https://doi.org/10.2352/ISSN.2470-1173.2017.5.SD&A-356

Study of objective parameters of 3D visual fatigue based on analysis of salient area

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Abstract

Visual fatigue of 3D display restricts its wide application, moreover, human attention is one of important factors for visual fatigue due to the fact that perceptual salient regions determine the quality of experience of 3D contents. In order to study the relationship between 3D image salient area and 3D visual fatigue, an experiment is designed in which subjects are required to accomplish a task realized with 3D display system, eye tracking system and ECG detecting apparatuses. The aim of the task is to induce 3D visual fatigue with stimuli with different salient areas. ECG signals and eye tracking parameters are recorded during the whole process and the questionnaire is adopted to obtain the subjective fatigue parameters. Analysis of the experimental data shows the relationship between salient area and visual fatigue. In our research, an evaluation method of visual fatigue by considering both ECG signals and eye tracking parameters is developed, and a visual fatigue evaluation model based on salient area of 3D images is introduced. In our future study, more elements will be added into the experiment to find more factors which can induce 3D visual fatigue.

***Keywords**: Visual fatigue, 3D saliency, ECG, eye tracker*

Introduction

3D display has been expanded into such domains as education, medical and entertainment industry etc. benefited from its stereoscopic perception. However, users suffer from various discomfort symptoms which have been reported as visual fatigue while they are watching stereoscopic images or videos [1]. Visual fatigue can be caused by conflict between convergence and accommodation [2]. Usually, accommodation and convergence responses are closely related. However, conflict occurred due to stereoscopic stimulus as shown in Fig.1 [3]. Besides convergence and accommodation, users also shift their gazes to select a subset of the available stimulus before further processing [4]. This selection appears to be implemented in the form of a spatially circumscribed region of the visual field, which scans the scene in a rapid and saliency driven manner [5]. In recent years, visual attention has become an important research problem in both neuroscience and computer vision. Detecting salient object is one branch of visual attention, which has served as a pre-processing procedure for many vision tasks [21]. In this study, an objective study of visual fatigue based on 3D images with different salient areas are presented.

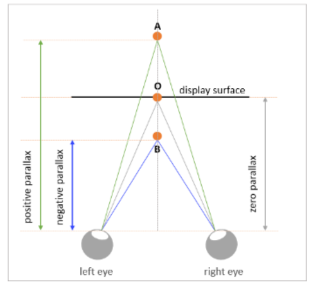


***Figure 1.** The illustration of binocular parallax*

In order to analyze the visual fatigue in viewing stereoscopic images on the 3D display, both subjective (e.g., psychophysical scaling and questionnaire) and objective measurement methods have been proposed in previous studies [6-9].

Objective measurement methods aim at finding reliable indicators for the visual fatigue such as biological signals [10]. J. Yu et al. proposed an eye movement measuring method using EOG signal based on voltage adjustment for visual fatigue caused by 2D and 3D display. Their results show that frequency of blinks and large saccade in case of 3D video is larger than those in case of 2D video [11]. Y. Kim et al. studied the difference of visual fatigue using a subjective method and made comparisons with those from electroencephalogram (EEG). Their studies show that beta power of EEG was stronger when viewing the 3D contents and the subjective results also showed stronger visual fatigue in the 3D condition than in the 2D condition [12]. A. Zhang et al. simulated a VDT (visual display terminal) experiment and collected electrocardiogram (ECG) signals to measure visual fatigue. Their results show that ECG signal features change significantly before and after VDT fatigue experiment [13]. ECG is a measure and record method of different electrical potentials of the heart and the elements in the ECG-complex as shown in Fig.2 [14]. A complete ECG signal has two segments and three intervals [15]. In this study, we designed an experiment of visual fatigue and collected ECG signals and eye tracking data for objective analysis.

