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Visual Fatigue during Continuous Viewing the 3D Movie

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Abstract

Three-dimensional (3D) displays become more and more popular in many fields. However, visual fatigue is one of the critical factors that impede the wide range of applications of 3D technology. Although many studies have investigated the 3D visual fatigue, a few of them are based on continuous viewing 3D contents. In this paper, we propose a method to evaluate visual fatigue through subjective scoring and objective measuring the physiological parameters during the continuous viewing 3D/2D movie. In the viewing, we test the objective and subjective indicators, including the heart rate (HR), blink frequency (BF) and percentage of eyelid closure over the pupil over time (PERCLOS) and the subjective scoring (SS). Before and after viewing the video, VRT, PMA and questionnaires are measured. Experimental results showed that the subjective score and objective indicates of visual fatigue increased gradually with viewing time although it was fluctuated. The symptoms of visual fatigue were generally more serious after viewing 3D movie than 2D ones. Based on the results above, a model was built to predict visual fatigue from HR and BF during continuous viewing 3D video processes.

Keywords

Stereoscopic display; Visual fatigue; Subjective and Objective evaluation; HR; BF; PERCLOS; Modeling

Introduction

In recent years, with the electronic display technology developing rapidly, stereoscopic display and content received more and more concern. It is treated as one of the most promising new digital technologies, and it has proven useful for a wide range of applications including education, entertainment, medical, and more. However, the causes of visual fatigue which results from viewing stereoscopic displays which are perceived based on the binocular fusion of parallax, are not well understood, even though much research has been done [1].Generally, the main causes of visual fatigue from viewing stereoscopic displays are thought to be conflict between convergence and the accommodation function and excessive binocular parallax [2]. Also, some characteristics of the video sequence, such as parallax distribution, binocular mismatches, depth inconsistency, perceptual and cognitive inconsistency, would burden the visual system and cause visual fatigue [3, 4]. Visual fatigue is one of the critical factors that impede the wide range of applications of 3D technology and significantly influence the user's satisfaction. In order to ensure the safety of 3D display application, reliable measurement methods for evaluating visual fatigue should be established.

In order to assess the visual fatigue caused by viewing stereoscopic content, all kinds of methods have been developed. Basically, there are two ways to measure stereoscopic visual fatigue: one is to measure subjective visual fatigue through questionnaires or grading scales and the other is to measure biological signals that have high correlation with the subjective visual fatigue. Subjective assessment methods as a means to perceptually evaluate stereoscopic content are nowadays widely accepted and applied [5, 6]. Subjective methods have also been used in some recommendations [7]. Many studies use questionnaires to assess the degree of visual fatigue [8]. Symptoms such as eyestrain, difficulty in focusing or blurred vision, stiff shoulders, and headaches are often measured for assessment of visual fatigue [9]. Subjective rating is also usually adopted to estimate visual fatigue subjectively [10, 11]. For example, Celestine et al. required the subjects to rate their visual fatigue in two experiments which were conducted to assess differences between 2D and 3D modes on an autostereoscopic display. Lambooij et al. studied the impact of video characteristics and subtitles on visual comfort of 3D TV, and the subjects were required to rate their visual fatigue with continuous assessment [12]. However, subjective methods have an inherent limitation. Subjective stereoscopic visual fatigue reported by subjects does not reveal pure visual fatigue because they are easily affected by various factors [13]. This kind of problem would be resolved if we can measure biological signals that would not be affected by high level human intention or cognition but have high correlation with subjective 3D visual fatigue [14]. For example, Lee et al. proposed a method to analyze the eye blinking and changes of pupil sizes (pupil accommodation), using a real-time image processing algorithm. And then analyze the degree of eyestrain based on the calculated blinking rate and the pupil accommodation speed [15]. Jae-Hwan Yu et al. proposed an eye movement measuring method using EOG signal based on basis voltage adjustment for visual fatigue caused by 2D and 3D displays [16]. Park thought the changes in autonomic balance and heart rhythm ought to be taken into consideration when assessing the visual fatigue of viewing 3D video and finding heart rates (HR), indicating arousal, and VLF/HF (Very Low Frequency/High Frequency) ratio (a measure of autonomic balance) increased significantly after viewing 3D video compared to 2D [17]. In our previous work, we have explored the laws between visual fatigue and objective and subjective indicators which include BF, PERCLOS, CFF, PMA and VRT [18]. However, many researches have not given prediction models or the models need to be improved.

