Brain activation and paralimbic-limbic cortex functional connectivity during human slow wave sleep: an fMRI study

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Background:

Scientists have realized that our brain might never truly be at rest during sleep state, but appeared to concentrate on keeping memory processing (1). However, they remain baffled by the underlying mechanism. Graph theoretical analysis of functional magnetic resonance imaging (fMRI) time series has revealed a small-world organization of slow-frequency blood oxygen level dependent (BOLD) signal fluctuations during wakeful resting (2).

Purpose:

The purpose of this study was to use graph theoretical approach to explore the changes of paralimbic-limbic cortex during slow wave sleep which are reflected in small-world properties and functional connectivity of our brain network.

Materials and Methods :

After institutional review board approval and written informed consent, twenty healthy subjects (23.8 ± 2.2 years, Male 10) were recruited to sleep in MR scanner between 11pm-7am. MR investigations were performed using a 3T whole-body system (Signa Excite HD; GE Medical Systems, Milwaukee, WI) with a standard head coil. Then, 2-min PASL and 6.5-min BOLD functional data were collected before sleep. After one 6.5-min sleeping-state BOLD measurement, 1-min PASL was performed for each moment of steady state sleep on all participates (see Fig. 1). These fMRI data were analyzed by SPM8 and then were dealt with by graph theoretical approach. Finally, functional connectivity analysis was focusing on neocortical region, paralimbic-limbic structure and centrencephalic system.

Results:

Figure 2 shows the small-world properties of human brain functional networks. At the whole range of degree, the brain networks of the sleep group demonstrated notable higher clustering coefficient (Fig. 2(A)) and local efficiency (Fig. 2(B)). Meanwhile, when human sleep, their brain networks indicate remarkable lower global efficiency (Fig. 2(C)) and longer characteristic path length (Fig. 2(D)). It is observed that brain networks proved stronger small-world characteristics during slow wave sleep state as compared to the wake state.

Figure 3 shows functional connectivity graphs of wake and sleep state. We observed that the paralimbic-limbic region of the slow wave sleep network (Fig. 3(B)) had less links to other cortices compared with the wake network (Fig. 3(A)). Meanwhile, it is found that the local efficiency of paralimbic-limbic cortex and centrencephalic system increased, whereas the value of neocortical decreased.

Conclusions:

This functional brain network in slow-wave sleep with both high "cliqueness" and fewer long-range connections is optimal for information processing. It is consistent with a memory reprocessing hypothesis of slow-wave sleep (3), which may explain why sleep insufficiency has adverse impact on memory. Moreover, result suggested that paralimbic-limbic cortex was getting more independent when human sleep. It means that our brain owns a kind of defense mechanism responsible for suppressing the external environment interference. Thus, our study provides a new insight for revealing the significance of sleep on memory process.

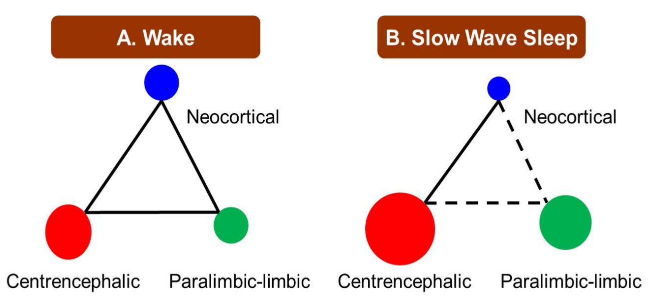

FIG.3. Functional Connectivity Graphs of Wake and Sleep State.

The blue node represents the neocortical region, the green node represents the paralimbic-limbic structure and the red node represents the centrencephalic system. The size of the dot represents the value of the corresponding local efficiency. Dotted line represents connections reduced in number.

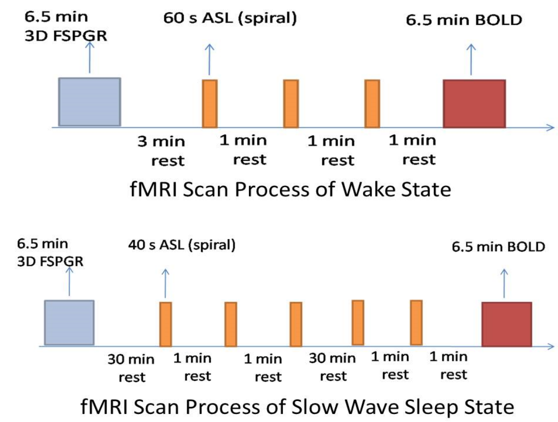

FIG.1. Scan Process of Our Study.

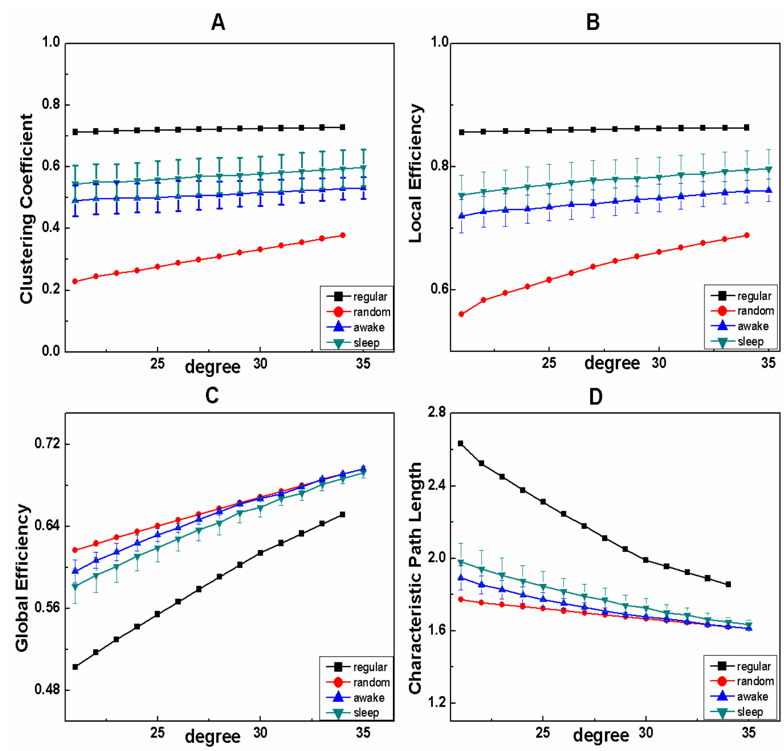

FIG.2. Small-World Properties of Human Brain Functional Networks

Group results of … (A) clustering coefficient, C_{net}, (B) local efficiency, E_{loc}, (C) global efficiency, E_{glob} and (D) characteristic path length, L_{net}, for sleep group (green dots) and wake group (blue dots) as a function for degree. Error bars correspond to standard error of the mean.

References:

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