

# The impact of mental fatigue on brain activity: A comparative study between resting state and task state using EEG

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## Research article

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# Abstract

Background: Mental fatigue is usually caused by long-term cognitive activities, mainly manifested as drowsiness, difficulty in concentrating, decreased alertness, disordered thinking, slow reaction, lethargy, reduced work efficiency, error-prone and so on. Mental fatigue has become a widespread sub-health condition, and has a serious impact on the cognitive function of the brain. However, seldom researches explore the differences of mental fatigue on electrophysiological activity between resting state and task state. In the present study, 20 healthy male individuals were recruited to do a consecutive mental arithmetic task to induce mental fatigue, and scalp electroencephalogram (EEG) data were collected before and after the task. The power and relative power of five EEG rhythms both in resting state and task state were analyzed statistically.

Results: The results of brain topographies and statistical analysis indicated that mental arithmetic task can successfully induce mental fatigue in the enrolled subjects. The relative power index was more sensitive than the power index in response to mental fatigue, and the relative power for assessing mental fatigue was better in resting state than in task state. Furthermore, we found that it is of great physiological significance to divide alpha frequency band into alpha1 band and alpha2 band in fatigue related studies, and at the same time improve the statistical differences of sub-bands.

Conclusions: Our current results suggested that the brain activity in mental fatigue state has great differences between resting state and task state, and it is imperative to select the appropriate state in EEG data acquisition and divide alpha band into alpha1 and alpha2 bands in mental fatigue related researches.

# Introduction

Mental fatigue refers to a condition of low alertness and cognitive impairment [1]. Too much brain activity and stimulation can make a person feel mentally exhausted, and this feeling is akin to physical fatigue. Mental fatigue can give rise to numerous bad consequences, for example, making the uncomplicated tasks turn to be increasingly difficult or even impossible. Mental fatigue has become a popular subhealthy states in nowadays society, and affects nearly all aspects of cognitive functioning in humans [2], such as driving fatigue [3]. Concerning the effects of mental fatigue on daily life, it is important to reveal the differences of mental fatigue on brain activity between resting state and task state.

Previous studies have been centered on the changes associated with task-related brain activity[4]. The fatigue-inducing mental tasks were widely used by researchers. The mental tasks that requiring different intensity of attention can differentiate the levels of mental fatigue, and their experimental duration could be distinct. The *n*-back task [5, 6] and psychomotor vigilance task [7, 8] (PVT) can be categorized as high-attention-demanding tasks, sleep deprivation [9] can be classified into low-attention-demanding tasks, meanwhile mental arithmetic task [10] and driving simulation task[11] fall into middle-attention-

demanding tasks. However, among these three-type tasks, the middle-attention-demanding tasks are greatly in line with our daily working load. Therefore, we chose mental arithmetic task to induce mental fatigue.

Historically, mental fatigue has been most prevalently studied with the neuroimaging technique of EEG on account of its high temporal resolution, low costs, and easy operation [12–14]. It has been widely proved that mental fatigue can lead to distinct changes in EEG[15]. Strijkstra has found that EEG during resting awake periods with eyes closed shows strong negative correlations of alpha power and positive correlations of theta power with subjective sleepiness[16]. With the mental fatigue increasing, the power spectrum density of alpha rhythm increases when eyes open and decreases when eyes closed[17]. These changes in EEG can be used to detect mental fatigue [10, 15], which is especially important and meaningful for driving fatigue estimation [7, 11]. From the above, we can conclude that EEG has become the most effective technical means for exploring the neuromechanism and detection of mental fatigue [18, 19].

The current study is also motivated by the studies which have divided the EEG bands into narrower bands. In mental fatigue related studies, some researchers divided alpha band into alpha1 (8–10Hz) and alpha2 (10–13Hz). Li has performed statistical analysis on the characteristics of alpha1 and alpha2 to estimate mental fatigue, and reported that alpha1 band is better for fatigue detection [10]. Sun has applied alpha1 frequency band for mental fatigue classification, and achieved a high prediction accuracy [20].

In the current study, we attempted to investigate the differences of mental fatigue on electrophysiological activity between resting state and task state. To this end, we administered a challenging sustained mental arithmetic math task for a group of young healthy male participants to induce mental fatigue, and EEG data for resting state and task state before and after the tasks were collected. Then the power and relative power of delta, theta, alpha1, alpha2, and beta were computed, and statistical analysis (analysis of variance, ANOVA) were carried on the results among different brain regions.

## Materials And Methods

### Participants

Twenty male participants (age was  $24.5 \pm 1.5$  years, and body mass index was  $20.7 \pm 1.8$  kg/m<sup>2</sup>) were recruited. Each subject should be right-handed, and should have a regular life, normal normal eyesight, and no brain diseases. Before the tests, every participant was required to do as follows: (1) not staying up late at night, (2) not drinking alcohol and drugs in one week preceding the EEG test, (3) not smoking and drinking coffee and tea in 8 hours before EEG data acquisition, and (4) washing their hair in 2 hours before the experiment. Every participant was informed the experimental procedures and the local Ethics Committee have approved this study. Each subject gained some monetary reimbursement to motivate their better performances during the tests.

# EEG data recording

EEG data were recorded by a digital EEG apparatus (SYMTOP NT9200) at the following nineteen electrodes of the 10–20 systems: Fp1, Fp2, F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, T3, T4, T5, T6, Fz, Cz, and Pz (A1 and A2 were chosen as the reference electrodes, Fpz was specified as the grounding-electrode, sample frequency was 1000 Hz, electrode impedance was controlled under 5000  $\Omega$ ). In order to induce mental fatigue, every subject was required to do a mental arithmetic task with 200 different problems for 100 minutes. The mental arithmetic problem was designed as: a random double-digit (between 60 and 90) plus another random double-digit (between 60 and 90) and then multiplied by a random single digit (between 6 and 9). Each math problem was designed to be done in 30 seconds determined by preceding pretests. As shown in Figure 1, the whole mental arithmetic task was equally divided into 4 tasks, and EEG was collected for both resting state and task state. Therefore, there were 5 times EEG data acquisition named as T0, T1, T2, T3 and T4 for the whole task. Besides, resting state means closing the eyes, being awake and relaxed, and subjects were required to concentrate their attention on the breath avoiding thinking about anything, whereas task state refers to keep the body still and do a mental arithmetic math problem, a three-digit subtracts a single digit continuously (keep same for every data recordings). All the mental arithmetic math problems were automatically displayed on the computer screen one by one. The whole test was carried on from 7 pm to 9 pm in a sound attenuated, and light, temperature, and humidity controlled room.