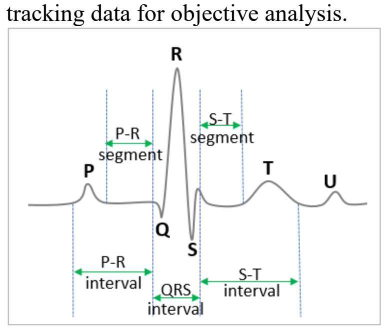


***Figure 2.** The elements of ECG-complex*

The aim of this study is to analyze how salient area of 3D images influence visual fatigue. We perform the comparative measure visual fatigue when respectively watching 3D images with different salient area by analyzing ECG signals and eye tracker data.

At the measurement stage, subjective results for some questionnaires are also used to make a comparison. In the rest of this paper, the experiment design, results and a detailed discussion will be presented.

Experiment Method

Equipment and environment

An LG D2792PB 3D TV was used to present a sequence of 3D images in left and right format. The display device is 23-inch with the resolution of 1920×1080 (horizontal by vertical) and equipped with polarized 3D glasses. A non-contact measuring device SMI eye tracker was used for collecting eye tracking data. Meanwhile, BIOPAC MP150 was used to collect ECG signals at the rate of 150Hz. The distance between the subjects and 3D TV was 90 cm according to the recommendations of 3D watching safety (3H to 6H), where the screen subtended a visual angle of 18° . The eye tracker was placed between the 3D TV and the subjects. Beside the subjects were BIOPAC MP150 and another two computers for controlling ECG signals and the eye tracking data collection process. The setup of the experiment environment is shown in Fig. 3.

Figure 3. *The experiment environment*

Visual stimulus

We gathered a total of 108 3D images (3DGaze dataset [17] and 3D photos website [18]) in left-right format. The content of all displayed 3D images is shown in Fig.4, different value in the figure means different number of images. The content of 3D images contains indoor and outdoor environment, and salient objects contain humans, animals, plants and etc.

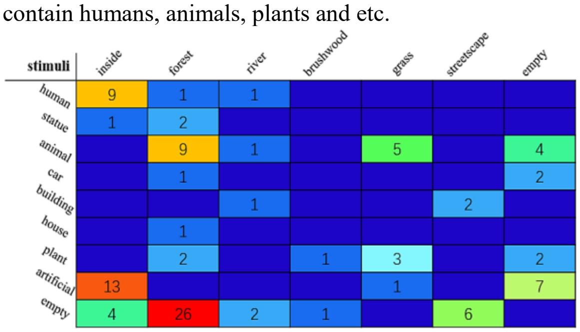


Figure 4. *The content of all displayed images*

To conduct compare measurement, 108 images were divided into two categories: (1) images with salient area; (2) images without salient area. Basically, the bottom-up approach via low level features such as border regions of the image are good indicators to distinguish salient objects from the background. To have an intuitive look of salient area, we calculate all displayed 3D images' saliency maps by using a novel saliency detection method [21] as shown in Fig.5. Fig. 5 (a) shows saliency maps of images with salient area. In contrast, Fig.5 (b) contains saliency maps images without salient area. However, some saliency maps are inaccurate because of the limitation of the saliency detection method.

Figure 5. *(a) The saliency maps of images with salient area*

Figure 5. *(b) The saliency maps of images without salient area*

Different stimuli combinations were adopted in our study. We used S1, S2 and S3 to indicate 3 sections, all images in these sections have salient area. Analogously, US1, US2 and US3 are sections which contain images without salient area. Table 1 shows watching order of the three group. There are 3 sections in each group, where each section contains 18 images and 9 minutes are needed to finish one group watching task.

Table1 The grouping situation of the experiment

Group	Subjects Number	Watching order
Group 1	4	S1→S2→S3
Group 2	4	US1→US2→US3
Random Group	4	Random sequence

Participants

12 subjects (6 females, 6 males, average 24.6 years, range 22-30 years) from Beijing Institute of Technology participated in this VFBS (visual fatigue based on saliency) experiment after finishing the eye ocular symptoms questionnaire, the visual acuity of 3 subjects is less than 0.8. During the entire experiment, every subject's eye tracking data and ECG signals had been recorded and the data from all 12 subjects were used in the analysis work.

