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Short communication

Effect of excessive Internet use on the time–frequency characteristic of EEG

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Abstract

We examined the effect of excessive Internet use on the time–frequency characteristic of the electroencephalogram by wavelet transformed and non-negative matrix factorization (NMF). The event-related potentials (ERP) of normal subjects and excessive Internet users were acquired using the oddball paradigm experiment. We applied the wavelet transformed and event-related spectral perturbation to ERP in order to extract the time–frequency values. The *F*-test statistics of time–frequency values were then decomposed into two components by NMF. Excessive Internet use resulted in a significant decrease in the P300 amplitudes ($P < 0.05$) and a significant increase in the P300 latency ($P < 0.05$) in all electrodes. The major effect of excessive Internet use on gamma oscillation occurred at ~300 ms after stimuli at 40–50 Hz on the parietal central region. Thus, these data suggest that excessive Internet use affects information coding and integration in the brain.

Keywords: NMF; ERSP; Gamma oscillation; Event-related potentials (ERP)

1. Introduction

In recent years, Internet addiction disease (IAD) has become a serious social problem due to the popularization of the computer and the Internet and can affect people's physical and mental health and family harmony [1]. IAD is diagnosed in people who cannot control their Internet use without drugs and whose Internet use induces social and psychological dysfunction [2]. Conventional studies of IAD only employ psychological methods, although the electroencephalogram (EEG) of IAD is increasingly being used. The study which reported the early face processing mechanism of patients with IAD may be different from normal people by using the ERP method [3]. Another study reported that excessive Internet use could reduce EEG complexity [4]. However, the effect of IAD on the EEG time–frequency (TF) characteristic has not been reported.

EEG contains many different frequency components including delta bands (0.3–3 Hz), theta bands (4–7 Hz), alpha bands (8–13 Hz), beta bands (14–30 Hz), and gamma bands (30–60 Hz). Many studies have demonstrated that the gamma band is important when examining the brain cognitive domain. Recently, attention has focused on the candidate-binding mechanism of "Gamma synchrony" [5]; high frequency oscillations in electrical brain activity (typically 40 Hz, but varying from 30 to 60 Hz) occur synchronously (in cycle) across brain regions. The synchronous cycling of Gamma activity is considered to underlie the integration of diverse brain activities and associated neuronal networks [6]. Several groups have reported that coherent, distributed, and strongly phase-locked (evoked) early oscillatory gamma band responses to auditory stimuli could be detected using EEG and magnetoencephalogra-

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phy scalp recordings [7–9] and that gamma activity was strongly phase-locked to P300 [10].

Non-negative matrix factorization (NMF) is a new method to factorize a matrix and can extract the most important characteristics from different conditions and determine the weight, which is easy to explain. NMF has been widely used in image processing and EEG signal processing. In recent years, some researchers have also used NMF to extract attention-related EEG features [11].

In the present study, to examine the effect of excessive Internet use on the time–frequency characteristic of the EEG, we extracted the ERP (event-related potential) of target stimuli in an auditory oddball task using the average technology and determined differences in ERP between IAD and normal subjects. Next, we extracted the gamma activity time–frequency information of the EEG using the wavelet transformed and event-related spectral perturbation (ERSP). The *F*-test statistic of ERSP of the two groups of subjects was decomposed into two components by NMF to determine the most important EEG differences in the TF-spatial domain.

2. Experimental setup

2.1. Subjects

Twenty undergraduate students aged from 19 to 25 years (10 patients with Internet addiction that were diagnosed by the Institute of Psychology of Tianjin University and 10 normal subjects) were used in the present study. All subjects were right-handed, and healthy, had normal hearing and vision, and had no history of neurological or mental disease. Their native language was Chinese.

2.2. EEG recording

EEG was recorded using an electrode cap with 19 electrodes (Ag/AgCl) located with the reference electrode on the right earlobe (A2) and the ground electrode on the frontal midline (Fz), according to the international 10/20 system (Fig. 1). To monitor eye movements, the horizontal and vertical electrooculograms (EOGs) were recorded separately. The electrode impedance was maintained below

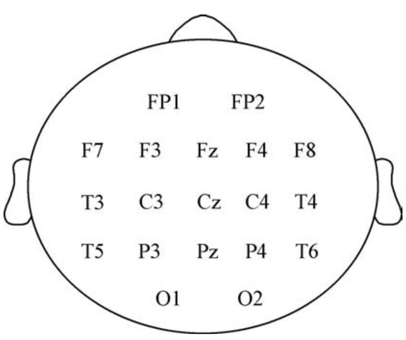

Fig. 1. Position of the 19 electrode sites according to the International 10/20 system.