## EEG data preprocessing

EEG signals from only eighteen subjects were analyzed for further analysis. The other two were excluded because of their big head movements when recording the EEG. In the current analysis, ten pieces of five seconds of artifact-free continuous EEG data (containing no eye blinks, no slow eye movements, no electrocardiogram artifacts (eliminated by Fast ICA), and no baseline drift (removed by baseline correction)) were selected from each condition by EEGLAB. These pieces of data were then down sampled from 1000Hz to 256 Hz. And EEG rhythms (delta: 2–4 Hz; theta: 4–8 Hz; alpha1: 8–10 Hz; alpha2: 10–13 Hz; beta: 13–30 Hz) were extracted by digital FFT filtering.

## Computation of EEG indices

In this study, the power and relative power of every EEG rhythms were explored. The frequency spectrum  $X(f)$  of EEG signal  $x(n)$  was obtained by means of FFT, and then the power spectrum  $P_x(f)$  of EEG were gained with equation (1). The power  $E(h)$  and relative power  $R(h)$  were calculated through equation (2) and equation (3). Where, in equation (1), equation (2) and equation (3),  $N$  is the number of EEG signal  $x(n)$ ,  $h$  represents the EEG rhythms (such as delta, theta, alpha1, alpha2, beta),  $f_h$  and  $f_l$  are the upper and lower frequencies of  $h$  rhythm respectively,  $E_{total}$  is the total power of all EEG rhythms. Besides, all the

calculated power spectrum are the average value of the selected 10-segment EEG signals for each condition. In order to study the differences of mental fatigue in different brain regions[21], we divided the whole brain region into five brain functional regions. As shown in table 1, the nineteen electrodes are also divided into five groups. And EEG indices are also computed based on the five brain functional regions.

[Due to technical limitations, equations 1-3 are only available as a download in the supplemental files section.]

## Statistical analysis

One-way ANOVA was carried out to distinguish the significant statistical differences between the five periods (T0, T1, T2, T3 and T4). This ANOVA analysis was performed on the power and relative power of EEG bands. Results are demonstrated as mean  $\pm$  SD. Significant level is reported at  $p < 0.05$ .

## Results

Figure 2 and table 2 depict the results of EEG power, it has been found that the power of each rhythm in resting state and task state varies in the evolutionary process of mental fatigue, but there are few statistical differences. In resting state, the alpha1 rhythm power at frontal and temporal have a marked tendency to increase, and the alpha2 power at parietal has a significant reduction. In task state, only the beta power at parietal and occipital have obvious decrease. The reason for the insignificant statistical differences may be that the power of EEG rhythms is not sensitive to the mental fatigue, and the small changes of EEG power will be masked by individual differences and power spectrum fluctuations. Therefore, the other widely used EEG index, relative power, was analyzed in the study.

Figure 3, figure 4 and table 3 show the results of EEG relative power in resting state. Figure 3 is the brain topography of the relative power for every rhythms. Figure 4 is the average relative power of all electrodes. Table 3 is the statistical results of EEG relative power in different brain regions. As shown in figure 3, figure 4 and table 3, the relative power of delta rhythm presents a monotonically decreasing trend throughout the whole brain, and has significant statistical differences across all brain regions. The results of theta rhythm indicate that only in the central region has a significant increasing trend, and there are no statistic difference in other brain regions. Whereas, both alpha1 rhythm and alpha2 rhythm have significant statistical differences among all the brain regions, and beta rhythm have significant statistical differences only in frontal, temporal, and parietal regions. But the changing regularities of alpha1, alpha2, and beta rhythms are not monotonous.

Figure 5, figure 6 and table 4 show the results of EEG relative power in task state. Figure 5 is the brain topography of the relative power for every rhythms, figure 6 is the average relative power of all electrodes, and table 4 is the statistical results of EEG relative power in different brain regions. As shown in figure 5, figure 6 and table 4, the relative power of delta rhythm presents a decreasing trend throughout the whole brain, and has significant statistical differences in frontal, central, parietal, occipital regions. Both theta

rhythm and alpha1 rhythm have a non-monotonic increasing trend for the results of relative power, but only in temporal and parietal regions for theta rhythm, and only in central and parietal regions for alpha1 rhythm that have significant statistical differences.

## Discussion

In the present study, we analyzed the difference in spontaneous neural activities caused by performing prolonged fatigue-inducing mental arithmetic tasks between resting state and task state. Five EEG rhythms were evaluated among five brain regions in the two states. The delta rhythm power was  $7.1 \pm 0.54 \mu V^2$  in the resting state, and had the lowest proportion (10%) in all EEG rhythms; in the task state, the power was  $6.1 \pm 0.34 \mu V^2$ , but the proportion increased to 21.5%. This is mainly because Alpha1 and Alpha2 rhythms were significantly suppressed in task state (see figure 5), leading to a significant increase in the proportion of corresponding delta rhythm. The delta rhythm power had no statistical difference among T0, T1, T2, T3 and T4 both in resting state and task state (see table 1), which is consistent with its actual physiological meaning. Because delta rhythm is related to people's deep sleep[22], and it usually appears in large quantities in adult's deep sleep, anesthesia and hypoxia. As for the relative power of delta rhythm, it decreased significantly along with the accumulation of task time in both resting state and task state, which is in line with the results reported by Jap when researching driving fatigue[21]. Some literatures also have pointed out that the amplitude and relative power of delta rhythm increased under fatigue state[23]. However, in many fatigue evaluation studies, delta band was directly removed by researchers and technicians [22]. Because they believe that delta rhythm reflects the state of deep sleep, and general brain fatigue status does not show significant changes. Moreover, the frequencies of EEG artifacts (such as blink artifacts, eye movement artifacts, electrocardio artifacts, etc., except for power-frequency artifacts and myoelectricity artifacts) mainly coincide with the delta frequency band. The removal of the artifacts is highly subjective, and the removal effect varies from person to person. Therefore, the results of delta rhythm in this study will not be in too further discussion.

