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Study on the influence of 3D motion characteristics on the blinking rate

Yuan Gao, Yue Liu, Yiwang Qian, Yongtian Wang, Beijing Engineering Research Center of Mixed Reality and Advanced Display, School of Optoelectronics，Beijing Institute of Technology, Beijing, China

Abstract

With the rapid development of the human computer interaction technology, the requirements on immersive 3D displays have increased greatly. However visual fatigue has become the bottleneck of the technology development of 3D display, it’s necessary to investigate the objective evaluation parameters of the visual fatigue and to find out the main factors that affect the visual fatigue in the 3D contents. The purpose of this paper is to study the relationship among the blinking rate, the motion characteristics and the visual fatigue when watching 3D videos. 20 subjects participate in the evaluation experiment and the blinking data are achieved from the output of an SMI eye tracker. The stimuli are different on the motion type, velocity and disparity. N-way ANOVA test and multiple comparison test are adopted to analyze the experimental data and the analysis results show that the linear relationships have been found between the subjective scores and the blinking rates, but the correlation coefficient is lower than that in the previous study. The results will be helpful for further research, and the different blink mechanisms of 3D motion types can be studied at the same time.

Keywords: *blinking rate, visual fatigue, motion characteristics of 3D videos*

Introduction

3D display technology is experiencing fast developments recently. In 2009, the film Avatar obtained such a great success that people rekindled the interests in 3D film and this success is established on the more mature 3D technology. At the same time, 3D display technology has also been widely used in various aspects in our daily life such as education, medical and entertainment industry. The ultimate goal of 3D display technology is to make the virtual images appear as vivid as the natural scenery. However, there are still a lot of problems hindering the development of 3D display technology. When people watch 3D videos for a long time, they will have a sense of discomfort or visual fatigue, thus it's necessary to study the causes of this phenomenon.

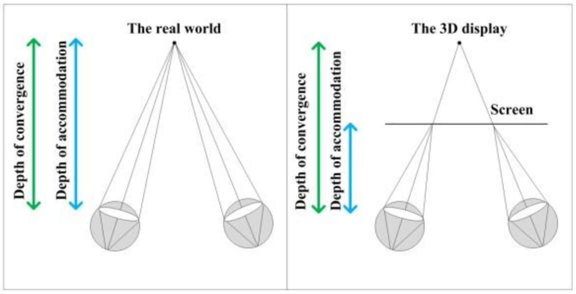

Figure 1. *The conflicts between accommodation and convergence*

Many factors can be attributed to the visual fatigue when watching 3D displays, and various researches have focused on analyzing the causes from different aspects. It can be concluded from the previous literatures that three major causes can potentially lead to visual discomfort which are respectively the conflicts between the accommodation and convergence, excessive binocular parallax as well as the dichoptic errors as shown in Fig. 1[1].

However, among the above-mentioned factors, the most important cause of discomfort is the excessive binocular parallax in the stereoscopic images[2-4]. Besides the disparity magnitude that does not change across space and time, some researchers focused on the motion disparity parallax. F. Speranza et al. investigated the relationship between binocular disparity, object motion and visual comfort using computer-generated stereoscopic video sequences. Their results indicated that change in disparity magnitude over time might be more important in determining visual comfort than the absolute magnitude of the disparity[5]. S. Yano et al. found that the low subjective reports of comfort may be due to the high velocity of the 3D motion combined with the large disparity offsets[6]. S. Lee et al. investigated visual discomfort induced by fast motion of salient object in a stereoscopic video. They observed the changes of the visual discomfort with varying velocity and direction of object motion and derived a visual comfort model from their observation. The experimental results showed that the predicted visual comfort score of the model correlates well with the actual subject score[7]. In order to investigate the relationship between the 3D motion characteristics and the visual fatigue, motion type, velocity and disparity have been considered in the stimuli design in our research. Accordingly, the 3D videos which are generated by the software have been used in our experiment because we can control the variables more conveniently in generated videos than those in natural scenes videos.