Experiment procedure

All subjects were informed to have a rest to keep a daily state on the day before the experiment. Each of them is asked to fill in a questionnaire which contains individual ocular symptoms before the formal experiment.

Before the formal watching task, the experimenter needs to paste 3 electrodes on the subjects' both legs and left wrist for ECG signals recording, and set up the BIOPAC MP150. SMI eye tracker needs to be calibrated under the subjects' cooperation. After all these preparations, the subjects can start the formal free-viewing task.

Fig.6 shows the details of the experiment procedure. A SMI calibration work was finished under subjects' cooperation. In this watching task, the subjects just need to watch the 3D images for a period of 9 minutes which include 3 sections and finish a questionnaire after each section.

To ensure that ECG signals and SMI eye tracking data can be recorded without interference during the whole experiment, subjects were asked to keep their head and body still until finishing the whole experiment.

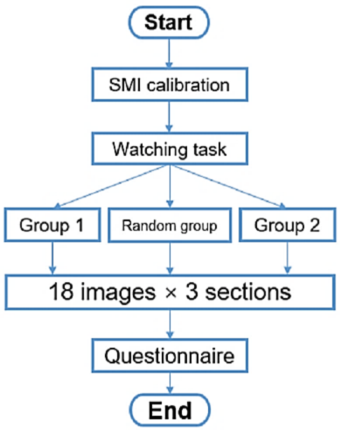


Figure 6. *A summarized description of the experiment procedure*

The 10-level-scale questionnaire used in our study is shown in Fig.7, where "1" means comfort without any malaise, and "10" means a strong sense of discomfort. Subjects were asked to put a cross in this scale bar so that experimenter can measure the exact number.

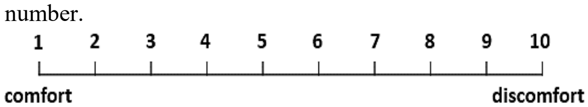


Figure 7. *10-level-scale of eye discomfort degree*

Experiment Results

Subjective result

Subjective assessment was performed after each section by using a 10-level-scale method. One-way ANOVA (0.95 confidence interval) test was adopted to analyze the relationship between time and subjective feelings. The result of significance for 12 subjects' subjective data is far less than 0.05, which means that there is a marked difference between time and subjects' visual fatigue. Fig.8 shows the variation tendency of subjective results. It can be seen from Fig. 8 that almost all groups have a trend of increase which means that all subjects suffer from visual fatigue after the experiment. However, no data illustrate the correlation among the 3 groups because all the significance between group 1, group 2 and random group are over 0.05.

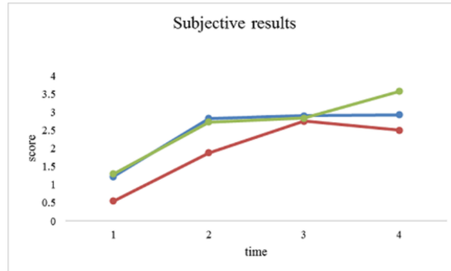


Figure 8. *The subjective results of group1(green line), group2(red line) and random group (blue line)*

Objective results

Fig. 9 illustrates a contrast of area of interest (AOI) of displayed images, where groupS means the images with salient area and groupNS means the images without salient area. We divided each image into 16 patches, and the SMI eye tracker calculates the mean gaze time of each patch. For images with salient area, subjects attend to gaze at the salient area for longer time. Hence we found out each image's patches whose mean gaze time is more than 500ms and 400ms respectively, and calculated the max value and the sum of time for each image. We only calculate the period of 0-5 seconds to ensure a more accurate result. The contrast result is shown as Fig.9, where blue bar represents images with salient area, and orange bar represents images without salient area. It is obvious that mean gaze time of images with salient area is higher than images without salient area in all situation. This contrast result also confirms the reliability of the displayed images' classification further.

