Decreased Connectivity in Left Frontal Orbital Cortex After Sleep Deprivation

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Abstract: Men are reported to be likely to express more anger than women. Insufficient sleep may lead to cognitive changes, and most adults are plagued by this problem. Researches have proved that lack of sleep can cause the emotion of anger. However, the neural mechanisms of this phenomenon still need to be discovered. Aiming to explore why men tend to experience anger after sleep deprivation (SD) by utilizing the method of brain network science, a generalized PsychoPhysiological Interaction (gPPI) analysis was administered. A total of 18 male participants were enrolled in this study. As a vital area for regulating emotions, the left frontal orbital cortex (FOrb) showed decreased connectivity to the posterior cingulate gyrus (PC) and cerebellum, while PC and cerebellum are known to involve in emotion regulation. Decreased connectivity in these areas might provide a plausible explanation for how SD influences male to process the emotion of anger. Our results provide further evidence that sleep deprivation is closely related to the emotion of anger and the adoption of brain network science offers new insights in uncovering the neural mechanism for SD's impact on men's processing of anger.

1 INTRODUCTION

Humans spend approximately one-third of their lives asleep. (Farahani et al., 2019). Previous researches indicate that emotional abilities are fairly disrupted due to sleep deprivation (Krause et al., 2017). According to Saghir et al (2018), sleep deprivation leads to the bursts of anger. Anger is a syndrome of relatively specific feelings; certain physiological reactions are urged to damage some target (Berkowitz et al., 2004). Although it has great impact on our daily life, it remains one of the least studies of the basic emotions (Alia-Klein et al., 2020). Men are more emotionally reactive to anger, and this can trigger more aggressive tendencies (Potegal et al., 2004; Iverson et al., 2019, Kim et al., 2022; Fernández-Modamio et al., 2020). Potegal and Archer (2004) demonstrated that men were more frequently the targets of anger than women. Iverson et al. (2019) illustrated that a significant minority of middle-aged men reported some degree of anger and aggression, which are correlated with depression and anxiety. Kim et al. (2022) illustrated that men tend to be more aggressive than women when they experience the same level of anger. Fernández-Modamio et al. (2020) found that men recognized disgust and neutral expressions better than women. Previous studies have proved that men experience more anger, which leads to acute consequences for their life quality. However, most studies focus on questionnaire survey, it is necessary to probe into the influence of anger by way of objective measurements.

Previous neuroimaging researches based on functional magnetic resonance imaging (fMRI), a non-invasive technique to observe activation or connectivity activity of the brain, also demonstrated that emotion functions were greatly influenced by sleep deprivation. By means of brain networks, self-organized associations are revealed among various brain regions in order to accomplish different cognition functions. Under the condition of sleep deprivation, the functional connectivity between the amygdala and the ventral anterior cingulate cortex (vACC) was significantly decreased, which resulted in aggravation of subjective mood including anger (Motomura et al., 2013). Resting-state functional

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MRI (fMRI) was used to examine the changes in functional connectivity of the basolateral amygdala (BLA) and centromedial amygdala (CMA) following sleep deprivation (Shao et al., 2014). The findings indicated that a lack of sleep led to a significant decrease in the functional connectivity between the basolateral amygdala (BLA) and various executive control regions. These studies demonstrated that sleep deprivation may worsen anger emotional states.

In short, males are affected by anger to a great extent, and sleep deprivation has effect on men's negative emotion like anger, while the underlying neural mechanism is not clear. In this paper, we adopted Stockholm Sleepy Brain Research to reveal how sleep deprivation affect men's angry emotion processing.

2 METHODS

2.1 Study Design

Neuroimaging data used in this study were obtained from the Stockholm Sleepy Brain Project which is publicly available as one OpenNEURO database (Tamm, 2019). The study was a randomized crossover design with the interval of one month. They underwent fMRI scanning under full sleep and 3-hour sleep deprivation with the interval of one month in a counterbalanced order. The experiment employed three different emotional paradigms, and two resting state sessions.

2.2 Participants

Participants filled out an online screening form after being recruited through the website, posters and a newspaper advertisement (Nilsonne et al., 2017). In this study, a total of 18 males are enrolled. All of them passed the inclusion criteria, including no psychiatric or neurological illness, no working or studying experience in psychology, behavioral science or medicine, no color blind, and all right-handed. They also completed the insomnia severity index (ISI) to test the insomnia symptoms, and the Karolinska Sleep Questionnaire (KSQ) to test the sleep patterns. Besides, the Hospital Anxiety and Depression Scale (HADS) was used to test the depressive symptoms.