The power and relative power results of theta rhythm were unanimous both in resting state and task state, demonstrating an increasing trend, which was consistent with the results of most fatigue studies [16, 21–23]. Generally, theta rhythm is considered to reflect the early state of sleepiness[24], which is related to brain fatigue[25] and has a sensitive response to fatigue[26]. As shown in table 3 and table 4, the response result of theta rhythm in the task state was slightly better than that in the resting state, because there were statistical differences in the temporal region and parietal region in the task state, while there were statistical differences only in the central region in the resting state.

Alpha rhythm reflects the state of relaxation and wakefulness. When focusing attention, external stimulation or visual input, alpha rhythm will be blocked[27]. Alpha rhythm is considered to be the most sensitive indicator of brain fatigue [25, 26], which is consistent with the statistical analysis results of alpha1 and alpha2 showed in table 3 and table 4. In the increase of mental fatigue, the power and relative power of alpha rhythm were reported to be significantly increased [22, 23]. Several other researchers reported the opposite changing tendency [21]. However, it is now widely accepted that alpha rhythm

intensifies as the brain transformed from normal into fatigue [28, 29] (see detailed statistical results of relevant studies in reference [27]). As shown in table 3 and table 4, the effect of alpha1 and alpha2 rhythm in depicting mental fatigue in resting state is better than that in task state

In this study, alpha band was further divided into two sub-bands, alpha1 and alpha2, obtaining some meaningful results: the relative power of alpha1 rhythm increased significantly both in resting state and task state, while alpha2 rhythm decreased significantly in the resting state, but showed an increasing trend in the task state, which were consistent with the power change trend shown in figure 2. In similar research results, it is also pointed out that alpha1 rhythm power increases with the increase of fatigue level [29–31], and alpha2 rhythm has the same changes in task state[29]. The change rule of alpha1 and alpha2 in the resting state is completely opposite, and that in the task state is consistent, indicating that it is essential to divide alpha frequency band into alpha1 and alpha2 sub-bands in brain fatigue research based EEG. Klimesch has emphasized that using narrower frequency band in the study can reduce the risk that the frequency effects are cancelled out or not discovered[32], which is well demonstrated in the results of alpha1 and alpha2 rhythms in this study. In addition, narrower frequency band division can enhance the physiological meaning of the sub-bands and make their statistical results more significant. The contrary change trend and significant statistical results of Alpha1 and Alpha2 rhythms in the resting state can prove this inference.

Klimesch has pointed out through the analysis of event-related potential that alpha1 rhythm is related to attention, and its power will increase significantly when the attention task increases and the subjects are required to stay awake and not allow sleep and rest [32], which is consistent with the results of alpha1 rhythm in this study. As for alpha2 rhythm, Klimesch et al. have indicated that alpha2 desynchronization is positively correlated with brain long-term memory function by comparing the performance of subjects with different memory abilities in memory tasks[33]. In their subsequent studies, it has been further proved that alpha2 rhythm is correlated with memory [34–37] and cognitive behavior[38]. When the memory task increases, alpha2 rhythm (in the state of eye closure at the time of EEG data collection) shows synchronization [34, 35, 39], that is, the power decreases, which can explain the change trend of alpha2 rhythm in the resting state in this study.

Further analysis of the brain topography in the fourth column of figure 3 and figure 5, we found that: (a) alpha2 rhythm power is mainly distributed in the occipital region, which is consistent with the results of topography given by Craig et al. [29]; (b) in resting state, alpha2 rhythm is very strong in all brain regions in the baseline state (referring to the T0 period), but when the brain enters the fatigue state (referring to the T1, T2, T3 and T4 periods), alpha2 rhythm is mainly concentrated in the occipital region; (c) in task state, alpha2 rhythm is mainly concentrated in occipital region, and tends to strengthen in the parietal region and right temporal region with the increase of tasks. The above results suggest that alpha2 rhythm is also closely related to visual information processing in the brain, as the occipital lobe is mainly responsible for visual functions. In the resting state, there is no visual information input in the brain, and the influence of memory task is dominant in the brain, so the brain is shown as de-synchronization [33], and the power and relative power are shown as decreased. In the task state, the brain has a large amount

of visual information to be processed, then the neural centers in the occipital area and nearby brain areas are activated (manifested as increased energy of alpha2 rhythm) to complete the visual information transmission and processing tasks. The influence of visual information processing task is dominant, while the influence of memory task is covered. Under these two kinds of comprehensive effects make the alpha2 power has increasing trend, but no statistical difference. Under the combined action of these two influences, the power of alpha2 rhythm tends to increase, but there is no statistical difference.

With the deepening of mental fatigue, the relative power of beta rhythm decreases significantly in both resting state and task state, which is consistent with the change trend of its power. Consistent research results have also been widely reported[21, 22]. Beta rhythm are usually associated with the excited state of the brain (e.g., mood and mental activity). When the brain converts from resting state to task state, it needs to maintain a high concentration to complete the tasks, and its beta proportion rises from 15% to 28%. According to the brain topography in the fifth column of figure 3 and figure 5, beta rhythm is mainly distributed in the temporal region, which is consistent with the results of the brain topography given by Jap et al. [21]. Based on the statistical results in table 3 and table 4, the effect of beta rhythm on depicting mental fatigue in resting state is slightly better than that in task state.