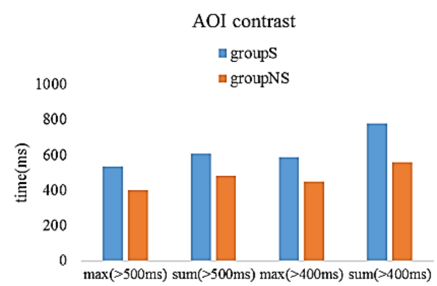
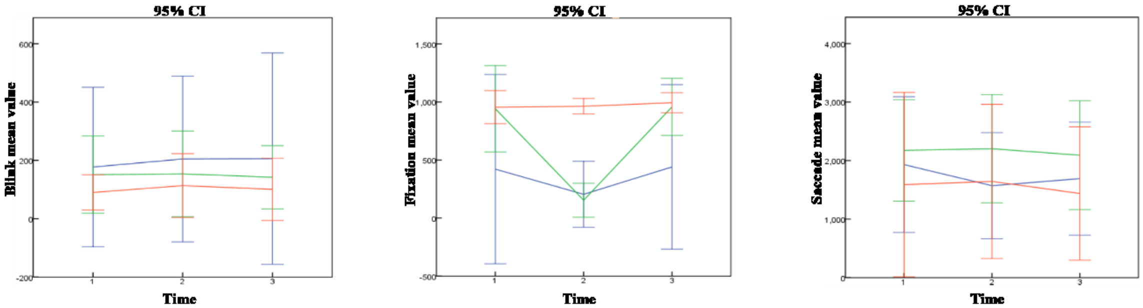


Figure 9. *The AOI contrast of the stimuli. The blue bar represents images with salient area, and the orange bar represents images without salient area*

The objective parameters for evaluating visual fatigue include both ECG signals and eye tracking data. Fig.10 illustrate the results of eye tracking. Three parameters were calculated by one-way ANOVA with 95% confidence interval and the significance value is shown in table 2. However, none of these three parameters shows a significant correlation with time. The mean value graphs of blink frequency, eye fixation and saccade are shown in Fig.10.

Fig.10 (a) illustrates that the blink frequency of group 1 is lower than random group and group 2, which illustrates that the visual fatigue in group 1 is more severe than that of the other two groups because of a decreased blink frequency means rising fatigue [19]. Previous studies have found that both saccade and fixation durations depend on the location relative to the change region. An increasing fixation suggests that the change region had some salient features which attract attention [20]. Neither of these two parameters' variation can reflect the effective contrast of visual fatigue effectively in this study.



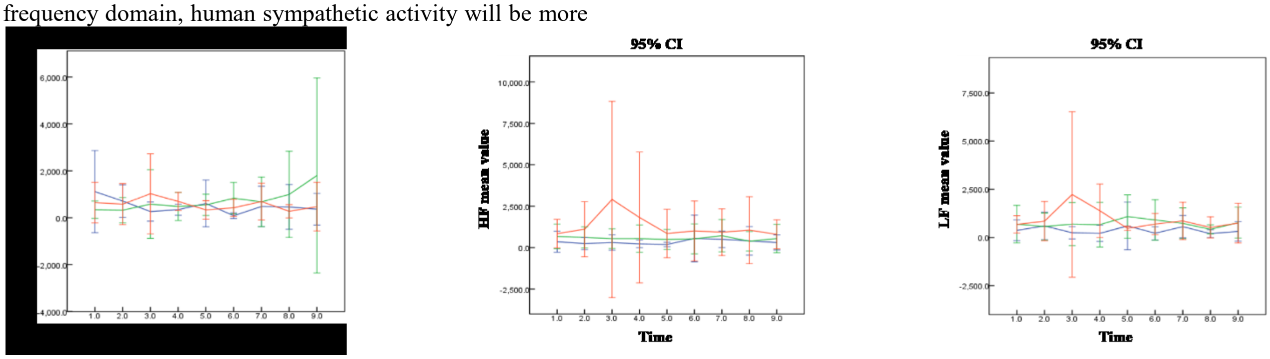
(a) (b) (c)

