Using Brain Oscillations to Model Cognitive Fatigue During Sleep Deprivation

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Background

- Sleep deprivation is one of the most common physiological stressors experienced by Service Members during training and deployment.
- Fatigue degrades cognitive performance, increases the likelihood of operational errors, and threatens mission readiness.
- Characterizing network interactions that track behavioral deficits during sleep deprivation is critical for fatigue management research.

Study Design / Methods

- Healthy participants (n=19) underwent 39 hours of continuous sleep deprivation under constant environmental conditions.
- Repeated MRIs and cognitive/vigilance assessments were administered every 6 hours.
- Functional data were preprocessed and analyzed using SPM12 and the MATLAB toolbox CONN (v22).
- Network connectivity was modeled using both a standard seed-to-voxel connectivity analysis and graph theory network efficiency analysis.

Results

Left Inferior Frontal Gyrus Network Integration Across Sleep Deprivation | **Right Temporal Fusiform Cortex Network Integration Across Sleep Deprivation**

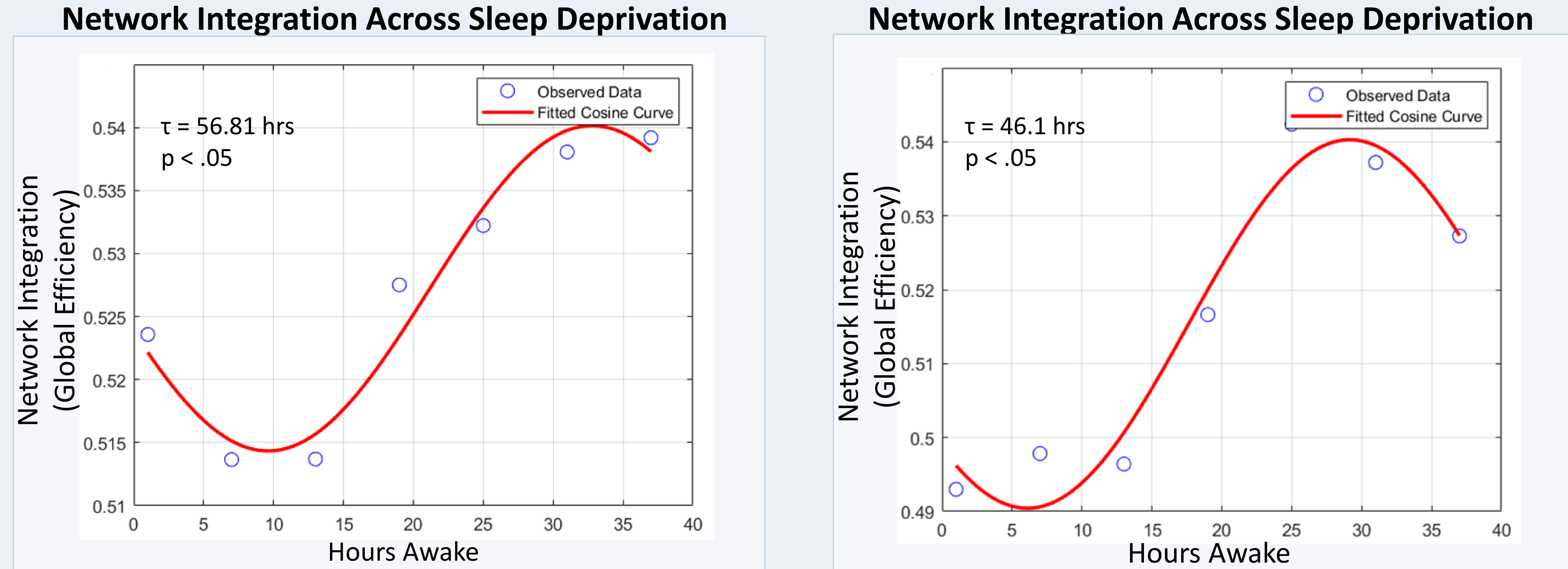

Figure 1 | Fitted cosinor curves of mean regional global efficiency across the sleep deprivation protocol. Points represent group mean global efficiency for the left inferior frontal gyrus (left) and right temporal fusiform cortex (right) at each scan session. Solid lines represent the fitted cosinor models.

