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Assessment visual fatigue of watching 3DTV using EEG power spectral parameters

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ABSTRACT

Although the three-dimensional television is popular for its stereoscopy, the fatigue caused by the prolonged watching of 3DTV should not be underestimated. Electroencephalogram (EEG) has been widely used for monitoring the brain's functional activities. Based on our previous research of 3DTV fatigue, one more objective and effective 3DTV fatigue evaluation model is proposed on gravity frequency of power spectrum and power spectral entropy. As the fatigue changes, the gravity frequency reflects the transition of EEG power spectrum and the power spectral entropy describes the level of chaos of EEG. 16 channels of EEG data of twenty-five subjects watching 2DTV and 3DTV were collected, and gravity frequency of power spectrum and power spectral entropy were then calculated and analyzed. These two parameters of the 3D group changed more significantly comparing with that of the 2D group on several electrodes. There are significant decreases in gravity frequency and power spectral entropy in several brain regions after long time of watching 3DTV, which indicates the decline of subjects' alertness level. Based on the subjective evaluation and two significant parameters, gravity frequency and power spectral entropy, an accurate evaluation model for 3DTV fatigue was established using the regression equation.

1. Introduction

Three-dimensional television is popular for its stereoscopy, which can bring the audience a sense of realism with stunning visuals. Since 3DTV services have arrived to the general public recently, such as the release of the generally successful 3D movies and the development of 3DTV broad casting technologies, users can experience life-like visual home entertainment [1]. However, several primary undesirable effects are associated with 3DTV: headache, nausea and visual fatigue. In particular, visual fatigue, also called eye strain, as a topic of a few early studies, usually occurs about 30 min after watching 3D displays. Hence, watching three-dimensional television will affect human health [2,3]. To investigate the effects of 3DTV fatigue, a reliable and valid method and objective evaluation criteria are needed. Those can not only help develop a counter measure to reduce the fatigue caused by watching 3DTV, but also can effectively promote the 3DTV industry.

Several methods have been proposed for the measurement of 3DTV fatigue, either under the subjective evaluation or the objective evaluation [4]. Subjective evaluation relies on questionnaires to obtain each individual's fatigue status. The fatigue level is measured subjectively by assessing eyestrain, difficulty in focusing, headache and so forth [5]. Although subjective assessment is a reliable method for evaluating an individual's fatigue state, it is easily affected by individual differences, and there are non-uniform evaluation criteria [6].

Prior researchers have selected objective measurements to assess the fatigue state, which are based on biological signals: electrooculogram (EOG), electrocardiogram (ECG), electroencephalogram (EEG), galvanic skin response (GSR) or photo plethysmogram (PPG) [7–13]. All of the physical, mainly the eyes, and mental activities associated with viewing are reflected in EEG signals. Although quantitative physiological indicators are available to describe each individual's fatigue status, the EEG signal is perhaps the most promising, reliable and predictive indicator [14–16]. Kim and Lee [17] performed comparative measurements of visual fatigues when respectively watching 2D and 3D displays by analyzing EEG frequency bands. They only recorded the EEG signal at Oz site, and found that beta band activity changed more significantly compared with alpha band. Zhao et al. [18] utilized a multivariate autoregressive model to extract the EEG feature to measure driving mental fatigue. Based on these, it is necessary to establish an evaluation

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model incorporated effective parameters to assess fatigues caused by watching 3DTV.

Literatures have shown that numerous methods such as energy of power spectrum, gravity frequency and entropy have been used to quantitatively analyze the EEG signal. It has been found that four feature waves of the EEG signal, alpha (α), beta (β), theta (θ), delta (δ), have significant connections with the brain activity and that the power of feature waves would change with the level of fatigue [19]. In our previous study, a multiple regression model based on several algorithms, $(\alpha + \theta)/\beta$, α/β, $(\alpha + \theta)/(\alpha + \beta)$, θ/β and the energy of β waveband, had been established to detect fatigue associated with watching 3DTV [20]. However, the previous model needs too many parameters and lacks accuracy and stability.

In subsequent research, we found that gravity frequency and power spectral entropy have strong correlations with the fatigue status. Researchers analyzed brain alertness levels by combining artificial neural network with the EEG power spectrum, and found that the EEG power spectrum could reflect fluctuations of the vigilant state [21]. Moreover, gravity frequency of the power spectrum curve can not only characterize the larger frequency components of the signal and reflect the density distribution of power spectrum, but also can reflect the migration of the EEG power spectrum gravity center under different conditions [22]. Additionally, the power spectral entropy is a measure of complexity reflecting the disorder of time sequence signals and the level of chaos of multi-frequency components. The more uniform the signal energy distribution in the whole frequency components is, the more complex the signal will be [23]. So, the evaluation model involving gravity frequency and power spectral entropy should be superior to our previous model in describing the inhibition of brain activities during long period of watching 3DTV.