Figure 10. *The mean value of (a) blink frequency, (b) fixation and (c) saccade (the red line represents group 1, the green line represents group 2 and the blue line represents random group)*

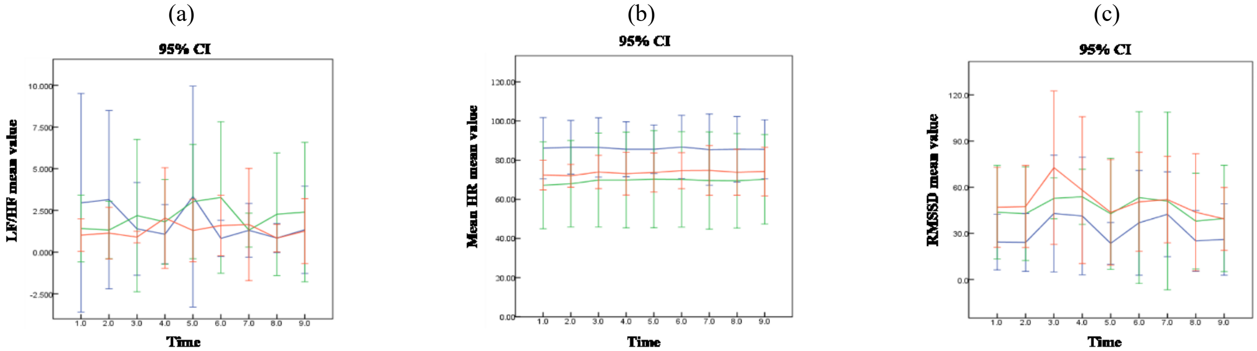
ECG signals are collected by BIOPAC MP150 at the rate of 150Hz. Both time domain parameters (mean HR, SDNN, STD HR, RMSSD) and frequency domain parameters (VLF, LF/HF, LF, HF) of ECG signals were calculated by one-way ANOVA (95% CI) and the significance value of all parameter is shown in table 2. All significance value of frequency domain parameters in group 1 and random group are less than 0.05 which means a significant correlation between the ECG and experiment time. In group 2, all time domain parameters show a significant correlation with time except mean HR. The non-linear parameter ApEn doesn't show any significant difference in three groups.

The tendency of change of 9 parameters is shown in Fig.11 (a)-(i). In frequency domain, human sympathetic activity will be more active with an increasing visual fatigue which cause LF to rise and HF to fall [15]. Accordingly, Fig.11 (b) shows that HF of group1 is less than the other two groups, which illustrates the visual fatigue of group 1 is more severe. Fig.11 (e)-(i) shows an obvious tendency of change of time domain and non-linear parameters. The results of group 1 is higher than the other two groups for mean HR, STD HR and ApEn. All these parameters have a positive proportional relation with visual fatigue except RMSSD and SDNN [15].

