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Using Bold-fMRI to detect cortical areas and visual fatigue related to stereoscopic vision ☆

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ABSTRACT

Purpose: The location of cortical areas and visual fatigue related to stereoscopic vision were explored by two types of fMRI designs, namely block stimulation and event-related stimulation. The stimulations consist of 2D/3D images and different depths of the stereoscopic 3D images.
Method: 20 normal subjects were randomly divided into the block group and the event-related group. Blood oxygenation level-dependent functional magnetic resonance imaging (Bold-fMRI) was performed in two groups. Functional data was preprocessed and statistically analyzed by SPM8. The result was reported by REST.
Result: In the block stimulation group, compared to 2D image stimulation, 3D image stimulation results in more activated brain areas, including frontal lobes, occipital lobes and limbic lobes, especially in the frontal eye field (Brodmann Area 8, BA8) and middle occipital gyrus (BA18/19). In the event-related group, compared to 2D images, viewing 3D images causes significant activations in temporal lobe, mainly represented in BA19/13/31/37. Additionally, 3D image stimulation with the focus set at front depth can lead to the activation of more brain areas compared to the back depth, including inferior parietal lobule and posterior central gyrus.
Conclusion: The formation of the stereoscopic vision requires the collaboration of more brain areas, so that viewing stereoscopic videos for a long period may result in visual fatigue; meanwhile, the front depth of field can contribute to more activated brain areas than the back depth of field. As a parameter of stereoscopic images, it is valid to state that the depth of field may affect visual fatigue.

1. Introduction

Recently, 3D technology has become one of the most popular research topics worldwide. Compared to traditional 2D videos, 3D videos are able to bring more realistic perceptions and stronger visual impact. As the 3DTV gradually becomes prevalent, potential health risks caused by watching 3D videos, including severe visual fatigue, nausea and headache, have drawn researchers' attention [1]. According to the result of the subjective questionnaire, while watching 3D movies, 36% of the subjects experienced severe visual fatigue and 7% had to stop watching due to the visual fatigue [2]. Therefore, studying 3DTV's influence on people's health is extremely necessary.

Since visual fatigue is the most prominent symptom of long period of watching 3DTV, many studies have been conducted on this topic. Lambooij [3] clarified the most pertinent factors contributing to visual fatigue, including temporally changing demand of accommodation-vergence linkage, three-dimensional artifacts and unnatural blur. Cho [4] studied visual discomfort caused by watching stereoscopic 3D content in the term of depth and proved that the visual fatigue is proportional to the depth of field. Yu [5] utilized the eye movement signal to detect the visual fatigue caused by 2D and 3D displays and found that compared with 2D videos, 3D videos would increase the blink frequency and scanning range, which are both proportional to visual fatigue. Kim [6] conducted research on the power spectrum of the electroencephalogram (EEG) and noticed the significant variations of the β wave in the occipital region after watching 3DTV.

Functional Magnetic Resonance Imaging (fMRI) is widely used in the research of brain due to its noninvasiveness, high temporal and spatial resolution. There are two major designs for fMRI study—the block design and the event-related design, each with specific advantages and disadvantages. Block visual stimulation requires a long time to stable signals and has relatively stronger activation and larger activated regions. This paradigm suits for

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the detection and location of regions of interest (ROI) during particular tasks. However, the block visual stimulation does not account for the transient responses at the beginning and end of task blocks. Event-related visual stimulation will be displayed alternately with short time for each image, which can detect Blood Oxygenation Level Dependent (BOLD) changes caused by instantaneous visual stimulation and will further our understanding of the dynamic nature of the neurophysiology of the human visual cortex. Thus, Event-related visual stimulation has a decrease of signal-to-noise, leading to less activity than block visual stimulation [7]. Jung [8] used fMRI to identify the cortical areas associated with the experience of visual discomfort in the viewing of stereoscopic images. Nakagawa [9] utilized block design fMRI to compare the variations of the brain activation between the first and last quarter during the attention task experiment and significant fatigue-induced deactivation was observed in frontal, temporal, occipital, and parietal cortices, cerebellum and midbrain. Gur [10] explored emotion processing deficits in patients with schizophrenia by using block BOLD fMRI and revealed that patients failed to activate limbic regions during emotion processing tasks. As for the application of block design fMRI in visual research, Dongchan [11] used fMRI to investigate the relationship between visual fatigue and binocular parallax. When the visual stimulation exceeds the comfort depth, neuron activity will be stronger in the frontal eye field (FEF). Additionally, he considered that the excessive binocular disparity stimulus may induce overload to the intraparietal sulcus [12]. Chen [13] revealed that 3D group showed more significant differences in brain activation compared with 2D group in occipital lobe and parietal lobe. However, during this experiment, 3D and 2D image stimulations were carried out alternately without interval and the influence of the hemodynamic response function (HRF) was ignored. Nevertheless, the block design averages the positive and negative responses occurred in a single block [14]. As a result, the urge to extract transient BOLD activity leads to the development of the event-related design. Marsman [15] used eye fixations as events in fMRI study to reveal cortical processing during the free exploration of visual images and found that fixations on different objects in different task contexts resulted in distinct cortical patterns of activation.