2.3 Experimental Paradigm

The Karolinska Directed Emotional Faces (KDEF) database served for the source of the experiment materials (Lundqvist et al., 1998). The study employed happy, neutral and angry emotional pictures in a block design. Every block lasted for 20 seconds and 20 faces were included, each of which was displayed for 0.5 seconds. In total, there were 12 blocks of images (4 happy, 4 angry and 4 neutral). They were organized in groups of three, such as happy-neutral-happy or angry-neutral-angry. Participants were required to grade how happy and angry they felt on a visual analog scale of 0-100 after each set of three (Nilsonne et al., 2017).

2.4 Data Acquisition

fMRI data were obtained from a 3T Discovery 750 MRI scanner (General Electric) with an 8-channel head coil. T1-weighted anatomical scans were acquired with a sagittal BRAVO (brain volume imaging) sequence, TR=6.4ms, TE=2.81ms, inversion time=0.45ms, FA=11°, FOV=240mm × 240 mm × 180mm, 180 slices, slice thickness=1 mm, interleaved bottom-up. Functional scans were acquired in a gradient echo-planar-imaging (EPI) sequence, TR=3000ms, TE=34ms, FA=80°, FOV=220 mm × 220 mm × 110mm, 46 slices, slice thickness=2.3mm, interleaved bottom-up.

2.5 fMRI Preprocessing and Analysis

To investigate task-modulated changes in connectivity, we performed generalized PsychoPhysiological Interaction (gPPI) measures. gPPI is a special type of multiple regression that includes a psychological regressor, a physiological regressor, and a condition specific interaction regressor, which reveals whether the functional connectivity between separate nodes depending on what task the participant is currently doing. Its computation comes from multiple regression model corresponding with each individual ROI (Region of Interest) time series. Each time course was deconvolved and then its output was regarded as physiological regressors. In detail, the experimental conditions of emotion contagion were taken as psychological regressors. The interactions between the time-courses of ROI seeds and the experimental conditions were used as PPI regressors, which were convolved with HRF, and different β values were generated, as presented in Figure 1.

Data were analyzed in CONN toolbox V.20.b. (Whitfield-Gabrieli, 2012). Functional images were first realigned, where all scans are coregistered and

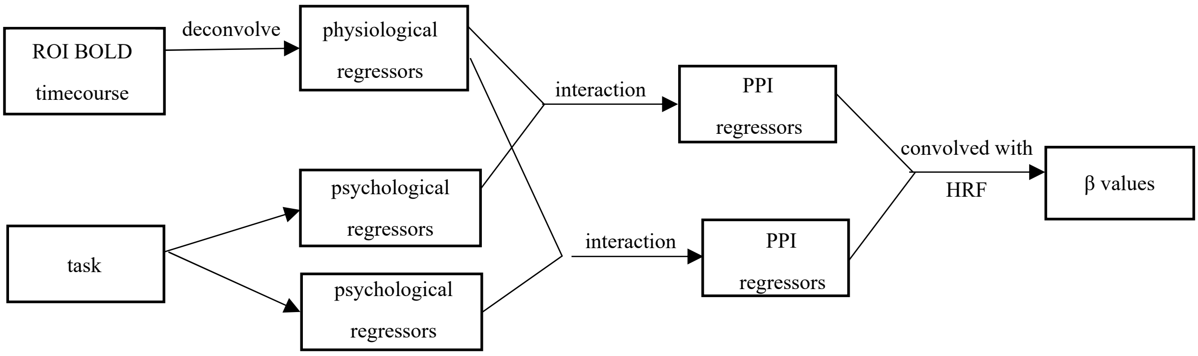

Figure 1: gPPI analysis process.

resampled to a reference image. Next, temporal misalignment was corrected by slice-timing. Outlier identification was then applied to identify potential outlier scans. Later, structural and functional data were segmented into grey matter, white matter, and CSF tissue classes and normalized into standard MNI space (Ashburner et al., 1997). The functional data was then smoothed using spatial convolution with a Gaussian kernel of 8mm full width half maximum (FWHM). Subsequently, the denoising step, which applies linear regression and band-pass filtering, was used to remove unwanted motion, physiological, and other artifactual effects from the BOLD signal (Nieto-Castanon, 2020). In the end, a paired t-test were conducted to compare functional connectivity between full sleep and sleep-deprived conditions.