To find the 3D motion characteristics that can lead to visual fatigue, a key issue is to find a suitable indicator to evaluate the visual fatigue of 3D displays. The methods used to evaluate the visual fatigue can be divided into subjective and objective methods and most of the existing literatures use the subjective questionnaire to evaluate the visual fatigue. [5].

The subjective measurement methods include three approaches: explorative studies, psychophysical scaling, and questionnaires[8]. There are two measurement methods in psychophysical scaling: the first is performance-oriented method which is used to facilitate a certain task; the second is appreciation-oriented method which is used to evaluate the visual fatigue caused by stereoscopic displays. The psychophysical scaling method can conveniently quantify the subjective sensation and in this paper, a five-level scale is used to evaluate the subjective visual discomfort scores.

The objective measurement methods can also be divided into three classes: optometric instrument based measurements, optometric clinical based measurements and the physiological signals based measurements[9-13]. The first two methods are simple and easy to be implemented, but the objective data cannot be obtained by these methods in real time, thus the researchers are trying to find other physiological indicators that can be monitored in real time.

S. Park et al. looked into changes in autonomic balance and heart rhythm when comparing the overall impact of viewing 2D

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video and 3D video on human health. Their research results showed that the subjects had a more disordered heart rhythm pattern and an increasing heart rate after watching the 3D contents, and this means that 3D viewing can induce lasting activation of the sympathetic nervous system and interrupt autonomic balance[14]. C. J. Kim. et al. found that galvanic skin response and skin temperature could be used to measure and compare autonomic nervous responses of the subjects after viewing 2D and 3D displays[15].

Some researchers found that the neuronal activity in the brain also reflected visual fatigue as a consequence of viewing 3D contents, and thus electroencephalography (EEG) was used to observe the relationship between the EEG signals and visual fatigue. C. Chen et al. compared the 2D/3D changes of both energy values of EEG in the four wavebands alpha (α), beta (β), theta(θ), delta (δ), and the values of four fatigue related algorithms ($(\alpha+\theta)/\beta$, α/β, $(\alpha+\theta)/(\alpha+\beta)$ and θ/β. The results showed that the parameters of the subjects in the 3DTV group, except theta rhythm, changed more significantly than those of the subjects in 2DTV groups in some brain regions. The above-mentioned parameters, combined with subjective evaluations, can serve as objective indicators to evaluate the visual fatigue of 3DTV[16]. H. O. Li et al. developed a paradigm to measure 3D visual fatigue using background EEG and ERP signals, and they found that the power of beta frequencies increased as watching duration increased and it was much stronger in 3D rather than in 2D condition[17]. Although many 3D visual fatigue models have been established based on the EEG/ECG signals, how to obtain the above-mentioned physiological signals is not convenient and these signals are vulnerable to external environmental impact, especially for the EEG signals.

One purpose of our research is to find an objective factor which can be obtained easily, and that can predict the 3D visual fatigue properly. As early as in 1994, J. A. Stern et al. listed many literatures which used blinking rate as a measure of fatigue in their review, which revealed that either the time on task or the variables could affect the blinking rate[18]. After that, many researchers used the blinking rate to evaluate the visual fatigue[19-20]. E. C. Lee et al. measured the frequency of blinking to quantitatively compare the amount of eyestrain when watching 2D and 3D displays. They found that the eye blinking frequency is a reliable parameter by confirming the high correlation between the results of the objective and subjective tests[19]. However, C. A. Chu et al. proposed an unusual view in their research. They compared the blinking pattern of the computer screen versus hard copy in their research. The results showed that the mean blinking rate has no significant difference between these two presentation styles. It is proposed that the differences in blinking rate were more likely to be produced by changes in cognitive demand rather than the method of presentation[21]. Thus, whether the blinking rate is able to evaluate the visual fatigue caused by the 3D displays or not is still controversial. In this paper we try to conduct an experiment to find whether there is certain relationship between the blinking rate and visual fatigue evoked by 3D motion contents. The results will be helpful for further research, and the different blink mechanisms of 3D motion types can be studied at the same time.