Left Inferior Frontal Gyrus Network Integration & Psychomotor Vigilance | **Right Temporal Fusiform Cortex Network Integration & Fatigue**

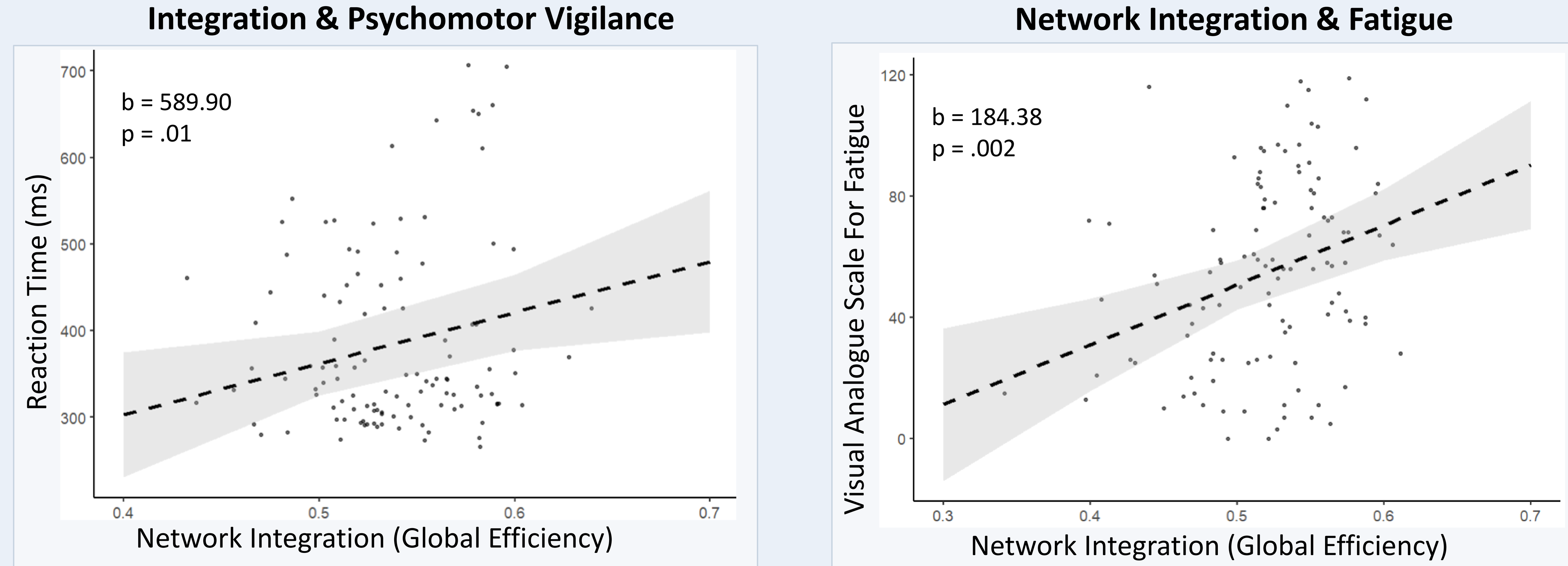

Figure 2 | Linear mixed-effects models of the relationship between network integration and behavioral outcomes across sleep deprivation. Points represent individual observations from repeated measurements within subjects. The dashed line and shaded region represent the group-level fixed effect estimate and 95% confidence interval, respectively. Subject was included as a random effect to account for baseline differences.

