Discrepancy of Functional Connectivity in Sensorimotor Network between Pre- and Post-Sleep Conditions

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INTRODUCTION

"Sleep" is associated with spontaneous brain fluctuations that are thought to participate in sleep homeostasis and to support the processing of information related to the experiences of previous awake period (1). Recent studies supported such point of view by evaluating the variation of self-referential network during sleep using resting-state fMRI techniques (2). Not only does the decay of consciousness come with sleep, but other cognitive functions would be modulated as well, such as sensorimotor functions (3). The combined effects refresh our daily fatigue and rejuvenate our body. How does sleep tweak the brain functions and generate such relaxing and refreshing effects? To answer this question, we compared the functional connectivity in the sensorimotor network between Pre- and Post-sleep using resting-state functional MRI.

MATERIAL & METHODS

Ten healthy, right-handed subjects (all males; age; 24.2±2.94 years) participated in the experiments on a 3T Tim Trio system (Siemens, Ettlingen, Germany) with a head volume coil. No participants had medical history or sleep disorders. Before the experiments, PSQI (Pittsburgh Sleep Quality Index) were provided by participants for the evaluation of personal sleep quality.

Using MR-compatible 32-channel amplifier (BrainAmp MR; Brain Products) and a MR-compatible EEG cap (BrainCap-MRI 32-Channel-Ctandard), EEG was recorded in the MRI scanner room simultaneously with fMRI acquisition. The EEG cap included thirty scalp electrodes, as well as one electro-oculogram (EOG) channel and one electrocardiogram (ECG) channel. By using abrasive electrolyte-gel (ABRALYT HiCl), electrode-skin impedance was kept < 10 kOhms (all EEG-Channels are with 5 kOhm-resistors). Data were transferred through fiber-optic cables to a personal computer, and then BrainVision Program (BrainVision Recorder, Brain Products) was synchronized to the scanner clock.

All images were obtained with a gradient echo-planar imaging (EPI) method on the whole brain (35 slices) along the AC-PC line, with FOV of 220 mm, MTX of 64×64, slice thickness of 3.4 mm. Imaging parameters were: TR of 2500ms, TE of 30 ms, and flip angle of 80º. The experiments could be divided into three parts: (i) **Pre-sleep** — after the preparation procedure, subjects were instructed to keep their eyes closed and not to think of anything in particular and the most important thing was, no sleep. The scan lasted for 6 min. (ii) **Sleep** – subjects were requested to fall into sleep as soon as the scan begins and this session would be terminated until they could not sleep anymore and wanted to leave, or for a maximum of 3000 scans (125 min). (iii) **Post-sleep** –the instructions and scanning procedure were set like pre-sleep with a 6-min scan length. In this current work, we only focused on (i) and (iii) to investigate the disparity between Pre- and Post-sleep conditions and the EEG recordings were only used to differentiate whether the subjects fell into sleep successfully by one clinical specialist. The dataset of (ii) and the EEG results were left for other investigation interests.

Data were pre-processed by Statistical Parametric Mapping 5 (SPM5; http://www.fil.ion.ucl.ac.uk/spm/software/spm5) and REST (http://restfmri.net/forum/) implemented in MATLAB version 7.1. Preprocessing methods included motion correction, normalization ($2\times2\times2$ mm^3), smooth (FWHM=6mm), detrend (to remove linear drift), and low-pass filter (0 ~ 0.1Hz). Six motion parameters, and the averaged time-series retrieved from the CSF and whole brain mask were regressed out as nuisance covariates in the process. A spherical seed with 6 mm diameter was chosen from the left motor area [-36, -28, 53] in the Talairach space to generate functional connectivity maps. Group-level analyses were performed to reveal significant connected brain area ($p < 3.69\times10^{-4}$, uncorrected) for both Pre- and Post-sleep. Individual motor masks were generated from Pre-sleep to evaluate correlation coefficients between left primary motor cortex (M1), right M1 and supplementary motor area (SMA).

RESULTS

From the EEG recordings, the stage II of none-rapid eye movement sleep was guaranteed for each participant. The group-level connectivity maps of the motor network are shown in Fig. 1 (Fig. 1a for Pre-sleep and Fig. 1b for Post-sleep) overlaid on the averaged anatomical images. Comparing to Post-sleep's connectivity maps, Pre-sleep's connectivity maps have larger spatial extents. The connection from the seed (left M1) to right M1 and to SMA is apparent during Pre-sleep, but the connection is not detectable during Post-sleep.

The average correlation coefficients during Pre- and Post-sleep are shown in Fig. 2, evaluated by individual motor masks. Within the masks, the correlation coefficients during Pre-sleep was significantly higher than Post-sleep in all region comparisons.

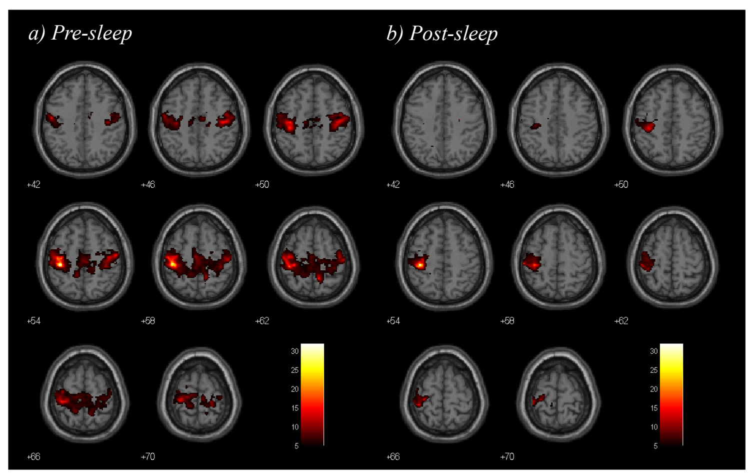

Fig. 1 Functional connectivity maps ($p < 3.69\times10^{-4}$, uncorrected) of the motor cortex over 10 subjects during (a) Pre-sleep and (b) Post-sleep. The group-level statistics were spatially overlaid over the anatomical images.

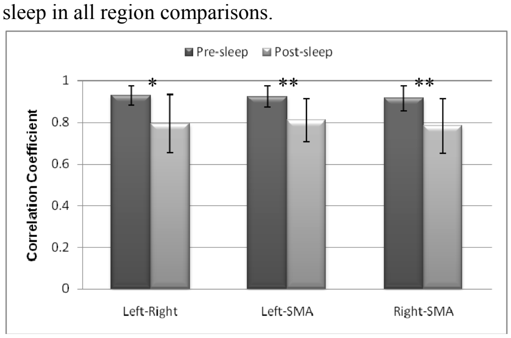

Fig. 2 The average correlation coefficient of 10 subjects during Pre- and Post-sleep. Notice that significant differences were observed between Pre- and Post-sleep. * $p < 0.05$ and ** $p < 0.005$.

DISCUSSION & CONCLUSION

In this study, the connectivity strength of spontaneous fluctuations to the interhemispheric site and SMA was significantly reduced after a duration of sleep, which may be associated with the fading of consciousness during certain stages of sleep and leading to a breakdown in effective sensorimotor connectivity (3). Such breakdown or "unbinding" between motor areas may be a common feature representing the "physical relaxing" effect after/during sleep (3), and so as in the anesthesia status (4) or during the rest periods after the fatigue task (5). However, further detailed investigations are required for further understanding the underlying mechanisms of the functional connectivity within human brain networks during Pre-, Post-sleep and the most important, sleeping state.

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