The rest of this paper is organized as follows. The second section describes equipments, environment, stimuli and procedure of the experiment. The third section presents the results of the experiment. Finally, the last section discusses the experimental results and concludes the paper.

Method

Laboratory equipment and environment

A 23-inch polarized 3D display is used to present a sequence of stimuli of 3D contents which are generated by the software Unity 3D. The display device is LG D2792PB with the resolution of 1920×1080 and equipped with polarized 3D glasses. In the experiment a non-contact measuring device-SMI eye tracker is used to record the subjects' eye movement and eye blinking data. The eye tracker is placed between the screen and the subjects during the whole experiment. The observation distance is 90cm. The experimental environment is set up according to ITU-R BT.2293-0 as shown in Figure 2.

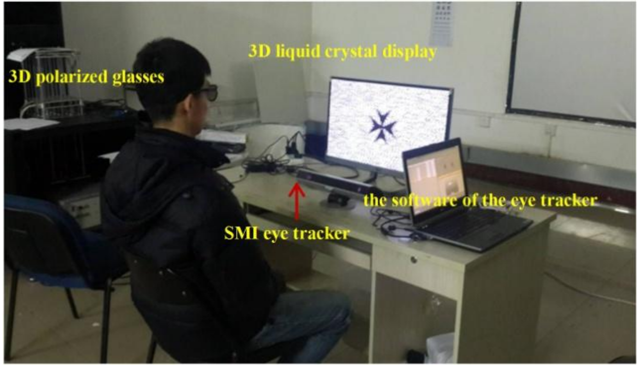

Figure 2. *The experimental environment*

Test stimuli design

The experimental stimuli are designed as 44 short 3D videos each lasting 10 seconds. The scenes of the videos are composed of foreground object and background. The background is designed to be a random dot stereogram (RDS) whose disparity is -1.4° and the size is the same as the 3D display screen. The foreground object is a black Maltese cross that can move in different motion types. The size of the Maltese cross is unchanged in the videos. The use of the random dot stereogram (RDS) can remove other depth cues in scenes. All the 3D scenes were generated by the software Unity 3D and a screenshot of the software is shown in Figure 3.

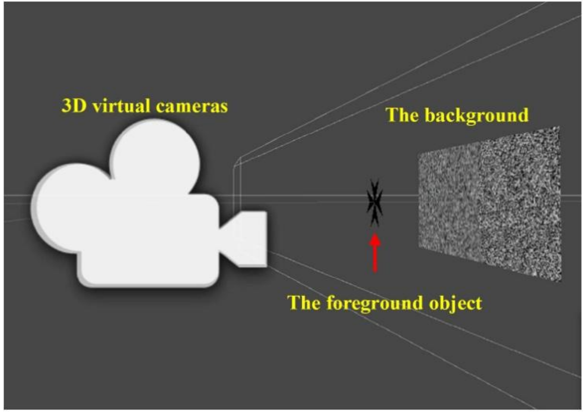

Figure 3. *The screenshot of the software Unity 3D*

Three different kinds of 3D motion types have been adopted for the Maltese cross : i.e. planar motion, static situation and in-depth motion. Correspondingly, different disparities and velocities have been designed for every motion type. In the planar motion, the Maltese cross moves circularly around the center of the screen. The radium of the circular trajectory is a fixed value. Three velocity levels of 71.8°/s, 179.5°/s and 287.2°/s are selected to

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stand for slow, medium and fast motions respectively, and five angular disparities of 0°, ±0.65° and ±1.3° are selected to stand for different depths, which accounts a total of 15 stimuli of planar motion. Figure 4 is a schematic diagram of the planar motion.