## Conclusions

In the present study, a strictly controlled experiment was conducted to study the differences of mental fatigue on electrophysiological activity between resting state and task state. To this end, mental fatigue was induced by the mental arithmetic math task and EEG data was collected before and after the tasks. Then five EEG rhythms (delta, theta, alpha1, alpha2, and beta) were calculated and discussed between resting state and task state. The results suggested the following conclusions: firstly, mental arithmetic task can successfully induce mental fatigue in the enrolled subjects; secondly, the relative power index of each EEG rhythm is more sensitive than the power index in response to mental fatigue, indicating that relative power can be used to estimate brain fatigue level; thirdly, the relative power of each EEG rhythm is better at assessing mental fatigue in resting state than in task state; finally, it is of great physiological significance to divide alpha frequency band into alpha1 band and alpha2 band in fatigue related studies, and at the same time improve the statistical differences of sub-bands.

## Abbreviations

EEG: electroencephalogram; ANOVA: analysis of variance; EEG DAQ: EEG data acquisition.

## Declarations

## Ethics approval and consent to participate

This study was approved by the Ethics Committee of Shandong University, and written informed consent was obtained from each participant.

## Consent for publication

Not applicable.

## Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

## Competing interests

The authors declare that they have no conflict of interest.

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## Authors' contributions

LG: conception and design, experimental procedures, analysis and interpretation of the results, writing the article. JY and JW: conception and design, analysis and interpretation of the results. LY and GZ: perform and analyze experiments, and interpret results. HS and ZJ: interpretation of the results, critical revision of the article. All authors have read and approved the final manuscript.

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## Reference

1. Boksem MAS, Tops M: Mental fatigue: Costs and benefits. *Brain Research Reviews* 2008, 59(1):125–139.
2. Jin SH, Lin P, Hallett M: Abnormal Reorganization of Functional Cortical Small-World Networks in Focal Hand Dystonia. *PLoS One* 2011, 6(12):12.

3. Ahn S, Nguyen T, Jang H, Kim JG, Jun SC: Exploring Neuro-Physiological Correlates of Drivers' Mental Fatigue Caused by Sleep Deprivation Using Simultaneous EEG, ECG, and fNIRS Data. *Frontiers in Human Neuroscience* 2016, 10.
4. Peng Q, Hua R, Lingyun G, Xiaobing Z, Tianshu Z, Yu T, Nitish T, Anastasios B, Jinsong L, Yu Sun %+ Department of Control S et al: Neural Mechanisms of Mental Fatigue Revisited: New Insights from the Brain Connectome. *Engineering* 2019, 5(2).
5. Ishii A, Tanaka M, Shigihara Y, Kanai E, Funakura M, Watanabe Y: Neural effects of prolonged mental fatigue: A magnetoencephalography study. *Brain Res* 2013, 1529:105–112.
6. Tanaka M, Ishii A, Watanabe Y: Neural effects of mental fatigue caused by continuous attention load: A magnetoencephalography study. *Brain Res* 2014, 1561:60–66.
7. Dimitrakopoulos GN, Kakkos I, Dai Z, Wang H, Sgarbas K, Thakor N, Bezerianos A, Sun Y: Functional Connectivity Analysis of Mental Fatigue Reveals Different Network Topological Alterations Between Driving and Vigilance Tasks. *IEEE Transactions on Neural Systems and Rehabilitation Engineering* 2018, 26(4):740–749.
8. Sun Y, Lim J, Meng J, Kwok K, Thakor N, Bezerianos A: Discriminative analysis of brain functional connectivity patterns for mental fatigue classification. *Annals of biomedical engineering* 2014, 42(10):2084–2094.
9. Kar S, Bhagat M, Routray A: EEG signal analysis for the assessment and quantification of driver's fatigue. *Transportation Research Part F Traffic Psychology & Behaviour* 2010, 13(5):297–306.
10. Li G, Li B, Wang G, Zhang J, Wang J: A new method for human mental fatigue detection with several EEG channels. *Journal of Medical and Biological Engineering* 2017, 37(2):240–247.
11. Hu J, Min J: Automated detection of driver fatigue based on EEG signals using gradient boosting decision tree model. *Cognitive Neurodynamics* 2018, 12(4):431–440.
12. Lim J, Quevenco F-C, Kwok K: EEG alpha activity is associated with individual differences in post-break improvement. *Neuroimage* 2013, 76(1):81–89.
13. Lawhern V, Kerick S, Robbins KA: Detecting alpha spindle events in EEG time series using adaptive autoregressive models. *BMC Neurosci* 2013, 14.
14. Huang J, Ulke C, Sander C, Jawinski P, Spada J, Hegerl U, Hensch T: Impact of brain arousal and time-on-task on autonomic nervous system activity in the wake-sleep transition. *BMC Neurosci* 2018, 19:11.
15. Tian S, Wang Y, Dong G, Pei W, Chen H: Mental Fatigue Estimation Using EEG in a Vigilance Task and Resting States. *Conference proceedings: Annual International Conference of the IEEE Engineering in*

Medicine and Biology Society IEEE Engineering in Medicine and Biology Society Annual Conference 2018, 2018:1980–1983.

