# Decoupling of the default mode network during deep sleep

**S. G. Horovitz[1,2], A. R. Braun[3], W. S. Carr[4], D. Picchioni[5], T. J. Balkin[5], M. Fukunaga[2], and J. H. Duyn[2]**

[1]Human Motor Control Section - MNB, NINDS-NIH, Bethesda, MD, United States, [2]Advanced MRI - LFMI, NINDS-NIH, Bethesda, MD, United States, [3]Language Section Voice, Speech and Language Branch, NIDCD - NIH, Bethesda, MD, United States, [4]MSC USN, Naval Medical Research Center, Silver Srping, MD, United States, [5]Department of Behavioral Biology, Walter Reed Army Institute of Research, Silver Srping, MD, United States

INTRODUCTION: The default mode network (DMN) is a set of brain regions that is highly active in absence of overt behavior. Its function was originally attributed to self-reflective thoughts[1]. However, this network has recently been found to remain active during light sleep[2] and in anesthetized animals[3], raising further questions regarding its role. In the present work we studied human DMN activity at naturally varying levels of conscious awareness,during wake and sleep.

METHODS: We performed simultaneous EEG-fMRI on 18 normal volunteers after 44 h of complete sleep deprivation. EEG was collected from 16 channels using a BrainAmps system and pre-processed with Analyzer (BrainVision). 7 subjects reached at least 15 min of continuous deep sleep, based on manual scoring[4]. BOLD-fMRI was collected on a 3T (GE) scanner equipped with a 16-channel coil (Nova Medical) using an EPI sequence (TE:45ms, TR:3s, 25 slices, gap:0.5mm, 3.75x3.75x4.5mm$^3$) modified to decrease sound level (96dB) by decreasing the bandwidth to 62.54kHz and limiting gradient slew-rate to 25 T/m/s. fMRI pre-processing included slice timing correction and rigid body motion correction. Data were high-pass filtered (≥0.006Hz) to remove baseline drifts. The global signal change, the cardiac rate and the respiration volume per time were regressed out. Data sets were converted to percentage signal change. Activity was inferred from low frequency (below 0.08Hz) fMRI signal fluctuation levels, and both coherence and amplitude of activity in the various regional components of the DMN were studied. DMN coherence was determined from analyses based on seed-region correlation and correlations between multiple time-series extracted from network-based regions of interest. To define a functional mask, data was collected from 5 subjects during resting wake, and processed in similar fashion. Time courses were also correlated to the EEG activity.

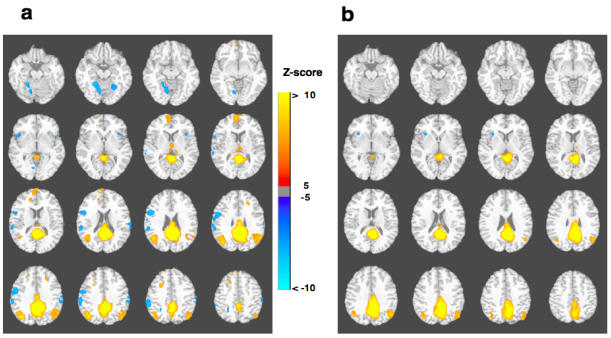


Figure 1: Composite maps showing correlations with posterior cingulate cortex during wake (a) and deep sleep (b).

RESULTS: Similar to earlier results[5] substantial DMN activity was observed during both sleep and waking conditions. However, close inspection of coherence levels indicated a decoupling of frontal areas from posterior regions during sleep (Figs 1,2). Moreover, the activity level in each area remained unchanged, suggesting it is not activity per se but rather the coherent activation of the parts that lead to conscious experience. The dissociation is also observed in the correlation of fMRI with EEG delta (1-4Hz) activity, with posterior ROIs showing a negative correlation, while the MPFC was positively correlated (table 1).

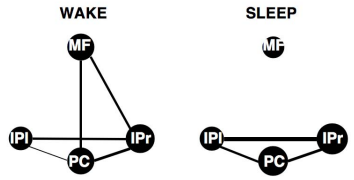


Figure 2: Connectivity of the main components of the default-mode network. Connectivity is measured as the correlation coefficient between average time courses of each ROI both in wake and sleep condition. Each ROI is defined as the voxels within the anatomical region that are significantly connected to the PCC seed during WAKE, (p=0.0001 uncorrected). Size of the circles represents within region connectivity, while thickness of lines represents between region connectivity strength. MF middle prefrontal /anterior cingulate cortex; IPl: left inferior parieta l/angular gyrus; IPr: right inferior parietal /angular gyrus; PC: posterior cingulate/precuneus.

DISCUSSION: The finding that the MPFC is functionally decoupled from the rest of the DMN during deep sleep is consistent with the hypothesis that integrated DMN activity may reflect ongoing conscious mentation. Taken together, our findings also support notion that waking, conscious awareness is an emergent consequence of coordinated activity in multiple brain regions[6], that it may require coherence between frontal and posterior brain regions[7], and that local cortical activity may be necessary but not sufficient to support conscious awareness[8]. We show that there is a decoupling of frontal areas from posterior regions, suggesting that reduction of consciousness is reflected in altered levels of network coherence, most notably a reduced involvement of frontal cortex.

REFERENCES: (1) Gusnard, D. A.; Raichle, M. E. *Nat Rev Neurosci* **2001,** *2*, 685. (2) Horovitz, S. G.; Fukunaga, M.; de Zwart, J. A.; van Gelderen, P.; Fulton, S. C.; Balkin, T. J.; Duyn, J. H. *Hum Brain Mapp* **2008,** *29*, 671.(3) Vincent, J. L.; Patel, G. H.; Fox, M. D.; Snyder, A. Z.; Baker, J. T.; Van Essen, D. C.; Zempel, J. M.; Snyder, L. H.; Corbetta, M.; Raichle, M. E. *Nature* **2007,** *447*, 83.
(4) Rechtschaffen, A.; Kales, A. *A manual of standardized terminology, techniques and scoring system for sleep subjects. Allan Rechtschaffen and Anthony Kales, editors*; Bethesda, Md.,: U. S. National Institute of Diseases and Blindness, Neurological Information Network, 1968. (5) Horovitz, S. G.; Fukunaga, M.; Carr, W. Zwart, J. A.; van Gelderen, P.; Balkin, T. J.; Braun, A. R.; Duyn, J. H. BOLD low frequency fluctuations during An EEG/fMRI study, 2007; (6) Baars, B. J. *Prog Brain Res* **2005,** *150*, 45.(7) Tononi, G.; Koch, C. *Ann N Y 1124*, 239. (8) Kanwisher, N. *Cognition* **2001,** *79*, 89.

| ROI | Correlation coefficient |
|---|---|
| MPFC | 0.187 |
| PCC/Pc | -0.339 |
| IPl | -0.101 |
| IPr | -0.342 |

Table 1: correlations between delta activity and BOLD fMRI for each of the four ROIs