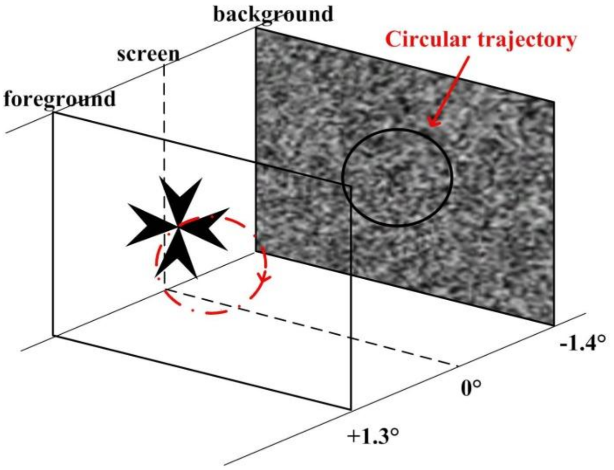

Figure 4. *The schematic diagram of the planar motion stimuli*

In the static situation, the Maltese cross is fixed in the center of the screen and five angular disparities of 0°, ±0.65° and ±1.3° are adopted to stand for different depth levels. Thus, the number of the stimuli under this case is 5 and the schematic diagram is presented in Figure 5.

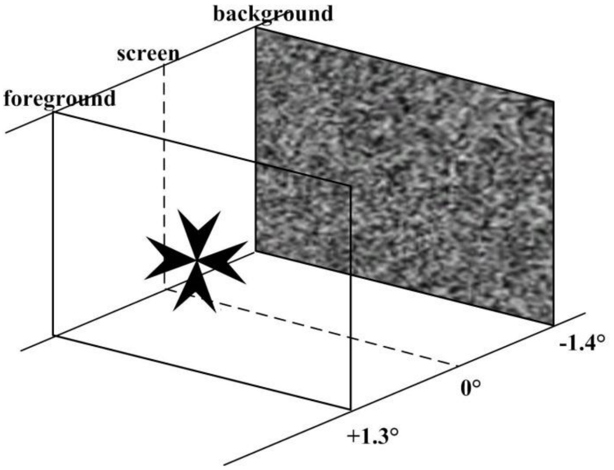

Figure 5*. The schematic diagram of the static stimuli*

In the in-depth motion stimuli, the black Maltese cross moves forth and back in an endless loop. Besides the velocity, the disparity amplitude and the disparity offset have also been designed. The disparity amplitude represents the difference between the nearest and the furthest point of the disparity. The disparity offset represents the center value of the disparity. 4 types of disparity amplitude(0.65°, 1.3°, 2°, 2.6°) and 3 types of disparity offset(-0.65°, 0° and 0.65°) are selected which stands for different ranges of depths and different medians of depths. 3 types of velocities(1°/s, 2°/s and 3°/s) are selected, which stands for slow, medium and fast motions respectively, thus generating a total of 24 in-depth motion stimuli. Figure 6 shows one of the in-depth motion stimuli. There are altogether 44 stimuli in the experiment. Figure 7 shows the disparity amplitude for the in-depth motion stimuli.