This paper is proposed to explore a method to evaluate visual fatigue through subjective scoring and objective measuring the physiological parameters which include HR, BF and PERCLOS that can be extracted from the biological signals during the continuous viewing 3D movie process, and to find laws of the visual fatigue. At the same time, the laws about visual fatigue between viewing the 2D and 3D movies are compared. Finally, we plan to build a model to predict visual fatigue using objective indicators measured during the viewing.

Experiment

Environment

The experiment was conducted in a laboratory, with suitable temperature and humidity. As shown in Fig. 1, the stereoscopic stimuli were displayed on a glass-free 3D media player - P65, and the 2D stimuli were displayed on the same display with the stereo effect off. A seat was fixed at a fixed distance, i.e. three times of screen height, away from the display. The participants were in the natural condition when watching the stimuli.

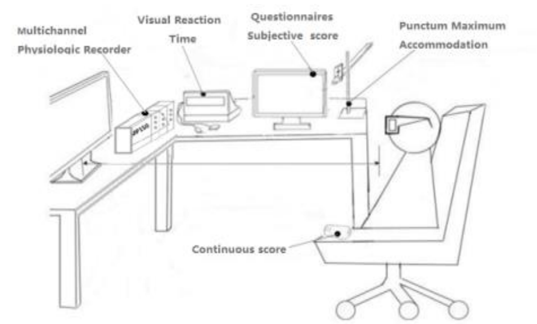

Fig.1 The environment of the experiment

Subjects
We invited fifteen participants to view the 2D and 3D videos alternately. They were recruited from different age groups and professions. The stereoscopic vision was acceptable if the distinguishable disparity was equal to or smaller than 100".

Stimulus
A part of a commercial movie was used as the stimuli. The viewing time is 60-minutes. To compare the visual fatigue, the stimuli in 2D and 3D condition are the same. Because the subtitles may have influences on visual fatigue, we chose the version without subtitles.

Procedure
The survey includes subjective and objective indicators. For the subjective evaluation, the subjects need to assess their visual fatigue using a ten-point scale (1-10, where 1 means almost no visual fatigue, 10 means the most severe visual fatigue, and greater score represented greater visual fatigue) based on the scoring system which was developed by our own. In addition, the subjects need complete the pre-test and the post-test questionnaires respectively.

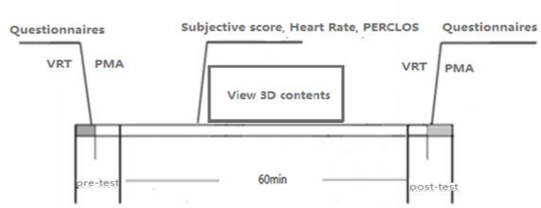

Fig.2 The experiment procedure

For objective measures, in the viewing(Fig.2), we test the objective and subjective indicators, including the heart rate (HR), blink frequency (BF) and percentage of eyelid closure over the pupil over time (PERCLOS) and the subjective scoring (SS). Before and after the viewing process, Visual Reaction Time (VRT) and Punctum Maximum Accommodation (PMA) are measured using a commercial device. The physiological parameters are measured from EOG, ECG signals. A specialized tool is designed to rate visual fatigue subjectively. The questionnaires related to different symptoms of visual fatigue [18]. So far, the participant completed the survey in one condition (2D or 3D). Then we changed the type of the video and repeated the steps in another condition. To avoid the impact of viewing order, we exchange 2D and 3D movie viewing order between different participants.

Data Analysis
The questionnaires and the scores were subjective measurements which were obtained directly from each measure during the experiment. HR, BF and PERCLOS were objective measurements. They could be extracted from the polygraph. The rest two (VRT and PMA) were also objective measurements.

The replies for the questionnaires and the scores were analyzed using statistic method. There were fourteen items included in the questionnaires, and they were analyzed respectively. As for the scores, the results of all the subjects were first aligned along time. Then they must be resampled to produce a uniform time interval because each subject rates their visual fatigue at different sets of time points.

Before extracting the data, the EOG, ECG signals for each subject were processed with a 50 Hz notch filter and band-pass filter. Considering that the movement of body may have an impact on measured data when we connect and remove measuring electrode before and after the experiment, in this experiment, we only use 58 minute intermediate data (1min-59min), every minutes as a segment, thus 58 data segments were obtained. To get the average values of HR, BF and PERCLOS within every segment, we extracted the data from the polygraph.
For each of VRT and PMA, each subject had a single value both before and after the viewing process. These data were also analyzed using statistical method.