Sleep Deprived Changes in Left Inferior Frontal Gyrus Connectivity | **Sleep Deprived Changes in Right Temporal Fusiform Cortex Connectivity**

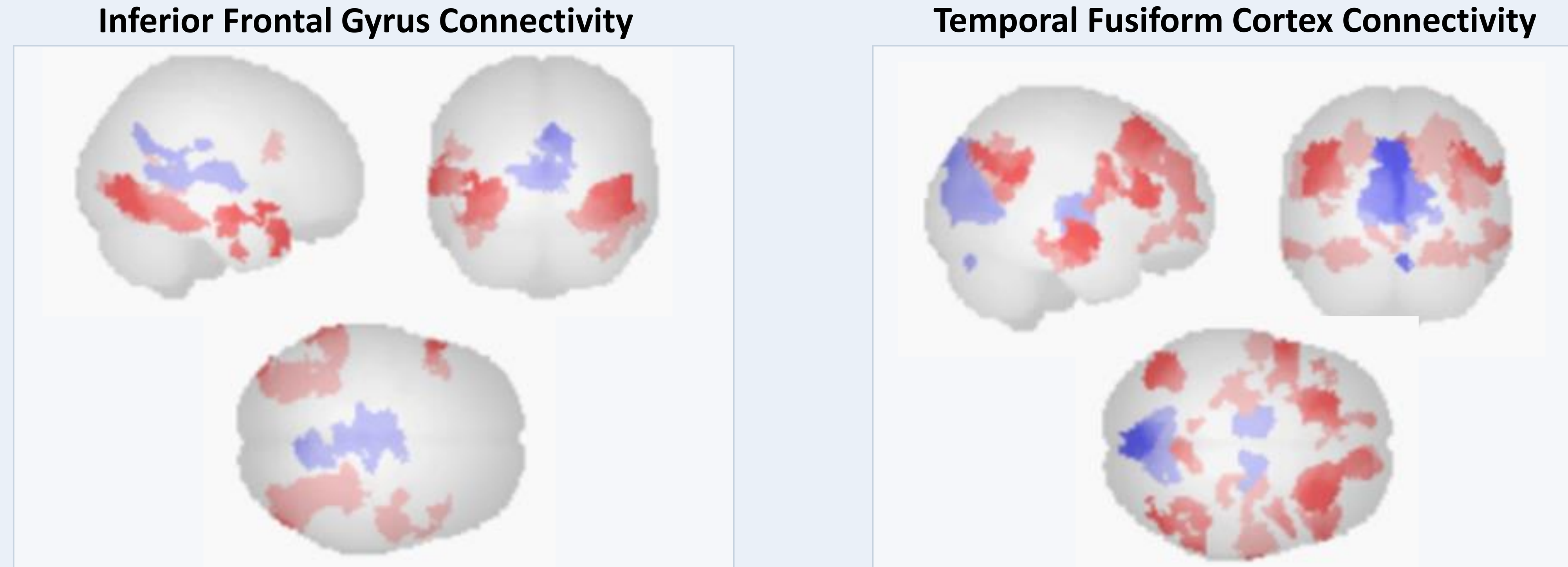

Figure 3 | Seed-to-voxel connectivity maps comparing sleep deprived to well-rested conditions. Areas in red show where connectivity significantly increased, whereas areas in blue show significant reductions in connectivity. Individual voxel threshold was maintained at p<.001. Clusters remain significant after false discovery rate correction p<.05.

Key Findings

- Changes in network integration show both a progressive breakdown and circadian fluctuation.
- Linear mixed-effects models of network integration significantly predict behavioral deficits in vigilance and fatigue.
- Impaired thalamic connectivity coincides with functional deficits in prefrontal and temporal regions.

Conclusions

- Prefrontal and temporal regions lose network segregation across sleep deprivation and may impair cognitive processing.
- Homeostatic and circadian processes jointly shape network changes across sleep deprivation.
- Decreased thalamocortical arousal modulation may underlie this loss of network segregation.
- Network integration may serve as a predictive biomarker of vigilance and fatigue.

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