3 RESULTS

According to the paired t-test, significant effects emerged in the left frontal orbital cortex (LFOrb). As demonstrated in Figure 2, the functional connectivity between LFOrb and the posterior cingulate gyrus (PC) was decreased after sleep deprivation. In addition, the functional connectivity between LFOrb and left Cerebellum was decreased. Decreased connectivity was also found between left amygdala and right hippocampus. Moreover, some visual areas such as right occipital pole and right frontal eye fields showed decreased connectivity. Increased connectivity was found between right rostral prefrontal cortex and left frontal pole. Besides, the right occipital fusiform gyrus showed increased connectivity with left temporal occipital fusiform cortex. The same results were not found under happy condition.

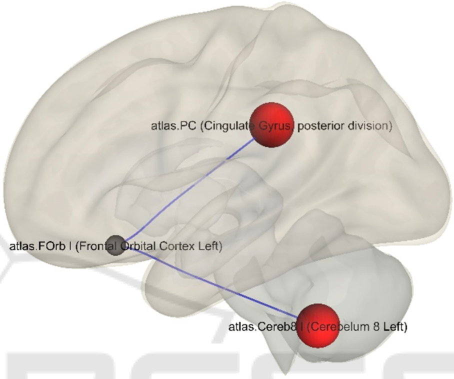

Figure 2: Decreased functional connectivity between left frontal orbital cortex and posterior cingulate gyrus (LPC), left Cerebellum 8.

4 DISCUSSION

According to the experimental results, the paired t-test showed significant effects in the left frontal orbital cortex (LFOrb) and posterior cingulate gyrus (PC). Previous researches indicated that men were facing with sleep problems and had difficulties in dealing with anger emotion simultaneously. This study intended to decipher the neural mechanisms underlying these phenomena. Results suggested significant effects in the left frontal orbital cortex (LFOrb) seed. Specifically, after sleep deprivation, the functional connectivity between LFOrb and posterior cingulate gyrus (PC) was decreased. In addition, the functional connectivity between LFOrb and left Cerebellum 8 was decreased.

As a crucial area for regulating emotion, the orbitofrontal area represents one critical structure in a neural system serving decision making (Arnsten et al., 2012; Bechara et al., 2000). Decreased connectivity of OFC would impair stimulus-reward reversal learning, response inhibition, and ability to balance the appropriateness of their behavior in the social context (Viskontas et al., 2007). Research has shown that there are changes in risk-taking behavior following sleep deprivation, bringing about more dangerous or risky decisions (Womack et al., 2013). Lack of sleep enhances the sensitivity of reward system. Negative emotional experiences are associated with the activation of the reward network, including orbitofrontal cortex. Posterior cingulate cortex plays a critical role in the default mode network. It receives strong feedback from areas involved in emotion processing and social behavior, including the orbital frontal cortex (Maddock et al., 2003). Cerebellum is in control of the arousal and reward system. The abnormal activation in this area might also influence the ability to deal with the negative emotion. Decreased connectivity in these areas might be able to explain why SD significantly influenced the emotion of anger of men.

Our results also found decreased connectivity between left amygdala and right hippocampus. Amygdala-hippocampus interactions allow for emotional processing in the amygdala to influence memory storage in the hippocampus, thereby mediating emotional memories' consolidation and retrieval. (Kirby et al., 2018; Yang et al., 2017; Roesler et al., 2021; Fastenrath et al., 2014). Yang et al. (2017) proposed that the amygdala and hippocampus can act synergistically to regulate emotion-based memories. The findings of a fMRI study suggest that the amygdala may be instrumental in regulating how emotional information is stored in the hippocampus. The study found that the connection between the amygdala and hippocampus is much stronger when emotionally positive or negative pictures are being encoded (Fastenrath et al., 2014). Decreased functional connectivity between the amygdala and hippocampus may indicate that sleep deprivation impairs male's ability of angry emotional memory retrieval and consolidation.

Sleep is an essential part of our life. Insufficient sleep could correlate with anger, which may lead to aggressive behaviors. It is of great importance to study the effect of sleep deprivation on anger. This study took males as participants and focused on how sleep deprivation influences angry emotion, which shed light on the study of male's emotion and sleep problems. However, this study did not investigate whether the same results exist in females. Further studies can make a comparison between males and females to depict gender differences in angry emotion processing under the condition of sleep deprivation.

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