5 k. The EEG and EOG were amplified and sampled at a rate of 256 Hz, then filtered with a band-pass filter of 0.05–70 Hz. The data were archived for off line analysis.

2.3. Task and procedure

All subjects were required to have sufficient sleep and could not use the Internet on the night prior to the experimentation. Experiments were performed in a sound-proof room which was well screened for electromagnetics. The background noise and luminance were 31 dB and 2 cd/m^2, respectively. Each subject was seated in an armchair, and the complete procedure for each subject took ~1 h. The subjects were told about the experimental content and requirements before starting the experiment.

For the experiment, all subjects were asked to finish auditory oddball tasks. With their eyes closed, subjects listened to sounds with two frequencies (a high tone of 2000 Hz and a low tone of 1000 Hz). They were asked to press a button as fast as possible when the high tone was broadcast. The sound pressure level of the stimuli was ~63 dB. The interval between signals was 1000 ms, and the duration of the tone was 50 ms. There were a total of 400 items in the test, of which 20% were high tones, the target stimuli.

2.4. Extraction of ERP

After rejection of artifact, including EOG and muscle movement by ICA, the ERP of the target stimuli of all subjects were derived by the ERP/EP system. The averaged epoch was 600 ms including a 100 ms pre-stimulus baseline. Reaction time and reaction right rate of target stimuli were also recorded.

3. Time–frequency analysis

3.1. Wavelet transform

Time–frequency (TF) transformation can be performed using a continuous wavelet transform which varies the window length over frequencies, from which an improved trade-off between temporal resolution and frequency resolution can be achieved. When considering the mother wavelet $\tilde{\varphi}$, the wavelet coefficient of the sampled signal $x(t_n)$ at time t_0 and at scale a can then be estimated as

$$X(t_0, a) = \frac{1}{\sqrt{a}} \sum_{n=-\infty}^{\infty} \tilde{\varphi}\left(\frac{t_n - t_0}{a}\right) x(t_n) \quad (1)$$

In the present study, the data were wavelet-transformed using a complex Morlet wavelet with a center frequency of one and a bandwidth parameter of two, i.e.,

$$\tilde{\varphi}(t) = \frac{1}{\sqrt{2\pi}} e^{-i2\pi t} e^{-t^2/2} \quad (2)$$

with frequency represented from 30 to 60 Hz (gamma band) with a 1-Hz interval. We applied a continuous wavelet transform to the EEG of each target stimuli (the averaged epoch was 600 ms including a 100 ms pre-stimulus baseline) sequentially to get the TF characteristic of the EEG. Every subject accepted 80 target stimuli.

3.2. ERSP

The event-related spectral perturbation is a measure of the average power over epochs at given channel-frequency–time points [12]. If $X_k\ (c, f, t, k)$ is the coefficient of the wavelet transform at channel c, at frequency f, and at time t for epoch k, and there is a total of n epochs, then the ERSP is given by

$$ERSP(c,f,t) = \frac{1}{n}\sum_{k=1}^{n}|X_k(c,f,t,k)|^2 \quad (3)$$

We calculated the ERSP of every subject in 19 electrodes with the frequency represented from 30 to 60 Hz and time represented from −100 to 500 ms and $n = 80$.

3.3. Data analyses

The ERSP of ERP and latency, the amplitudes of P300 and reaction time, and the reaction right ratio of the patients with IAD and normal subjects were ANOVA tested using SPSS11.0.

3.4. NMF

Lee and Seung first suggested NMF in 1999 [13], which is now a method with a wide spectrum of applications including data analysis, spectrometry, language modeling, signal and image processing, and neurophysiology. The NMF approach was proposed to search for a representative basis with only nonnegative vectors. Compared with some traditional matrix decomposition methods, the NMF has many advantages, including ease of use, its decomposition form, and the ease to explain the results. In addition, it occupies a smaller storage space.

The wavelet transform, ERSP, and NMF were performed in Matlab, and statistics were performed in SPSS11.0.

4. Results and discussion

4.1. Effect of excessive Internet use on mean reaction time and reaction right ratio

We averaged the reaction time and the reaction right ratio of the two groups of subjects when the target stimuli appeared. Results showed that the reaction right ratio of both groups of subjects exceed 99%, as the task was too easy. The mean reaction time of patients with IAD (395.6 ± 24.8 ms) was significantly longer than that of normal subjects (299.3 ± 22.7 ms) ($F = 102.2$, $P < 0.001$), suggesting that the reactive ability of patients with IAD to stimuli was weaker than that of normal subjects.