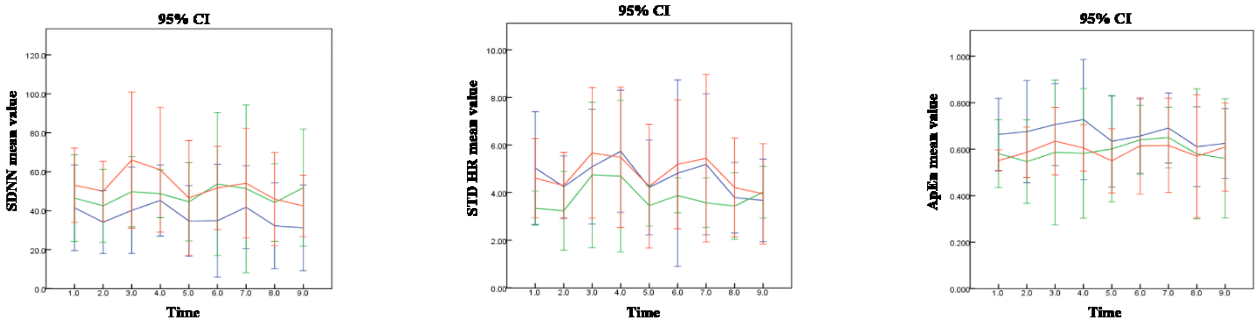
Therefore, it can be initially considered that visual fatigue of subjects in group 1 is more severe than the other two groups according to both ECG and eye tracking results.



(a) (b) (c)



(d) (e) (f)



(g) (h) (i)

Figure 11. *The results of ECG signals: (a) VLF; (b) HF; (c) LF; (d) LF/HF; (e) mean HR; (f) RMSSD; (g) SDNN; (h) STD HR; (i) ApEn (the blue line represents group 1, the green line represents group 2 and the orange line represents random group)*

Table 2 The significance value of ECG signals and eye tracker data

Group 1	Sig.	Group 2	Sig.	Random group	Sig.
Mean HR	0.671	Mean HR	0.997	Mean HR	0.999
SDNN	0.953	SDNN	0.002	SDNN	0.750
STD HR	0.191	STD HR	0.001	STD HR	0.533
RMSSD	0.540	RMSSD	0.006	RMSSD	0.643
VLF	0.001	VLF	0.002	VLF	0.000
LF	0.035	LF	0.227	LF	0.000
HF	0.014	HF	0.849	HF	0.003
LF/HF	0.019	LF/HF	0.085	LF/HF	0.000
ApEn	0.846	ApEn	0.144	ApEn	0.378
fixation	0.644	fixation	0.700	fixation	0.237
blink	0.960	blink	0.445	blink	0.260
saccade	0.076	saccade	0.987	saccade	0.987

Conclusions and future work

In this study, we conducted an experiment to introduce an objective metric on whether stereo visual fatigue can be influenced by salient area of 3D images. The experimental results consist of both subjective and objective parts. Subjective result shows an obvious trend that subjects suffer from visual fatigue after the experiment. Objective results consist of the analysis of three eye tracking parameters and 9 ECG parameters. According to analytical results of the blink frequency and ECG parameters, subjects in group 1 are more easily to have visual fatigue or have a more severe visual fatigue, which can be preliminarily inferred that users who watch 3D images with salient area may suffer from a more severe visual fatigue.

In this paper, the novelty contributions are twofold. First, an appropriate evaluation method of visual fatigue by considering both ECG signals and eye tracking data is developed. Second, an objective visual fatigue assessment based on salient area of 3D images is introduced.

However, there are still some problems to be resolved in our future study. Firstly, experiment duration and task design are potential influential impact factors, which should also be considered in our future studies. Secondly, the depth of the stereoscopic images is not unified in our experiment, when analyzing the relationship between salient area and visual fatigue, there might be influence from depth difference. Thirdly, there is not an exact definition for salient area, in this experiment, we estimate the salience based on "low level" features such as color, shape and edge, salience based on such "high level" features as semantic ones are not considered [21]. Finally, our experiment is free-viewing, although the SMI eye tracker can have a record for subjects' eye movements, we can't ensure that every subject's eyesight always concentrate on the images.

In our future study, we will try to resolve the above mentioned problems, more elements will be added into the experiment to find more factors which can induce stereoscopic visual fatigue.

Acknowledge

This work has been supported by the National Key Technology R&D Program (Grant No. 2012BAH64F01, 2012BAH64F02). The authors would like to thank all the volunteers who participated the experiment.

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