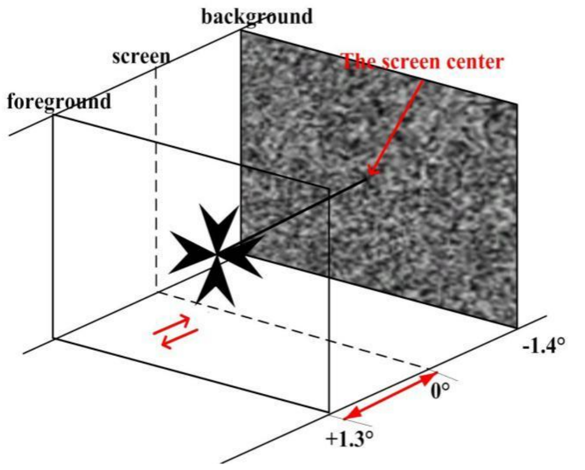

Figure 6. *The schematic diagram of the in-depth motion stimuli*

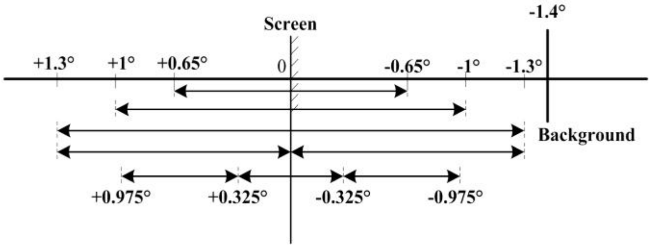

Figure 7. *Disparity amplitude for the in-depth motion stimuli*

Experiment procedure

All the participants are asked to undergo visual inspections to ensure that they have a normal vision before the formal experiment, which include the tests for visual acuity, stereo acuity and color vision. The standard logarithmic visual acuity chart, random dot stereogram patterns and the Ishihara test chart are used for these tests. The written informed consent has also been obtained from each participant. The experiment procedure is also explained to the subjects before the experiment. An extra experiment is designed for the subjects to practice the tasks before the formal experiment.

In the formal experiment, subjects wearing polarized glasses sit in front of the 3D display and the eye tracker to watch the 3D video clips. First, the calibration of the eye tracker is carried out under the cooperation of the subjects. After that, the 44 stimuli which have been described previously are presented to the subjects in a random order. Each stimulus lasts 10 seconds and there is a 5-second interval between every two adjacent stimuli during which the display becomes a blank gray background and the subjects are asked to give the score of the five-level scale orally. The answers will be recorded down manually by the experimenter. The five-level scale is shown in Figure 8. Figure 9 shows the procedure of the experiment.

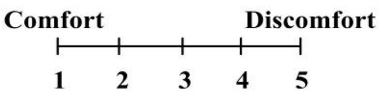

Figure 8. *The five-level scale for the subjective questionnaire*

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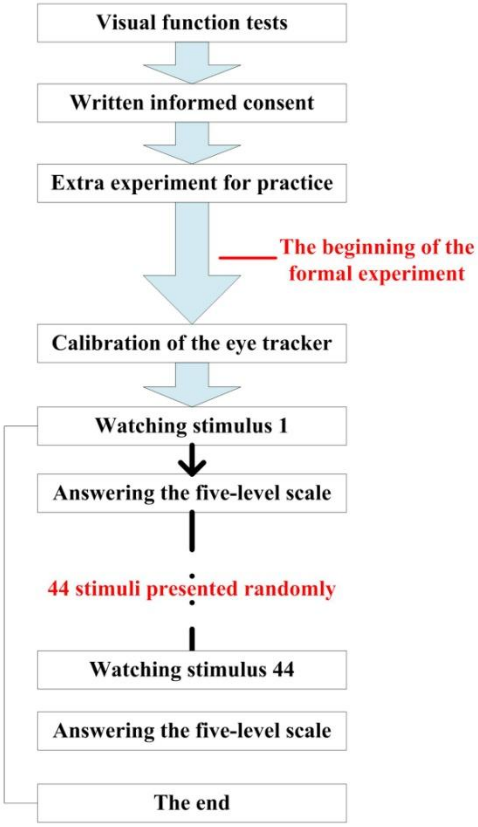

Figure 9. *The procedure of the experiment*

By comparing the scores of the five-level scale with the mean blinking rate of each stimulus, it can be used to determine whether the blinking rate is the objective indicator of the visual fatigue. The blinking mechanism for different motions can also be studied by combining the blinking rate with different motion characteristics.

Subjects

25 subjects are invited to participate in the experiment. Due to the results that one of the participants is an achromate and another two subjects' visual acuity are less than 0.8, 22 subjects actually participate the experiment after being screened. The blinking data are achieved from the output of an SMI eye tracker. Since one subject has something wrong with the calibration process of eye tracker, and another subject's eye data has not been recorded successfully by the eye tracker, our final sample consists of 20 individuals, 11 females and 9 males respectively.(age: mean 23.85 years; range:21-29). All the subjects are students from Beijing Institute of Technology.

Experiment results & analysis

The eye movement data achieved by the SMI eye tracker include the binocular information of the subjects. The blinking data contain the blink start time, the blink duration and the blink end time. When all three blinking indicators of the left and right eye are completely consistent, the blink will be regarded as a real blink to be processed. According to the medical definition of an eye blink, the blinks whose duration time is less than 50ms or more than 500ms will be discarded [22].