4.2. Effect of excessive Internet use on P300

The ERP of target stimuli of all subjects in the 19 electrodes were extracted by the ERP/EP system. The averaged epoch was 600 ms, including a 100 ms pre-stimulus baseline. The averaged ERP of the 10 patients with IAD and the 10 normal subjects can be seen in Fig. 2. The P300 amplitude of the patients with IAD was significantly lower than that of normal subjects ($P < 0.05$), and the P300 latency was significantly longer than that of normal subjects ($P < 0.05$) in all electrodes. These data suggest that excessive Internet use can alter the P300.

The P300 amplitude and latency can be used as an indicator of allocation of the attention resource. One study found that a longer latency and lower amplitude of P300 reflected reading and hearing process obstacles [14]. Erez

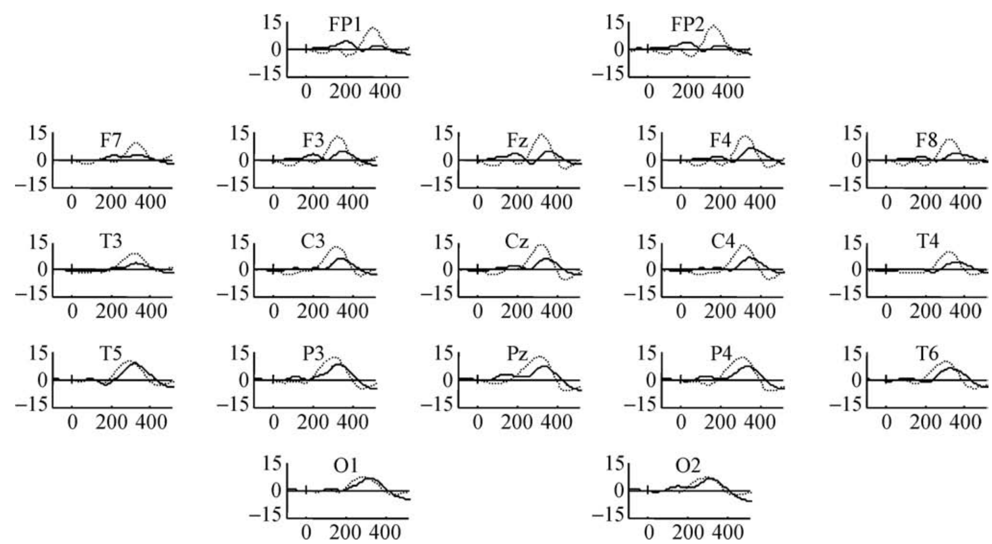

Fig. 2. The mean event-related potentials (ERP) of the Internet addiction disease (IAD) patients (solid line) and the normal subjects (dotted line).

and Pratt [15] also found that the P300 amplitude of children with a reading obstacle was lower than that of normal subjects using the oddball task, which comprised two meaningless monosyllabic and pure tone stimuli and suggested that children with reading obstacles did not have adequate attention resources. The P300 latency also depends on the speed of identification of the stimulus and the decision-making process, while the P300 amplitude also depends on the attention and the amount of receiving information of the subjects [16]. Therefore, in the present study, the decreased P300 amplitude and increased P300 latency in patients with IAD suggest that they do not have adequate attention resources or allocate attention resources inappropriately. Furthermore, the speed of stimulus identification was reduced in the patients with IAD.

Other studies have demonstrated that P300 is related to memory. For instance, the P300 latency increased with the addition of numbers in a number extension experiment, while in memory experiments we have shown that the P300 amplitude of a word which could be recalled was higher than that of a word which could not. Finally, the P300 latency of patients with dementia, whose main symptoms were a memory obstacle, was longer than that of a normal subject [16]. Thus, in the present study, the significant decrease in the P300 amplitudes and increase in P300 latency in patients with IAD suggest that the memory of these patients declined.

4.3. *Effect of excessive Internet use on the time–frequency characteristic of the EEG gamma band*

The EEG data processing steps used in the present study were as follows:

1. We applied a continuous wavelet transform to the EEG of each target stimuli in 19 electrodes (the averaged epoch was 600 ms including a 100 ms pre-stimulus baseline) sequentially to determine the TF characteristic of the EEG. Every subject accepted 80 target stimuli. Next, we calculated the ERSP of every subject in the 19 electrodes with frequency represented from 30 to 60 Hz and time represented from −100 to 500 ms.
2. The ERSP of the two groups were tested by the ANOVA and the F value determined.
3. The F-test statistic of ERSP of the two groups was decomposed into two components (TF components and topography components) by NMF, as shown in Fig. 3.

