural dynamics relating these neuroimaging modalities are not well understood. In this pilot study, we explore phase-amplitude coupling (PAC) between the low-frequency oxygenated hemoglobin concentration change (ΔHbO_2) time series measured using fNIRS and high-frequency electrical oscillations measured using EEG.

Material, Methods and Results: Three healthy participants completed three runs of an auditory task; each run included 24 blocks of six 40 Hz white noise click trains (500ms duration, 2s inter-stimulus interval (ISI)) followed by 15s of silence. EEG and fNIRS channel locations were selected to cover the frontal and left/right temporal/temporoparietal regions. Collection and preprocessing of the 15 channel EEG montage/respiration signals is described in [1], while recording of the 14 channel fNIRS montage is described in [2]. A set of regressors were generated using temporally embedded canonical correlation analysis (tCCA) as described in [3] using additional short-distance fNIRS channels and the respiration signal. A generalized linear model (GLM) was fit to the data using tCCA and task-related regressors. The estimated contribution of the tCCA regressors was subtracted from the original ΔHbO_2 signal, and a copy of the original signal was retained. EEG and fNIRS signals were filtered into frequency bands of interest [θ-band: 4-7 Hz, α-band: 7-14 Hz, β-band: 15-30 Hz, and γ-band: 30-55 Hz for EEG; very-low frequency (VLF): 0.07-0.2 Hz and low-frequency (LF): 0.2-0.5 Hz for fNIRS] and the Hilbert transform of both signals was taken. The PAC algorithm proposed by [4] was applied between the instantaneous phase of ΔHbO_2 and instantaneous EEG power amplitude (see [1]). Overall, we observed strong ($p < 0.005$) global PAC between the original VLF (0.07-0.2 Hz) ΔHbO_2 phase and EEG β-band (15-30 Hz) power across all three participants that diminished to no observed PAC in one participant and localized PAC in two others after tCCA regressor removal. Results from one participant are shown in Fig. 1.

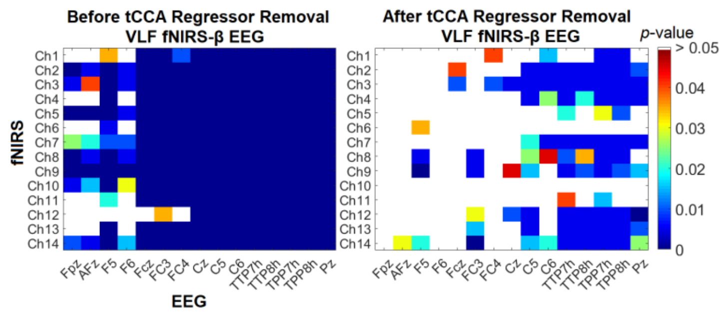

Figure 1. p-value maps of phase-amplitude coupling (PAC) between the phase of very-low frequency (VLF) ΔHbO_2 and EEG β-band power before (left) and after (right) removing tCCA regressors in one participant. Global electrovascular PAC in the original signal is reduced to local electrovascular PAC after tCCA regressor removal.

Discussion: These results suggest that electrovascular PAC is partially driven by components of global hemodynamics. However, the presence of significant PAC after the removal of global signals from ΔHbO_2 suggests that EEG amplitude may be coupled locally with cerebral hemodynamics as well.

Significance: These results identify global electrovascular coupling and provide insights into the potential sources of this phenomenon, which may inform subsequent hybrid EEG/fNIRS studies.

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