J. Vis. Commun. Image R. 38 (2016) 433–439

Contents lists available at ScienceDirect

J. Vis. Commun. Image R.

journal homepage: www.elsevier.com/locate/jvci

Small-world brain functional network altered by watching 2D/3DTV ☆

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ARTICLE INFO

Article history:
Received 29 January 2016
Revised 18 March 2016
Accepted 27 March 2016
Available online 29 March 2016

Keywords:
2D/3DTV
Visual fatigue
Resting-state fMRI
Brain functional network

ABSTRACT

With the development of display technology, the healthy problems caused by watching 2D/3DTV have received more and more attention. This paper utilized resting-state functional magnetic resonance imaging to study the changes of small-world brain network before and after one-hour 2D/3DTV watching, and explored the brain fatigue mechanism caused by watching 2D/3DTV. We conclude that one-hour watching of 2DTV will not increase the burden of brain. On the contrary, one-hour watching of 3DTV requires the brain to regulate the efficiency of brain areas, such as temporal lobe and occipital lobe, which may explain the fact that watching 3DTV can easier cause brain fatigue than watching 2DTV.

1. Introduction

As a developing display technique in recent years, 3DTV has drawn more and more attention in daily life. However, the health issue caused by 3DTV has always been an important factor that inhibits its popularity. Compare with traditional 2DTV, many consumers will have different levels of discomfort after watching 3DTV for a long time, including impaired eyesight, dizziness, blurred vision, sickness, convulsion and even stroke [1]. Therefore, it is extremely urgent to study 3DTV's effects on human health.

Visual fatigue is one of the main symptoms of watching 3DTV. In recent years, scholars all around the world have conducted a lot of research on the visual fatigue of watching 3DTV and obtained some preliminary results. Wang [2] has analyzed the visual fatigue caused by the display mode of 3DTV and parallax. He has found that the degree of fatigue caused by 3DTV is different from 2DTV. Gutierrez [3] analyzed the Quality of Experience (QoE) of each subject and found that watching 3DTV was able to cause visual fatigue. However, the results obtained from the subjective questionnaire can be easily affected by individual differences and psychological factors. Functional magnetic resonance imaging (fMRI) is non-invasive, has higher temporal and spatial resolution, and is widely used in the study of brain. Chen [4] utilized fMRI under the stimulation of 2D/3D pictures to explore the visual fatigue mechanism. Significant differences of activation signal were found in the brain area of BA8, BA17, BA18 and BA19. Additionally, the foreground of 3D picture has a greater effect than background. Kim [5] utilized fMRI to analyze the relationship between visual fatigue and binocular parallax and found that the neurons activities of frontal eye field would increase when the visual stimulation exceeded the comfortable depth. However, using fMRI to investigate the brain network and functional connectivity caused by watching 3DTV has never been reported.

More and more researches indicated that many advanced cognitive functions, such as attention, language, memory, are in need of synergistic effect on multiple brain regions [6]. The brain's structural and functional connectivity has complicated network characteristics. There are dense local connections and loose long connections between each brain area [7,8]. Graph theoretical approaches can disclose the topological structure of the brain functional network and characterize the relationships among all brain regions [9]. Yan used the directed graph-based order to represent the dependency relationships of coding tree unit [10]. The brain functional network would be altered by brain disease or different task state [11]. Wu [12] adopted graph theoretical tools and found that the brain functional network would re-integrate and the connectivity would significantly increase between cortex regions under the stimulation of music. Challenging cognitive tasks as well as fatigue can also significantly alter the parameters of brain functional network [13].

This study utilized resting-state BOLD-fMRI to study the difference of the brain functional network before and after one-hour watching of 2D/3DTV, and to further explore the mechanism of fatigue caused by watching 3DTV.

☆ This paper has been recommended for acceptance by Qionghai Dai.

