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Rathee, D., Cecotti, H., & Prasad, G. (2016). Effective Connectivity Analysis in Fronto-Centro-Parietal Network during Altered Levels of Consciousness. In *Unknown Host Publication* *Frontiers*.
<https://doi.org/10.3389/conf.fninf.2016.20.00058>

[Link to publication record in Ulster University Research Portal](#)

Published in:
Unknown Host Publication

Publication Status:
Published online: 18/07/2016

DOI:
[10.3389/conf.fninf.2016.20.00058](https://doi.org/10.3389/conf.fninf.2016.20.00058)

Document Version
Author Accepted version

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Effective Connectivity Analysis in Fronto-Centro-Parietal Network during Altered Levels of Consciousness

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Introduction

Administration of sedation is a common practice in most of the clinical and/or surgical interventions, especially in critical care environment. Although it is necessary to relieve critically ill patients from unpleasant physical and psychological experiences, continuous assessment of sedation is highly crucial as improper sedation practice may lead to serious complications such as delirium. To deal with these concerns, bio-markers for sedative-induced unconsciousness must be manifested through objective brain signal analyses. A balanced amalgamation of cortical integration and differentiation has been proposed by several theoretical developments in the field of consciousness, which involve substantial variations in information transfer networks across multiple scales (Tononi, 2004). These findings motivate further research to correlate these variations with altered states of consciousness and quantify them. In this work, Partial Granger Causality (PGC) (Guo et al., 2008) has been utilised to assess the effect of sedation on the Fronto-Centro-Parietal cortical network.

Method

An effective connectivity analysis has been performed on a 128-channel EEG dataset involving Seven healthy subjects under three distinct levels of sedation (Awake, Mild, and Moderate) (Chennu et al., 2016). The study has been restricted to artefact cleaned and bandpassed EEG data (8-12 Hz) of eight scalp electrodes (FP1, FP2, F3, F4, C3, C4, P3, and P4) covering the related brain areas. Levinson-Robinson-Wiggins (LWR) algorithm has been implemented for estimating Multivariate Autoregressive (MVAR) model coefficients over multiple 500 ms data segments. Akaike Information Criterion (AIC) and Durbin-Watson whiteness test have been used to evaluate the optimal model order and validate the model consistency, respectively. Furthermore, to remove the statistical biasness, permutation resampling test was used with a window size of 75 sample points and 20 permutations. The inference was done through statistical comparison ($p < 0.05$, FDR corrected for multiple comparisons) of each causal interaction and PGC node strength among the three conditions. In our previous work, this methodology has been implemented for estimation of effective connectivity during distinct motor-imagery tasks (Rathee et al., 2016).

Results

The results analysis presented a statistically significant decrease in strength of the effective connectivity features and node strengths at various electrodes as the level of sedation increases from awake to moderate level. These findings are consistent with previous study (Boly et al., 2013), which involved functional connectivity analysis at source level networks. Fig.1 depicts the mean PGC (across subjects) matrices while Fig.2 displays head plots of mean node strength (across subjects) for all the three conditions. Pairwise comparisons shown in Fig. 3 revealed maximum statistically significant directional connectivity indices and node strengths changes in Awake-Moderate pair. Mild-moderate comparison provided four significant node strengths

and six connectivity indices changes while least significant features (two node strengths and four connectivities) changes were observed in Awake-Mild comparison.

Conclusion

This study showed that scalp-level directed connectivity analysis can be implemented to distinguish between altered states of consciousness using a small number of electrodes and therefore reducing the computational cost and analysis time. Moreover, the Fronto-Centro-Parietal Network exhibits strong variations in the node strengths and it could be exploited for real-time monitoring of consciousness in a clinical setting.