This paper mainly characterizes the EEG signals using the gravity frequency and the power spectral entropy. By analyzing a lot of EEG data, these two parameters, combined with subjective questionnaire evaluations, are served as objective indicators to evaluate the level of 3DTV fatigue.

2. Materials and methods

2.1. Subjects

Twenty-five right-dominated college students (14 males and 11 females), between the age of 20 and 24 (mean age: 21.6), participated in this study. All subjects were in good health and none of them were reported of any cardiovascular disease or neurological disorders in the past nor had taken any drugs known to affect EEG [24]. Participants were also required to have normal stereoscopic feelings and provide informed consent prior to the study. These participants served as the 3D group to watch 3DTV in a temperature-controlled laboratory. They were then required to watch 2DTV under the same conditions the following day and functioned as the 2D group. 3D and 2D versions of Ocean Wonderland were prepared for watching.

This study was approved by the Institutional Ethics Committee. All subjects were reported to be in good condition both physically and mentally and to have excellent sleep quality prior to the experiment. Besides, wine, tea, coffee and drugs were also prohibited in order to maintain a normal mental condition. To avoid low blood sugar which will affect the measurement results, the subjects took the test within three hours after a meal.

2.2. Experimental protocol

EEG data was acquired using Neuroscan 32 channel system (Compmedics, Australia), with international 10–20 Montage systems. However, 16 channels with Ag/AgCl electrodes from locations Fp1, Fp2, F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, T3, T4,T5 and T6, will be discussed in this paper as the representations of front, central, parietal, occipital and temporal regions. The sampling frequency was kept at 256 Hz and the skin impedance was below 5 KΩ. The unipolar reference region was linked at the right and left ear lobes and the ground electrode was placed at AFz. The entire experiment was carried out in a quiet and comfortable environment. The flow chart of the study is shown in Fig. 1.

Subjects were briefed on the purpose of the experiment, the experimental procedures, and the relative points for evaluation before the experiment. Participants sat comfortably 3 m away from the TV [25]. The process of data acquisition and analysis are shown in Fig. 2. EEG data was recorded in the eyes-closed resting state for 5 min before watching TV. During the recording, all subjects tried to relax and avoid unnecessary movements. Blinking, nodding and body movements were recorded by video in real time. Subjects were then instructed to watch 2D/3D television for about 60 min without collecting EEG data (long time wearing of the EEG cap is very uncomfortable). Following that, another 5-min EEG data was immediately recorded in the eyes-closed resting state under the same conditions. Finally, the subjective questionnaire of fatigue was given and the level of fatigue was recorded. The subjective assessment procedure is the same as shown in Ref. [20]. In general, twenty-five 3DTV EEG data sets and twenty-five 2DTV EEG data sets were collected as test group and control group respectively.

2.3. Data processing

The raw EEG data will be contaminated with numerous high frequency and low frequency noise. The high frequency noise is due to atmospheric thermal noise and power frequency noise, while the low frequency noise is mainly due to eye movements, respiration and heart beat. Because EEG signal is always faint and generally about 50 μV, EEG signals that are larger than 100 μV are rejected as artifacts and should be removed [26,27]. Based on real-time video data, the noise signal caused by unnecessary movements could be eliminated manually. The raw EEG data of each trial for each subject was processed with a 50 Hz notch filter and 0.5–30 Hz band-pass filter. All 16 channels of EEG data were subjected to the IIR digital filter implemented in the EEGLAB v9.0.0.2b software package (Swartz Center for Computational Neuroscience, University of California, San Diego, http://www.sccn.ucsd.edu/eeglab). After that, the one-minute EEG data without obvious interference at the pre-watching and post-watching periods were extracted to be analyzed. For each one-minute EEG data, 8-second EEG data from the start point was chosen as the first segment and one second as step length. By shifting segment with step length from the start to the end of the one-minute clip, 52 data segments were obtained and averaged for the purpose of improving the accuracy [28]. Then power spectrum $p(\hat{w})$ was computed by [29]

$$p(\hat{w}) = \frac{1}{N}\sum_{i=1}^{N}|X(w_i)| \tag{1}$$

where N is 2048. And then gravity frequency of power spectrum was calculated by

$$GF = \sum_{w=w_1}^{w_2}(p(\hat{w}) \cdot w) / \sum_{w=w_1}^{w_2} p(\hat{w}) \tag{2}$$

Here GF is the gravity frequency of power spectrum, w_1, w_2 respectively represent frequency upper and lower limits, namely from 0.5 Hz to 30 Hz. Then the normalized power spectrum density function $p_n(i)$ was obtained by