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http://dx.doi.org/10.1016/j.jvcir.2016.03.023
1047-3203/

2. Materials and methods

2.1. Experimental design

This study was approved by the local ethics committee. All subjects provided informed written consent, in line with the Declaration of Guangdong Province Traditional Chinese Medical Hospital. Twenty right-handed subjects (16 males, 4 females; mean age 23 years; range 21–24) participated in the study. All subjects were free to withdraw from the experiment at any time. No subjects had a history of neurological disorder or abnormal stereoscopic visual senses. The experiment asked the subjects to have enough sleep the night before the test and liquor, tea, coffee or any other food or drugs that can excite the central nerves were forbidden. The 2D and 3D documentary film is "Amazing Ocean", as shown in Fig. 1. The subjects were comfortably seated inside a sound attenuated and temperature comforted chamber. To avoid the interference caused by watching different types of films, subjects watched 3D film on the first day and 2D film on the second day. The experiment procedure is shown in Fig. 2.

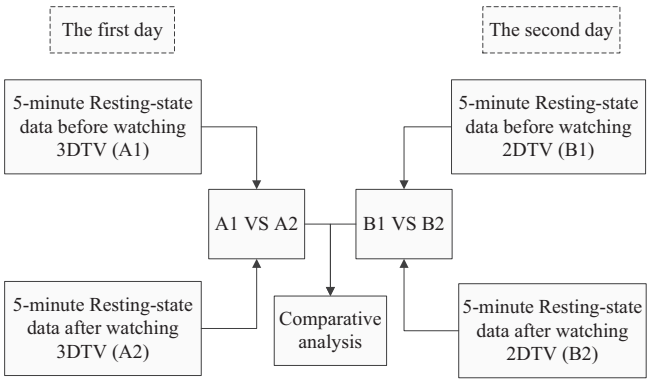

Fig. 2. Resting-state experiment flow chart.

2.2. Image acquisition and preprocess

All fMRI experiments were performed on a General Electric 3T Signa system with a standard head coil. Structural images were acquired using 3D gradient-echo T1-weighted sequence with the following parameters: TR = 7.796 ms, TE = 2.984 ms, Flip angle = 12°, matrix = 256 × 256, resolution = 1 mm × 1 mm, slice thickness = 1 mm, no gap, number of slices = 196, FOV = 256 mm × 256 mm. Functional images were obtained using T2 gradient-echo planar sequence with a different set of parameters: TR = 2000 ms, TE = 30 ms, Flip angle = 90°, matrix = 64 × 64, slice thickness/gap = 4/1 mm, number of slices = 32, resolution = 5 mm × 3.75 mm, FOV = 240 mm × 240 mm.

SPM8 (Statistical Parametric Mapping, Version 8, Welcome Department of Cognitive Neurology, University College of London, UK) is used for image preprocessing. The functional images were corrected by Slice timing, Realign, Co-register, Segment, Normalize and Smooth in SPM8. Series of images with maximum displacement in any direction larger than 1 mm or head rotation large than 1° were deleted, and the remained were co-registered with the corresponding anatomical image to facilitate transformation to Montreal Neurological Institute space. Then, these images were filtered by band-pass filter (0.01–0.08 Hz) to attenuate the effects of low-frequency drift and high-frequency noise [14].

2.3. Network analysis

Functional brain network means the interactional dynamic process among various regions, namely statistical significance relationship of functional signals in different regions during a period of time. The data sets preprocessed above were divided into 90 regions of interest (ROIs) based on the automated anatomical labeling (AAL) atlas. The mean time series of each region were then obtained by averaging the time series of all voxels in it. A 90 × 90 correlation matrix was obtained by calculating Pearson correlation coefficients between two regional time series. Each individual correlation matrix was converted to a standard normal metrics by means of the Fischer r-to-Z transformation [15]. Finally, the normalized correlation matrix was thresholded into a network with the nodes representing brain regions and the edges corresponding to the averaged correlation coefficients between two regions of the brain.

Several small-world parameters of the brain networks were obtained, including clustering coefficient, characteristic path length, global efficiency, local efficiency and regional nodal efficiency.

The network cost used for a threshold value to construct the network is defined as

$$C_G = K/(N(N-1)/2). \tag{1}$$

where N and K are the total number of the nodes and edges in the network, respectively.

The clustering coefficient C_i of node i can be formalized as

$$C_i = \frac{2E_i}{K_i(K_i-1)}. \tag{2}$$

where E_i represents the number of edges in the sub-network with node i, K_i is the number of adjacent nodes with node i.

C_{mean} is the mean clustering coefficient over all vertices, computed as

(a) (b)

Fig. 1. The 2D and 3D documentary film. (a) 2D film, (b) 3D film.