N-way ANOVA test and multiple comparison test are adopted to analyze the relationship between the 3D motion characteristics and the blinking rate after processing blink data. The mean blinking rates are obtained by averaging all observers' data. The results show that the correlations between the motion characteristics and the blinking rate are not significant.

The results of the multiple comparison test are present in Figure 10. It can be seen from Figure 10 that for the static situation, the blinking rate increases with the increase of the disparity offset. However, for the planar motion stimuli, there is no obvious correlation between the blinking rate and the disparity offset, and the blinking rate will decrease when the velocity increases. Three 3D motion parameters are analyzed in the in-depth motion stimuli, among which only the disparity offset apparently affects the blinking rate, i.e. the blinking rate increases with the increase of the disparity offset. Although there is a trend that the blinking rate decreases with the increase of the velocity, this is not obvious. Besides, no obvious trend is found between the blinking rate and the disparity amplitude in the in-depth motion stimuli.

The subjective score of each stimulus is achieved by averaging all of the subjects' scores of the five-level scales. Figure 11 shows the scatter diagrams of the relationship between the subjective scores and the mean blinking rate. The straight line in the graph is the fitting line of the scattered points. It can be seen from Figure 11 that some trends can be found between the blinking rate and the visual discomfort degree under different conditions. For the static situation and the in-depth motion stimulus, the blinking rate increases with the increase of the visual fatigue, but for the planar motion stimulus, the blinking rate decreases with the increase of the visual fatigue, which means that the blinking mechanisms are different among the different motion types. However, whether there is a linear relationship between these two factors or not is still uncertain because the correlation coefficients are relatively low for the fitting lines in the graphs.

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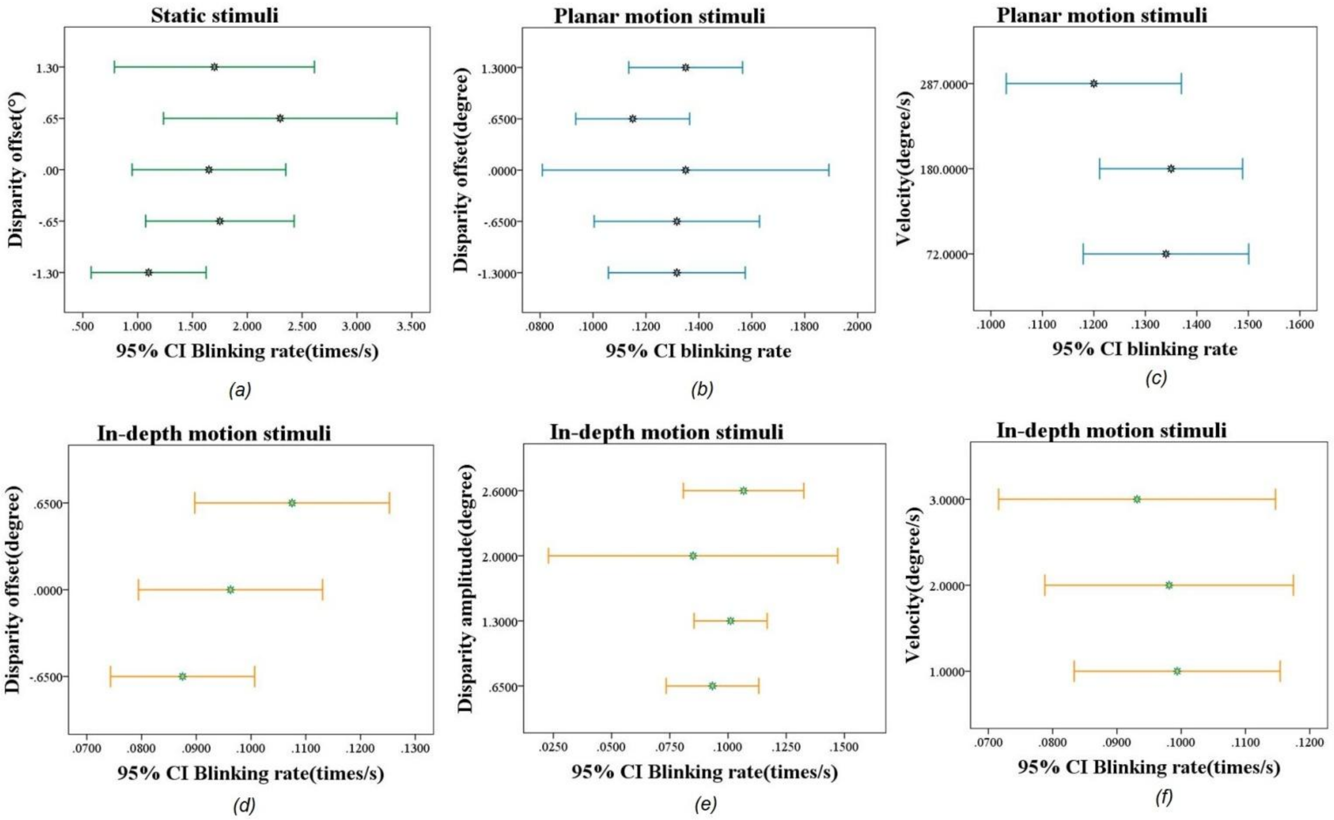