16. Strijkstra AM, Beersma DGM, Drayer B, Halbesma N, Daan S: Subjective sleepiness correlates negatively with global alpha (8–12 Hz) and positively with central frontal theta (4–8 Hz) frequencies in the human resting awake electroencephalogram. *Neuroscience letters* 2003, 340(1):17–20.
17. Putilov AA, Donskaya OG: Alpha attenuation soon after closing the eyes as an objective indicator of sleepiness. *Clinical and Experimental Pharmacology and Physiology* 2014, 41(12):956–964.
18. Chen J, Wang H, Hua C, Wang Q, Liu C: Graph analysis of functional brain network topology using minimum spanning tree in driver drowsiness. *Cognitive Neurodynamics* 2018, 12(6):569–581.
19. Li G, Li B, Jiang YH, Jiao WD, Lan H, Zhu CG: A new method for automatically modelling brain functional networks. *Biomedical Signal Processing and Control* 2018, 45:70–79.
20. Sun Y, Lim J, Kwok K, Bezerianos A: Functional cortical connectivity analysis of mental fatigue unmasks hemispheric asymmetry and changes in small-world networks. *Brain & Cognition* 2014, 85:220–230.
21. Jap BT, Lal S, Fischer P, Bekiaris E: Using EEG spectral components to assess algorithms for detecting fatigue. *Expert Systems with Applications* 2009, 36(2):2352–2359.
22. Eoh HJ, Chung MK, Kim S-H: Electroencephalographic study of drowsiness in simulated driving with sleep deprivation. *International Journal of Industrial Ergonomics* 2005, 35(4):307–320.
23. Lal SKL, Craig A: Driver fatigue: Electroencephalography and psychological assessment. *Psychophysiology* 2002, 39(3):313–321.
24. Åkerstedt T, Gillberg M: Subjective and Objective Sleepiness in the Active Individual. *International Journal of Neuroscience* 2009, 52(1–2):29–37.
25. Lal SKL, Craig A: Reproducibility of the spectral components of the electroencephalogram during driver fatigue. *Int J Psychophysiol* 2005, 55(2):137–143.
26. Torsvall L, Åkerstedt T: Sleepiness on the job: continuously measured EEG changes in train drivers. *Electroencephalography and clinical neurophysiology* 1987, 66(6):502–511.
27. Hartman AL: *Atlas of EEG Patterns*: Lippincott Williams & Wilkins; 2013.
28. Lal SKL, Craig A: A critical review of the psychophysiology of driver fatigue. *Biol Psychol* 2001, 55(3):173–194.
29. Craig A, Tran Y, Wijesuriya N, Hung N: Regional brain wave activity changes associated with fatigue. *Psychophysiology* 2012, 49(4):574–582.

- 30.Sun Y, Lim J, Kwok K, Bezerianos A: Functional cortical connectivity analysis of mental fatigue unmasks hemispheric asymmetry and changes in small-world networks. *Brain and cognition* 2014, 85:220–230.
- 31.Boksem MAS, Meijman TF, Lorist MM: Effects of mental fatigue on attention: An ERP study. *Cognitive Brain Research* 2005, 25(1):107–116.
- 32.Klimesch W: EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. *Brain Research Reviews* 1999, 29(2–3):169–195.
- 33.Klimesch W, Doppelmayr M, Pachinger T, Ripper B: Brain oscillations and human memory: EEG correlates in the upper alpha and theta band. *Neuroscience letters* 1997, 238(1–2):9–12.
- 34.Klimesch W, Doppelmayr M, Hanslmayr S: Upper alpha ERD and absolute power: their meaning for memory performance. *Progress in Brain Research* 2006, 159(1):151–165.
- 35.Sauseng P, Klimesch W, Schabus M, Doppelmayr M: Fronto-parietal EEG coherence in theta and upper alpha reflect central executive functions of working memory. *Int J Psychophysiol* 2005, 57(2):97–103.
- 36.Schack B, Klimesch W, Sauseng P: Phase synchronization between theta and upper alpha oscillations in a working memory task. *Int J Psychophysiol* 2005, 57(2):105–114.
- 37.Escolano C, Aguilar M, Minguez J, Ieee: EEG-based Upper Alpha Neurofeedback Training Improves Working Memory Performance. In: 33rd Annual International Conference of the IEEE Engineering-in-Medicine-and-Biology-Society (EMBS): Aug 30-Sep 03 2011; Boston, MA: Ieee; 2011: 2327–2330.
- 38.Zoefel B, Huster RJ, Herrmann CS: Neurofeedback training of the upper alpha frequency band in EEG improves cognitive performance. *NeuroImage* 2011, 54(2):1427–1431.
- 39.Klimesch W, Doppelmayr M, Pachinger T, Russegger H: Event-related desynchronization in the alpha band and the processing of semantic information. *Cognitive Brain Research* 1997, 6(2):83–94.

## Tables

Table 1: Division of the brain regions and their included electrode.

Brain region	Electrode name
Frontal	Fp1, Fp2, F3, F4, F7, F8, Fz
Temporal	T3, T4, T5, T6
Central	C3, Cz, C4
Parietal	P3, Pz, P4
Occipital	O1, O2

Table 2: ANOVA results of EEG power in different brain regions in resting state and task state.

State	Region	Delta	Theta	Alpha1	Alpha2	Beta
Resting state	Whole brain	0.118	0.792	0.403	0.572	0.710
	Frontal	0.366	0.819	<b>0.044</b>	0.372	0.656
	Temporal	0.135	0.574	<b>0.011</b>	0.221	0.078
	Central	0.513	0.887	0.119	0.114	0.273
	Parietal	0.141	0.735	0.203	<b>4.3E-4</b>	0.112
	Occipital	0.492	0.796	0.914	0.159	0.089
Task state	Whole brain	0.760	0.507	0.212	0.673	0.103
	Frontal	0.833	0.728	0.735	0.390	0.684
	Temporal	0.106	0.179	0.765	0.903	0.193
	Central	0.965	0.845	0.434	0.743	0.195
	Parietal	0.644	0.426	0.059	0.057	<b>8.9E-7</b>
	Occipital	0.223	0.724	0.757	0.324	<b>0.013</b>

Table 3: ANOVA results of EEG relative power in different brain regions in resting state.

Region	Delta	Theta	Alpha1	Alpha2	Beta
Whole brain	<b>1.5E-5</b>	0.955	<b>1.4E-15</b>	<b>7.1E-11</b>	0.079
Frontal	<b>2.2E-5</b>	0.664	<b>3.4E-15</b>	<b>4.5E-20</b>	<b>0.038</b>
Temporal	<b>0.025</b>	0.727	<b>2.3E-4</b>	<b>0.012</b>	<b>7.3E-5</b>
Central	<b>2.0E-4</b>	<b>0.005</b>	<b>1.7E-6</b>	<b>2.1E-9</b>	0.117
Parietal	<b>1.8E-4</b>	0.309	<b>5.5E-4</b>	<b>1.2E-5</b>	<b>0.043</b>
Occipital	<b>0.015</b>	0.950	<b>0.004</b>	<b>0.002</b>	0.750

Table 4: ANOVA results of EEG relative power in different brain regions in task state.

