

Sleep brain networks and sleep depth during somatosensory stimulation

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ARTICLE INFO

Accepted 18 July 2014

1. Introduction to the case

Functional neuroimaging has revealed persistence of ongoing activity in the idling brain, which is the default mode network (DMN) [1]. Other networks, which are devoted to physiological functions, have also been described; they have been recognised during wake time but also during sleep, although modulated by vigilance in extension and connections [2]. The present report described the modulation of these networks in two subjects, which spontaneously fell asleep in the scanner during an electrical stimulation.

2. Image analysis

Informed consent was obtained. Functional magnetic resonance imaging (fMRI) sequences were acquired during somatosensory stimulation at the right wrist, delivered via a custom-made MRI-compatible stimulator at 3 and 10 Hz (total protocol scanning length 15 mins) [3]. Independent Component Analysis (ICA) was used to divide the imaging data into independent activation maps. Participants sleep was assessed by means of self-report and video-recordings inside the scanner room. Spatial ICA were used to decompose fMRI time-series into spatial patterns (Brain Voyager QX software, The Netherlands). Thirty independent components were

estimated for each participant using FastICA algorithm. Finally, a threshold of z-scores was used to visualise Independent Components (IC) maps; voxels with absolute z-scores >1.5 were considered to be active. Fig. 1 shows blood oxygenation level-dependent (BOLD) signal changes in sleep and wakefulness.

3. Discussion

During somatosensory electrical stimulation, networks that have only previously been described in the during resting state, highlighting the brain's capacity to filter the access of information to the cortex during sleep [1,2]. Sleep cannot be a completed disconnection, leaving the sleeping to be prey to external aggressors; therefore, a certain flow of information has to take place. Based on previously published data [2], the extension of the DMN frontal module as a proxy for sleep depth was considered in the present report. Consequently, even minimally disturbing environmental events are registered during light sleep, whereas only disrupting perturbations make it through in the deep-sleep stages. In the present report, this phenomenon was depicted: the gradual deepening of sleep or its arousal-related fluctuations, signalled by the fading off of frontal DMN BOLD signals, is paralleled by the gradual disappearance of the stimulus-related activation (Fig. 1, first block). Thus, the deeper the brain is sleeping, the more the external perturbations are blocked at subcortical levels in order to preserve the sleeping cortex (Fig. 1, second block). Although EEG co-registration was missing, we are quite confident that the data reflect a sleep phenomenon. Sleep was referred and clinically checked inside the scanner; previously published data have demonstrated that an analogous DMN modulation [4], as well as dissociation between BOLD, increase the thalamic signal and concomitant deactivation of heteromodal associative cortices [5].

Conflict of interest

The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: <http://dx.doi.org/10.1016/j.sleep.2014.07.026>.

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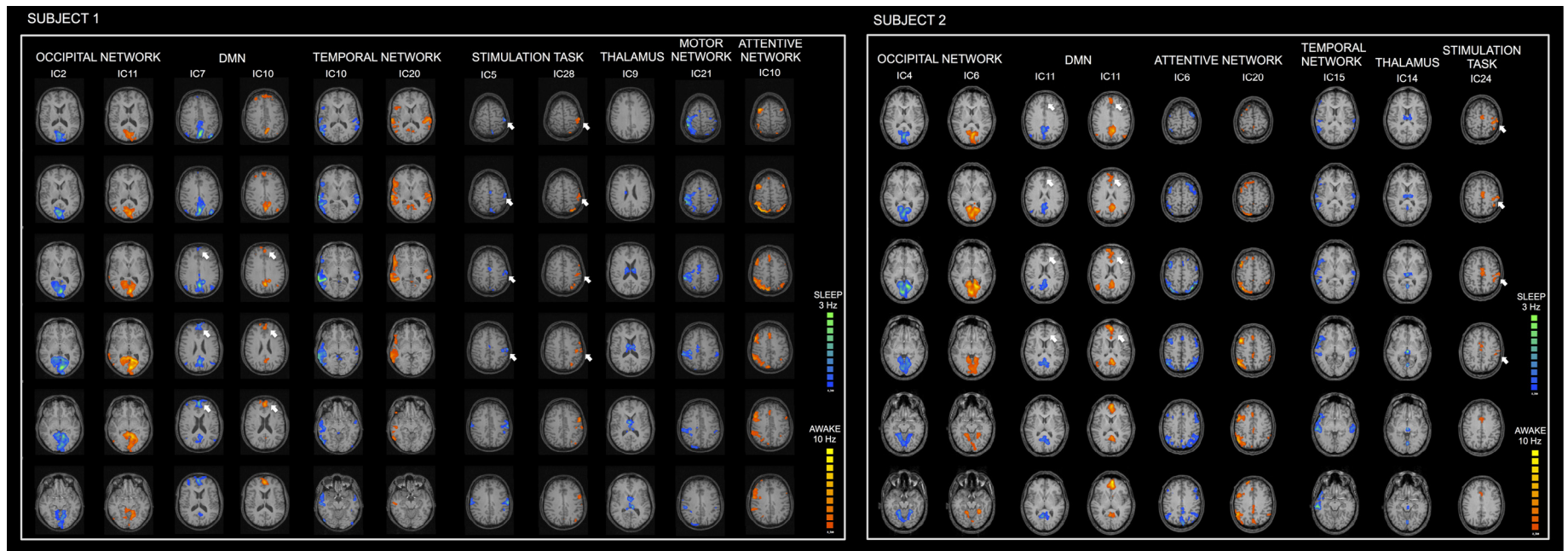


Fig. 1. Subject 1 (left panel): the first eight columns depict the comparison between BOLD activation in the occipital, DMN, temporal networks, and stimulation task activity during sleep (blue–green scale) and during wake (red–yellow scale). The last three columns of the first panel depict BOLD activations during sleep in the thalamus and motor network, and during the wake state in the attentive network. Of note: the persistence of BOLD frontal activation in the DMN during sleep and the presence of the task-related BOLD signal also in sleep. Subject 2 (right panel): the first six columns depict the comparison between BOLD activation in the occipital, DMN, and attentive networks during sleep (blue–green scale) and during wake (red–yellow scale). The last three columns depict BOLD activations in the thalamus and temporal networks during sleep and in somatosensory (task-related) network during the wake state. Note: the disappearance of BOLD frontal activation in the DMN during sleep, paralleled by the disappearance of the task-related BOLD signal in sleep, recorded only during wake.

References

- [1] Raichle ME, MacLeod AM, Snyder AZ, Powers WJ, Gusnard DA, Shulman GL. A default mode of brain function. *Proc Natl Acad Sci U S A* 2001;98:676–82.
- [2] Boly M, Perlberg V, Marrelec G, Schabus M, Laureys S, Doyon J, et al. Hierarchical clustering of brain activity during human nonrapid eye movement sleep. *Proc Natl Acad Sci U S A* 2012;109:5856–61.
- [3] Manganotti P, Formaggio E, Storti SF, Avesani M, Acler M, Sala F, et al. Steady-state activation in somatosensory cortex after changes in stimulus rate during median nerve stimulation. *Magn Reson Imaging* 2009;27:1175–86.
- [4] Horovitz SG, Braun AR, Carr WS, Picchioni D, Balkin TJ, Fukunaga M, et al. Decoupling of the brain's default mode network during deep sleep. *Proc Natl Acad Sci U S A* 2009;106:11376–81.
- [5] Del Felice A, Formaggio E, Storti SF, Fiaschi A, Manganotti P. The gating role of the thalamus to protect sleep: an f-MRI report. *Sleep Med* 2012;13:447–9.