***Figure 10.** The results of the multiple comparison test showing the mean value and 95% confidence interval (a) comparison of the disparity offsets for the static stimuli (b)-(c) comparisons of the disparity offsets and the velocities for the planar motion (d)-(f) comparisons of the disparity offsets, disparity amplitude and the velocities for the in-depth motion stimuli, respectively*

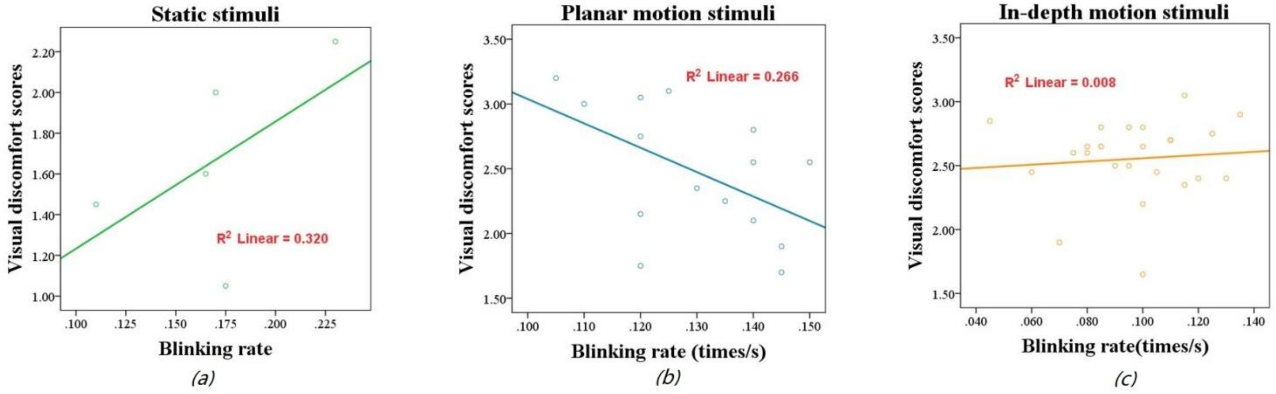

***Figure 11.** Linear relationship between the subjective scores and the blinking rate (a) Static (b) Planar motion (c) In-depth motion*

Conclusions

The paper investigates the relationship between the blinking rate and 3D motion characteristics based on the 3D scenes generated by the software Unity 3D. The eye blinking information is extracted from the output of SMI eye tracker which is a kind of non-contact device. The N-way ANOVA is adopted to analyze the relationship of these two factors, but no significant effects of the 3D motion characteristics on the blinking rate can be found in the experimental results. The results of the multiple comparison test show some trends of the relationships between the blinking rate and the 3D motion characteristics. For the static stimuli and the in-depth motion stimuli, the blinking rate increases with the increase of the disparity offset. However, for the planar motion stimuli, no regular trend is observed on the relationship between the blinking rate and the disparity offset. The results have also not shown an apparent trend of the relationship between the 3D motion velocity and the blinking rate neither for the planar motion stimuli nor for the in-depth motion stimuli, which is different from the previous study that the velocity is the main factors that affect the blinking rate[23].