Region	Delta	Theta	Alpha1	Alpha2	Beta
Whole brain	0.109	<b>0.044</b>	0.056	0.311	0.060
Frontal	<b>0.003</b>	0.114	0.115	0.526	0.1966
Temporal	0.406	<b>0.001</b>	0.225	0.084	<b>0.015</b>
Central	<b>0.004</b>	0.424	<b>7.7E-5</b>	0.859	0.326
Parietal	<b>0.006</b>	<b>0.021</b>	<b>3.6E-4</b>	0.164	0.103
Occipital	<b>0.037</b>	0.579	0.076	0.540	0.238

## Figures



Figure 1

EEG data acquisition (EEG DAQ) procedures. C1 means resting state and C2 means task state.

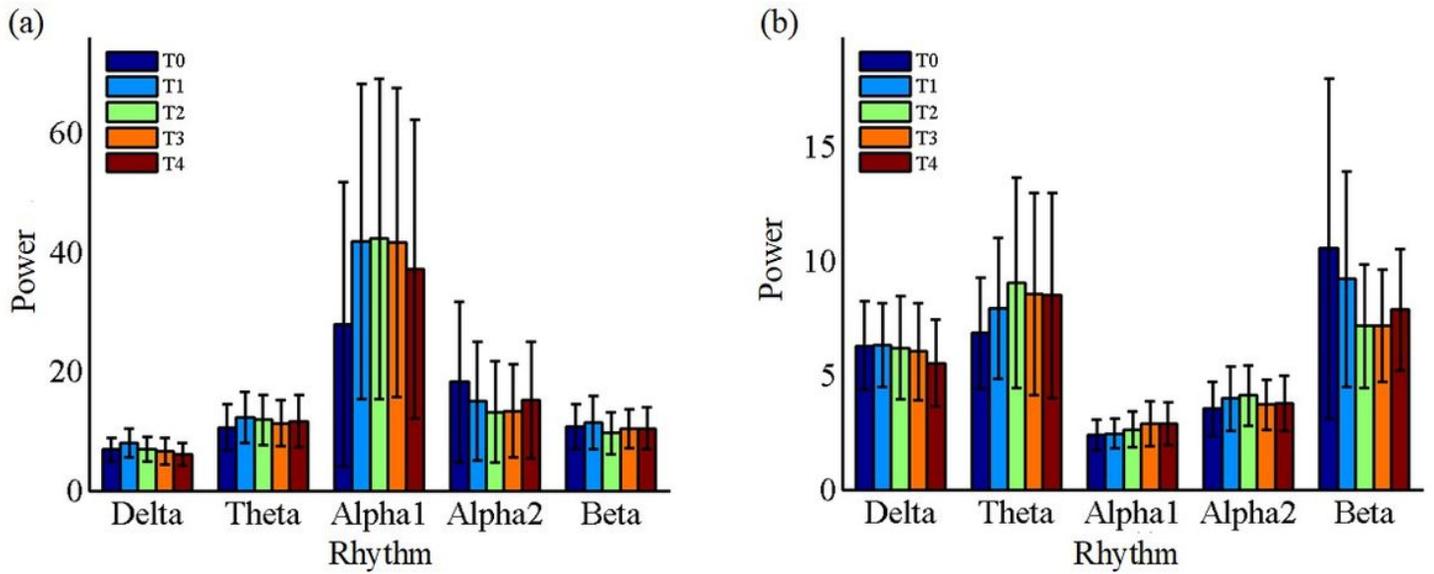


Figure 2

The power of EEG rhythms over the whole brain region at different time periods. (a) Resting state, (b) Task state.