The data in Fig. 3 demonstrated that two components of NMF accounted for 71.51% of all components of NMF. Thus, we can determine the most important difference of the ERP TF characteristic between the two groups from the two components. The major difference in the ERP TF characteristic between the patients with IAD and the normal subjects occurred on the parietal central lobes (Fz, Cz, Pz, C3, and C4) at a frequency of ~40–50 Hz (particularly at 40 Hz) and at around 300 ms after stimulus.

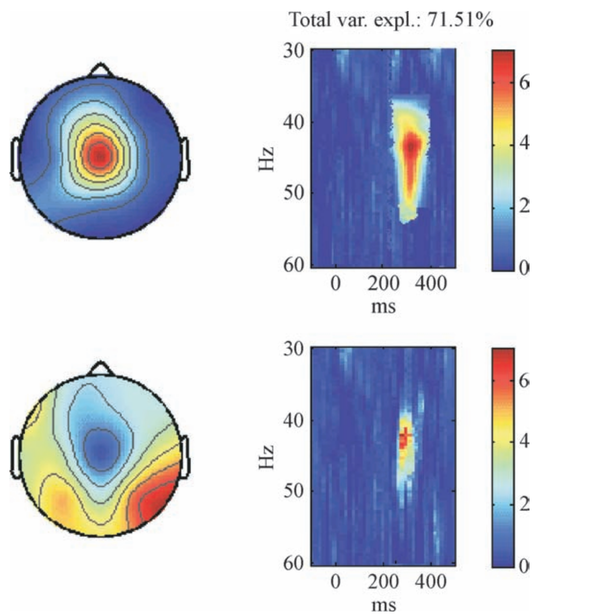

Fig. 3. Nonnegative matrix factorization (NMF) decomposition results of the F-test value.

Many studies have found that the gamma oscillation was strongly phase-locked, not only with stimulus, but also with P300 [17–19]. In the present study, the major effect of excessive Internet use on gamma oscillation occurred at about 300 ms after stimuli at around 40–50 Hz, while the P300 amplitude significantly decreased and the P300 latency significantly increased in all electrodes. Thus, excessive Internet use likely affects the gamma synchrony with P300. Recently, some studies have shown that gamma synchrony may be a neurophysiological mechanism of information coding and integration of the brain [20]. Therefore, the results from the present study suggest that excessive Internet use can alter neural information coding and integration.

According to the results of NMF, we extracted the ERSP of the patients with IAD and control subjects in a 300-ms, 40-Hz situation, and in Fz, Cz, and Pz electrodes (Table 1). These data demonstrated that the ERSP of patients with IAD in these TF-electrode situations were significantly smaller than that of normal subjects ($P < 0.05$). The ERSP value reflects the gamma oscillation

Table 1
The event-related spectral perturbation (ERSP) on a specified situation of the subjects in the two groups.

Electrode site	ERSP on 300 ms and 40 Hz situation		
	IAD patients	Normal subjects	F value
Fz	11.6 ± 2.1	15.2 ± 1.8	$F(1,10) = 16.61$, $p < 0.05$
Cz	12.4 ± 1.6	6.7 ± 2.2	$F(1,10) = 12.45$, $p < 0.05$
Pz	10.2 ± 1.4	14.7 ± 1.5	$F(1,10) = 13.23$, $p < 0.05$

intensity, thus suggesting that excessive Internet use weakens gamma oscillation intensity. Some studies have demonstrated that the gamma oscillation intensity is related to the dopamine level in the brain, the higher the dopamine level in the brain, the stronger the gamma oscillation intensity is [21]. Thus, excessive Internet use may have reduced the dopamine level in the brain, resulting in weakened gamma oscillation intensity.

5. Conclusions

The results of the present study demonstrated that the P300 amplitude was obviously decreased and the P300 latency was obviously increased in all electrodes because of excessive Internet use, suggesting that excessive Internet use can alter memory and reaction speed. Further, from the NMF results, the major effect of excessive Internet use on gamma oscillation occurred at ~300 ms after stimuli at around 40–50 Hz on the parietal central region, suggesting that excessive Internet use can affect the information coding and integration of the brain.

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