It can be seen from the analysis results of the relationship between the subjective visual discomfort score and the blinking rate that the same trends can be observed with the previous study [23]. For the static and the in-depth motion stimuli, the visual discomfort scores increase with the increase of the blinking rate. For the planar motion stimuli, the visual discomfort scores decrease with the increase of the blinking rate. However, the correlation coefficient of the fitting line in this paper is relatively low, thus there is no enough evidence to prove that the blinking rate can be regarded as an indicator of the 3D visual fatigue. However it can be inferred that the blinking mechanism of the planar motion may be different from the static state and the in-depth motion.

The main reasons to cause the different results from the previous study can be summarized as follows. Firstly, the non-contact device SMI eye tracker used in our experiment outperforms the electro-physiological measurement device because the output data will not influenced by the contacted electrodes; Secondly, the criteria for selecting the true value of the blink of an eye are slightly different, we use the medical definition to distinguish the real blinks from others (50ms-500ms), however, the previous study used the blinks whose durations are between 100ms to 400ms in the data analysis; Thirdly, we obtain the visual discomfort score from the five-level scale questionnaires of the subjects in the experiment, but in the previous study, the visual discomfort score for each stimulus was obtained by a previous subjective paired comparison method with 42 naive observers. Taking into the account that the individual differences may be very large, even the same person may generate a different score for the same stimulus in different time, the subjective scores in our experiment is more reliable.

In our future study, more types of 3D characteristics will be studied by combining with the various physiological signals to detect the main factors in the 3D motion videos that influence the visual fatigue. The model of the 3D visual fatigue based on the 3D motion characteristics will also be studied.

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Author Biography

Yuan Gao received her B.S. degree in optoelectronic information engineering from the Changchun university of science and technology, Jilin Province, China in 2010. She received her M.S. degree in instrument science and technology from the Changchun university of science and technology in 2013. In the year of 2014, she become a Ph.D. student of optical engineering at the School of Optoelectronics, Beijing Institute of Technology, Beijing. Her research interests is in the areas of 3D displays and the human visual fatigue caused by 3D displays.

Yue Liu received his Ph.D. degree in telecommunication and information system from Jilin University, Jilin Province, China in 2000.He is currently a Professor of optical engineering at the School of Optoelectronics, Beijing Institute of Technology, Beijing. His research interests include human computer interaction, virtual and augmented reality, accurate tracking of the pose of camera, 3D display system and camera calibration etc. He has published more than 100 technical papers. Dr. Liu is a member of council of China Society of Image and Graphics, a member of China Society of Optics, and he also serves on the editorial board of the Optical Technique.

Yiwang Qian received his B.S. degree in communication engineering from the Beijing Institute of Technology in 2010. In the year of 2014, he become a Graduate student of computer science and technology at the school of computer science and technology, Beijing Institute of Technology, Beijing. His current research interest is the virtual reality and augmented reality.

Yongtian Wang received the B.Sc. degree in precision instrumentation from Tianjin University, China, in 1982, and the Ph.D. degree in optics from the University of Reading, U.K., in 1986. He is currently a Yangtze River Scholar of the Chinese Ministry of Education, a professor and the director of the Center for Research on Optoelectronics and Information Technology in Beijing Institute of Technology. Dr. Wang is a Fellow of the Optical Society of America and the International Society for Optical Engineers. His research interests include optical design and CAD, optical instrumentation, image processing, virtual reality (VR) and augmented reality (AR) technologies and applications.