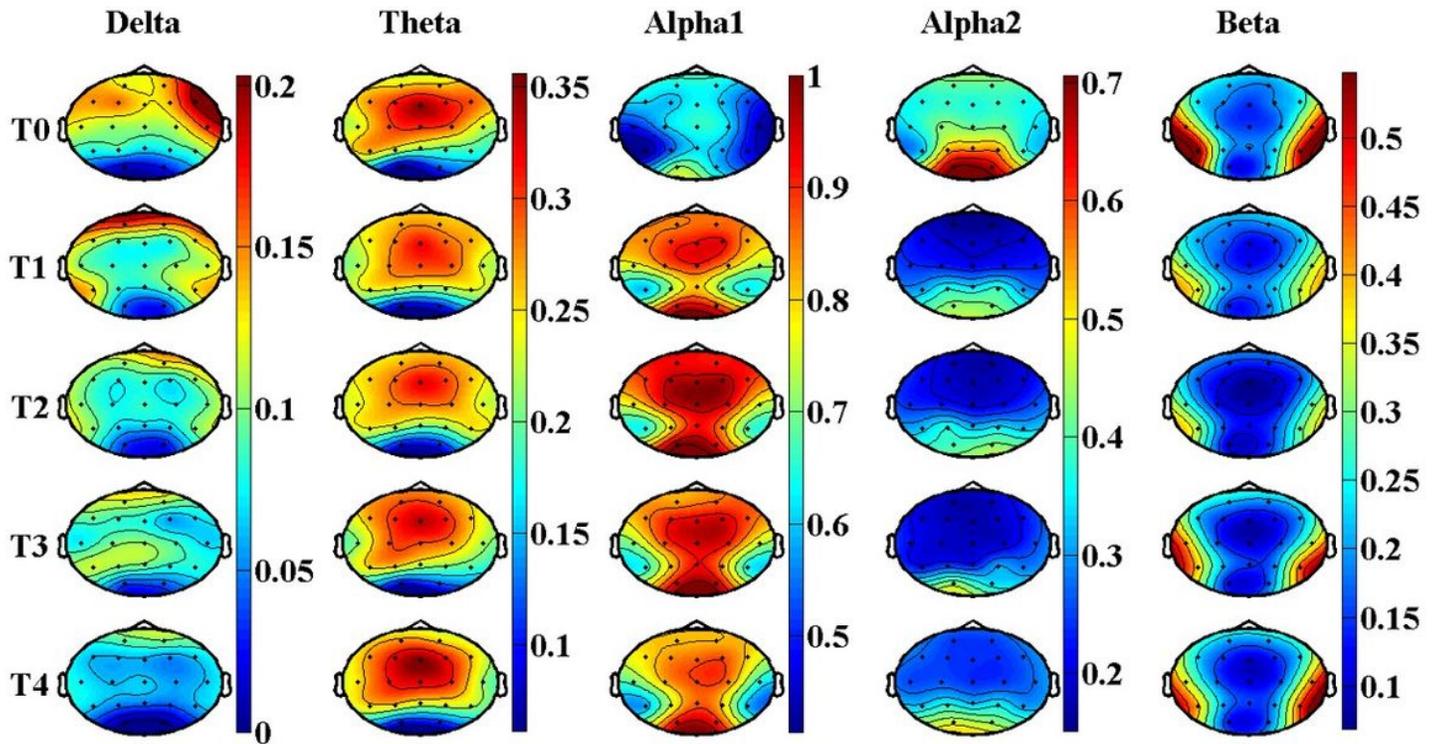


Figure 3

Brain topography of the relative power of EEG rhythms in resting state. In the figure, all the relative power values are normalized to 0-1.

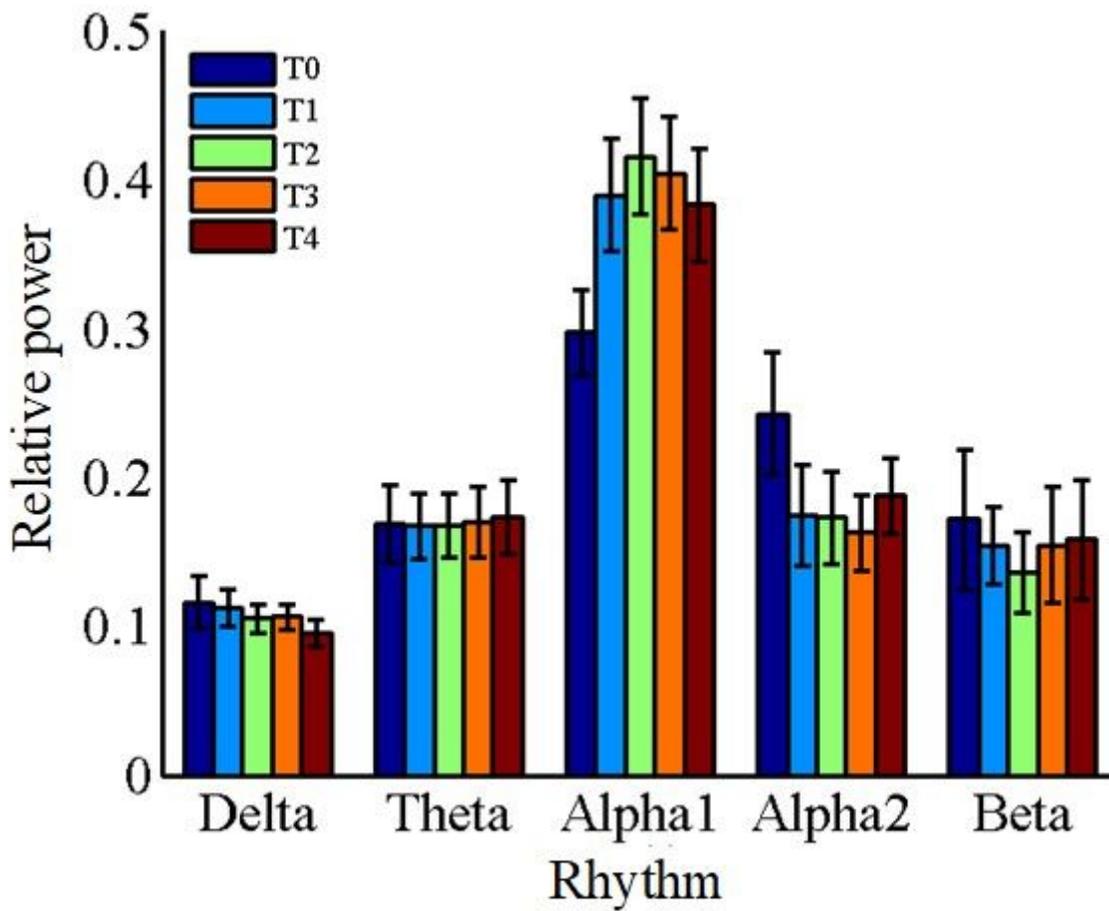


Figure 4

The average relative power of EEG rhythms over the whole brain region at different time periods in resting state.