Visual fatigue caused by watching 3DTV has been evaluated based on the subjective questionnaire in our previous work [16]. This paper incorporated block and event-related fMRI to study the cortex area related stereoscopic vision and its activation intensity under the stimulation with different stereoscopic depth of fields. This paper also discusses the brain functional mechanism that forms the stereoscopic vision, providing a reference to the objective evaluation of the visual fatigue caused by stereoscopic videos.

2. Method

2.1. Subjects

A total of 20 healthy dextromanual subjects (10 males, 10 females, with the youngest to be 19 and oldest to be 24, and an average age of 22.3) participated in the study. All subjects have normal vision or corrected vision and normal stereoscopic sense. Eight 3D-movie clips with four levels of depth of field (1/2 in front of and 1/2 behind the focus point) were displayed to ensure that they had normal stereoscopic sensitivity. In the meantime, they do not have medical contraindications such as severe concomitant disease, alcoholism, drug abuse, as well as psychological or intellectual problems which are likely to limit compliance. Subjects lay flat inside the scanner with their heads immobilized, wearing sponge earplugs to avoid audio stimuli during the fMRI scans. All participants have signed the informed consent form. Subjects were divided into two groups (block group and event-related group) randomly by statistical analysis and respectively received block and event-related stimulation.

The local ethics committee has approved the study protocol. Each participant has signed an informed consent form and received ¥300 (CNY) in compensation for their participation.

2.2. Experimental device

Subjects lay flat inside the scanner and watched the images projected on the optical reflector which fixed in the head coil of MRI. With the help of blue-and-red glasses, which replaced the metal joints with wood material, subjects could obtain the stereo view comfortably. The distance from subjects' eyes to the reflector was 38 cm. All images had the same 1920×1080 pixel resolution and different depth. Front depth of field 3D images had the average depth of 487 mm and standard deviation of 143 mm, compared to a back depth average of 460 mm and standard deviation of 125 mm.

2.3. Method for the visual stimulation

Block visual stimulation and event-related visual stimulation were performed to compare cortical activation between watching 3D and 2D images.

2.4. Block visual stimulation

Each subject performed a visual attention task comprised of alternating blocks of two different visual demands (3D images [A] vs. 2D images [B]) and rest [C]. The task sequence was designed by E-prime2.0 and the block design (A-C-B-C) is shown in Fig. 1. The task sequence includes 3D images, 2D images and rest. Block A contains 6 3D images displayed subsequently by red and blue stereoscopy; block B contains 6 2D images with each corresponding to the 3D image; each image will be shown for 2s in the center of the display; block C indicates the rest status, during which subjects will watch the black screen for 12s, with a white cross in the center ('+') to minimize eyeball movements. Block A-C-B-C was repeated for 7 times and a 12s rest was arranged prior to the task sequence in order for the subjects to familiarize with the experiment environment.

2.4.1. Event-related visual stimulation

The stimulation sequence was designed by E-prime2.0 and the event-related design shown in Fig. 2 was adopted as the visual stimulation. During the design of the visual stimulation, 30 3D and 30 2D images will be displayed alternately with 0.5s for each image. The interval between stimulations is set to be 6s and subject will look at a black screen with a white cross in the middle ('+') to minimize the eyeball movement during the rest. Subjects will familiarize with the experiment environment 10s before the test. To study the activation intensity under the stimulation of different stereoscopic depth of fields, front view and back view experiments were conducted separately in two days. Front depth of field and back depth of field 3D images were respectively adopted in each day's experiment as the stereoscopic stimulation.

2.5. Data collection

Functional and anatomical MR images were obtained with GESignaHDx3.0T Magnetic Resonance System in Guangdong Province Traditional Chinese Medical Hospital. The functional images were acquired with Gradient Echo-Echo Planar Imaging (GRE-EPI) sequence for whole brain images, which started slightly prior to