Results
The following is the result of subjective and objective measurement we obtained in the experiment. First of all, we analyzed the result of VRT and PMA. Secondly, we gave the subjective result of questionnaires. Finally, we analyzed the objective result of BF, PERCLOS and HR.

VRT
Fig. 3 shows the average VRT values of all the subjects. The first value was measured before viewing the stereoscopic contents, and the second value was measured after viewing.

It can be seen that the VRT value increased after viewing stereoscopic movies. Through the analysis of data, we found that there is a significantly statistical difference between before and after viewing 2D (p=0.048), but no significant difference in 3D (p=0.283). This indicator can indicate the increase of visual fatigue to some extent.

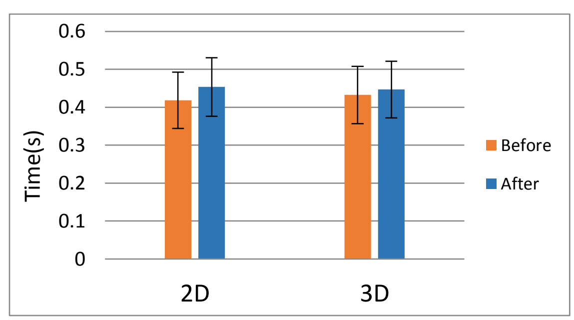

Fig. 3 the results of VRT

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PMA

Fig. 4 shows the average PMA values of all the subjects. Each value was the average of the results measured from both positive direction (move the target from near to far) and negative direction (move the target from far to near). The first value was measured before viewing the stereoscopic contents, and the second one was measured after viewing.

It can be inferred from the figure that PMA increased after viewing stereoscopic contents. Through the analysis of data we found that there is a significantly statistical difference between before and after viewing 3D (p=0.05), but no significant difference in 2D (p=0.597). The results implied that the increased PMA caused by viewing stereoscopic video continuously.

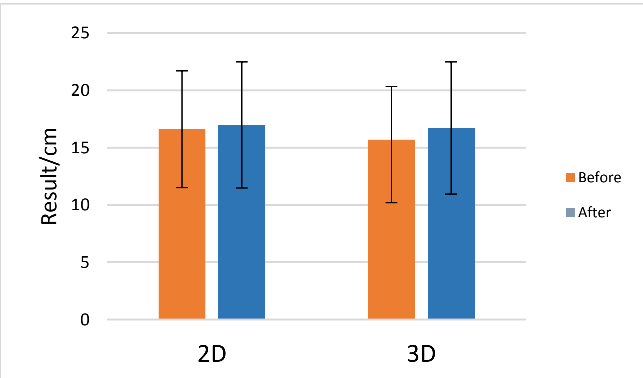

Fig. 4 the results of PMA

Subjective score

In the scoring system, the participants are required to score the fatigue at any moment in the 58 minutes. We integrate the data and get the mean score in every minute. As shown by Fig. 5, we can find the visual fatigue increasing with the video displaying. In addition, we notice that the fatigue degree in 3D is higher than that in 2D most of the time. Although 3D score was decreased at 48 minute, we consider it is significantly related to the plot of video.

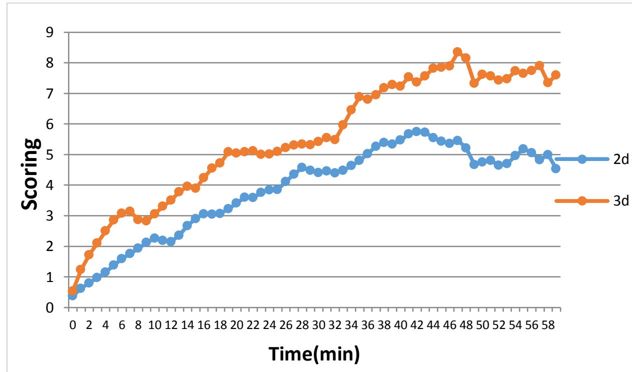

Fig. 5 the results of Scoring Results

Questionnaire

Fig.6 shows the results of the subjective questionnaires. We can see that the symptoms of visual fatigue were generally more serious than before, for both 2D and 3D conditions. Based on the statics analysis, we can find these factors: overall visual fatigue, tear, dry eye, sour eyes, had difficulty on focus and blurred sight increased significantly after viewing 2D contents (p<.05), and overall visual fatigue, pain in eyes, dry eye, sour eyes, headache, feel sick, feel dizzy, had difficulty on focus and blurred sight increased significantly after viewing 3D contents (p<.05) However, there are still some differences between 2D and 3D viewing conditions.