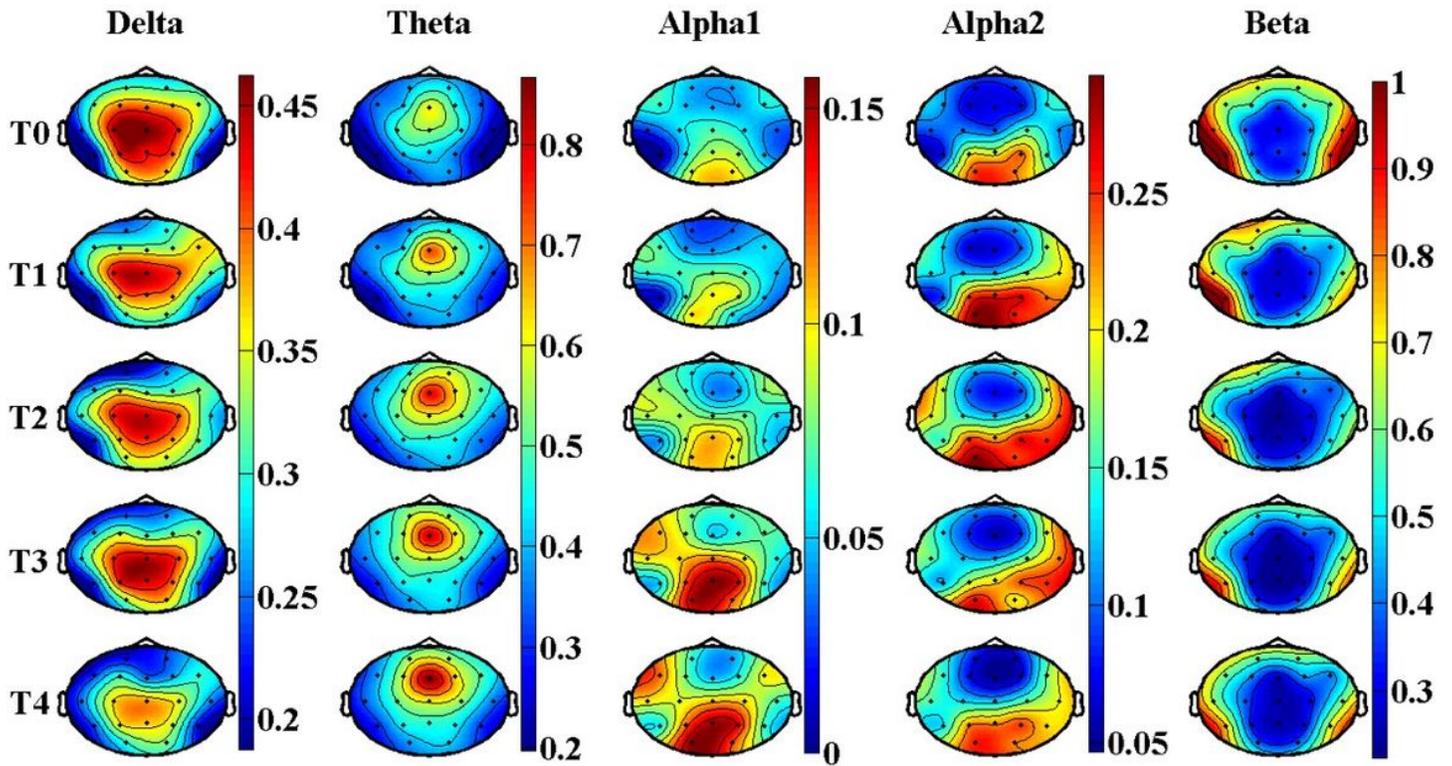


Figure 5

Brain topography of the relative power of EEG rhythms in task state. In the figure, all the relative power values are normalized to 0-1.

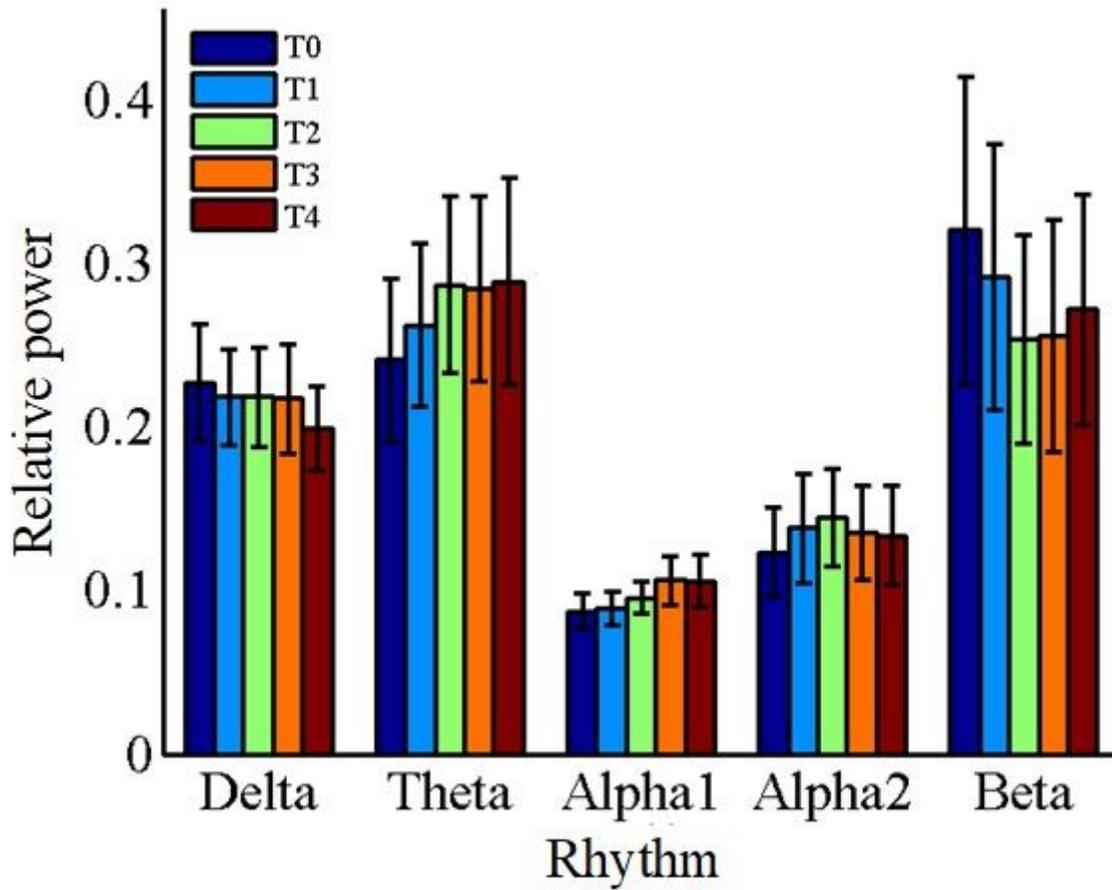


Figure 6

The average relative power of EEG rhythms over the whole brain region at different time periods in task state.

## Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [eq13.jpg](#)