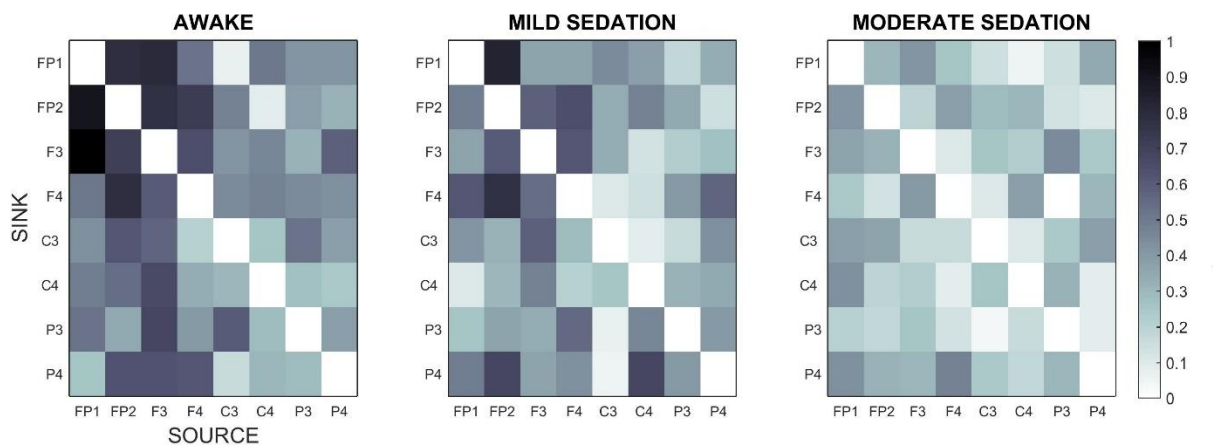


Figure 1. The results corresponding to the partial G-causality analysis for resting state EEG data for three levels of sedation. Each matrix consists of 56 non-zero mean effective connectivity indices across 7 subjects (normalized).

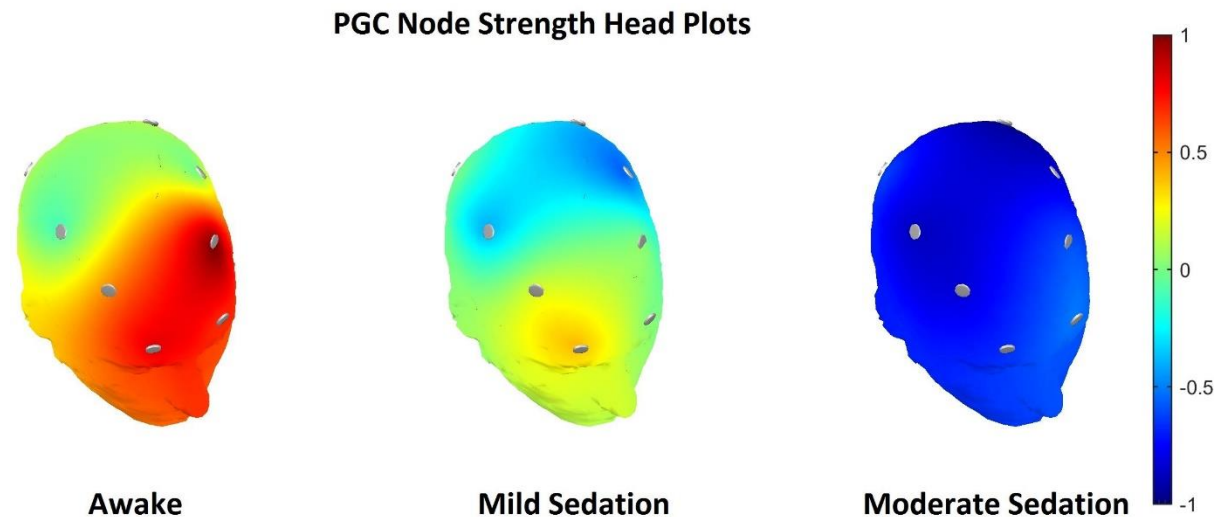


Figure 2. Head plots showing the mean PGC node strength values across 7 subjects for three levels of sedation (normalized).

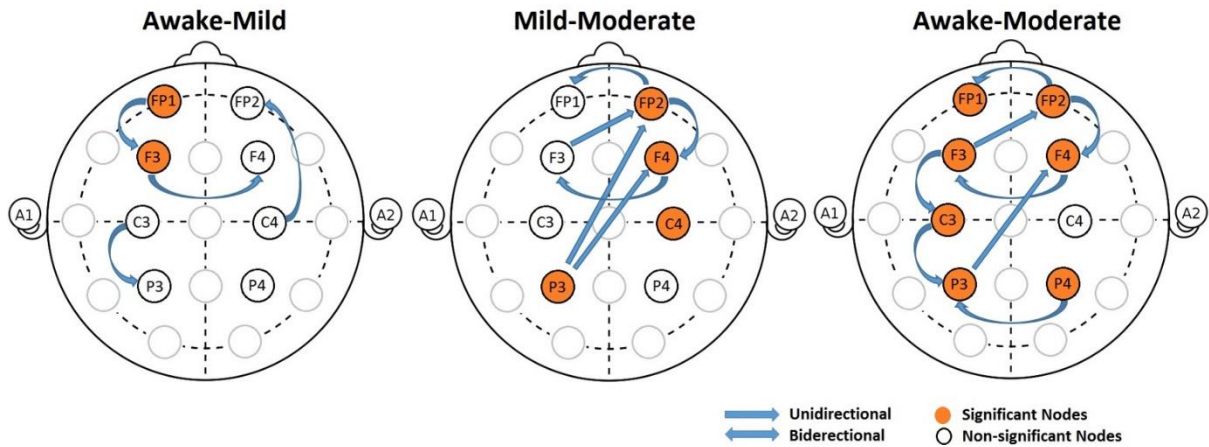


Figure 3. Significant directional connectivities and node strengths ($p < 0.05$, FDR corrected) for three pair-wise comparisons.

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