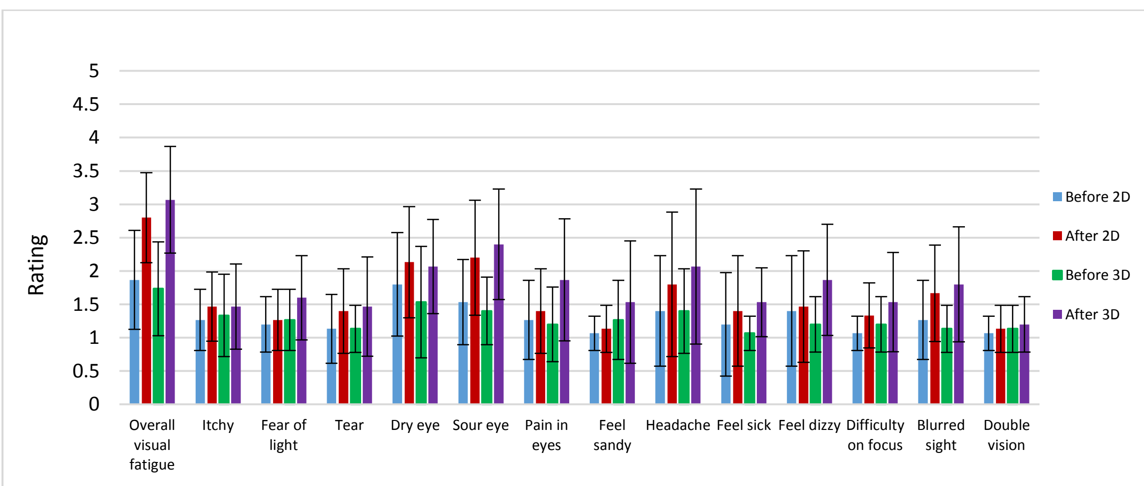

Fig. 6 the results of questionnaire

BF and PERCLOS

First, with the use of Acknowledge software provided by BIOPAC System, we process the EOG signal with a 50 Hz notch filter and band-pass filter for each subject, in order to remove the interference due to shaking caused by the subjects in the process of viewing. Second, we use the same threshold to cut signal for all subjects' signals, making the data that below the threshold become to 0, which above the threshold become to 1, Through Counting the number of square wave signals and the length of time that the signal is zero for every minute. Finally, we can get BF and PERCLOS. As shown by Fig. 7, 8 BF and PERCLOS during every minute varied by time. The overall tendency increased gradually, and decreased gradually after viewing about 37 minutes, we

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consider that it is significantly related to video content. In the period of 37 minute to 40 minute, we find the plot of video is more attractive; subjects are more likely to immerse in the plots. As a result, Blink and PERCLOS become less.

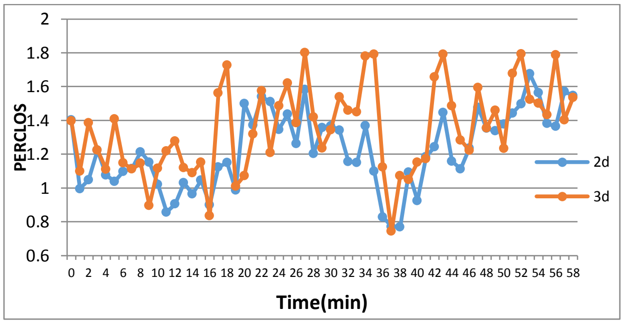

Fig. 7 the results of blink frequency

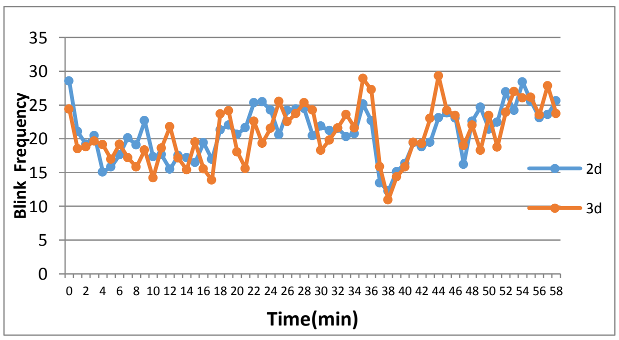

Fig. 8 the results of PERCLOS

Heart Rate

As shown in Fig.9, we find that HR increased gradually with the video playing; there are some fluctuations in the graph. Besides, the 3D curve is higher than the 2D curve. Although HR may be influenced by many factors, we consider that it is significantly related to visual fatigue because the participants also gave higher scores in the subjective evaluation in 3D condition. In addition, tendency of HR is consistent with subjective visual fatigue.

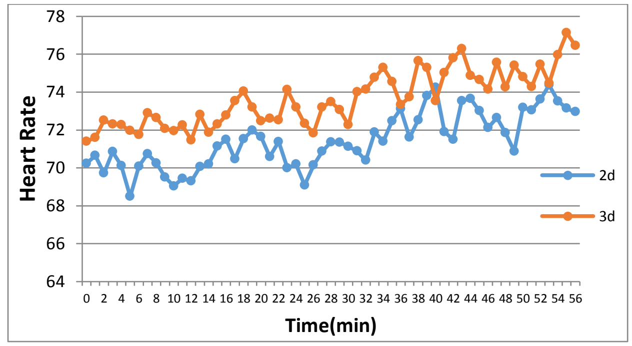

Fig. 9 the results of Heart Rate

Model

In this paper, through the analysis of the relationship between objective indicators and subjective scoring, we decided to use univariate and multivariate models for modeling respectively. Finally, the 3D visual fatigue prediction models are shown in Table1 and Table2.

As shown in Table 1, we analyzed the correlation between objective indicators and visual fatigue, and find visual fatigue is closely correlated with HR. Then we use HR to build the model, the model is shown as the following:

$$SS' = a \bullet HR + b \tag{1}$$

Table 1 The results of univariate Model

Model1	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	R	R Square	Adjusted R Square	Std. Error of the Estimate
	B	Std.Error	Beta						
Constant	-80.0200	7.640		-10.474	.000	.833	.695	.689	1.13235
HR	1.160	.104	.799	11.186	.000				

Table 2 The results of multivariate Model

Model2	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	R	R Square	Adjusted R Square	Std. Error of the Estimate
	B	Std.Error	Beta						
Constant	-78.282	7.713		-10.150	.000	.839	.704	.693	1.12559
HR	1.123	.107	.807	10.482	.000				
BF	.049	.038	.099	1.289	.203				

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Where, SS' is the predicted visual fatigue ($1 \leqslant SS' \leqslant 10$), and b is a constant. The coefficients are a = 1.160 and b = -80.02. The R^2 of the regression is 0.695, and the AVONA analysis shows significance ($p \leqslant 0.05$).
As shown in Table 2, in order to improve the performance of the model, we have built a multivariate model; we use SPSS to build the model from HR, BF by using stepwise variable selection. The model is shown as the following:

$$SS' = a \cdot HR + b \cdot BF + c \quad (2)$$

Where, SS' is the predicted visual fatigue ($1 \leqslant SS' \leqslant 10$), and c is a constant. The coefficients are a = 1.123, b = 0.49 and c = -78.282. The R^2 of the regression is 0.704, and the AVONA analysis shows significance ($p \leqslant 0.05$).

Table 3 The performances of Model

3D Model	CC	ROCC	RMSE
Model1	**0.833**	**0.845**	**1.13235**
Model2	**0.839**	**0.854**	**1.12559**

To test the performance of two models, three methods were used to measure, including CC, ROCC and RMSE. The results are shown in Table 3. We can find that the multivariate model is better. Ultimately, we choose multivariate model as prediction model. Due to the plot of video, the BF and HR have great fluctuation, while subjective scoring change is relatively stable, this may be the main reason of large RMSE.

Conclusion

In our study, there are fifteen subjects participate in the experiment. By analyzing the subjective and objective data, we can find that subjective score of visual fatigue increased with viewing time, although it fluctuated sometimes. In addition the score of viewing 3D content is higher than viewing 2D content and the symptoms of visual fatigue are generally more serious after viewing than that before at the same time; BF, HR and PERCLOS increased with time. Besides, visual fatigue also induced great changes of VRT and PMA. Based on the results above, a multivariate model was built to predict visual fatigue from HR and BF during viewing 3D movie. We validated the performance of model and the result showed the model was to be reliable and efficient in evaluating visual fatigue.
In the future, we hope that we can find more related indicators with visual fatigue to improve the prediction model and build a more accurate model based on multivariate, through the analysis of physiological signals such as EEG, EOG, ECG, skin conductance, and so on.

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