Research article

Reducing the discomfort in viewing 3D video with a prism device modified eye convergence

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ABSTRACT

A prism device is utilized in this study for modifying the eye convergence to reduce eye accommodation and enhance the comfort in viewing 3D video. Without changing the contents of 3D films, it aims to apply the myosis, convergence, and accommodation visual triad of eyeballs viewing near distance to not change the eyeball pupillary distance when viewing 3D films. Without convergence, the discomfort caused by intraocular muscle contraction when viewing near distance is reduced. Such an effect of a small prism lens is also proven in this study. When viewing 3D films with $1.0\triangle$ lenses, the physiological accommodation reaction of eyes would reduce (the right eye decreases 65% and the left eye decreases 70%), revealing the decreasing tension of intraocular muscle. The subjective psychological evaluation result also shows that viewing 3D images with small prism lenses could enhance the comfort. The evaluation of optical simulation, physiological reaction, and mental fatigue proves that the small prism lens proposed in this study could actually improve the comfort in viewing 3D films.

1. Introduction

It has become a trend to view 3D displays that they are broadly applied to TV, movies, handheld devices, or promotion marketing. Nevertheless, the symptoms of discomfort and visual fatigue [1, 2] occur on viewing 3D films with either stereoscopic, shutter glasses, polarized glasses, head-mounted displays or auto-stereoscopic 3D parallax barrier technique, lenticular technique, and phase diffractive element technique [3]. Human factor analysis and content design for 3D displays are therefore emphasized [4].

When parallax 3D images are displayed on a flat screen, the positive-zero-negative parallax ambivalent sense of 3D space could appear in the brain [5] to generate cognitive confliction, damage the visual triad co-ordination of eyeballs [6], and result in fatigue and dizziness of viewers. In order to acquire good 3D image visual experiences, an optical device, which could have eyes relax when viewing 3D films, is proposed in this study. The device is composed of lenses with small prism degrees, which could reduce eye convergent angle and reduce eye accommodation range through the optical deflection characteristics of a small prism lens, without changing the contents of 3D films, so as to reduce the discomfort caused by extraocular muscle tension when viewing 3D films [7].

2. Principles

Pupillary distance (PD) refers to the distance between the center of pupils when the visual axis is elevated and parallel [8]. When viewing 3D films, the extraocular muscle of human eyes would start the motion, the convergence would draw the pupils closer and change with the distance of an object. When viewing an object in the front, the pupillary distance is reduced, while it is widened when the object is moved farther. In this case, when defining the pupillary distance for viewing 3D films, the far pupillary distance (FPD) and the near pupillary distance (NPD) should be measured according to the viewing distance.

Prisms have been applied to the oblique correction, when high prism degree lenses are generally utilized for the processing [9, 10]. After prism adaptation, the left neglect symptoms could be improved by using $10°$

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rightward-displacing wedge prisms [11]. Other studies find that prism adaptation could induce previously-unsuspected visuospatial changes in healthy people [12, 13, 14]. Robert D.McIntosh et al. aosl showed 15°or higher degree prism could induce the visuospatial aftereffects of leftward prism adaptation efficiently [15]. However, low prism degree lenses have not often be used. A low prism degree lens (~1.0△), which is slightly changed the optical path characteristics and the pupil distance when viewing 3D films [16], is first used for the comfort of eyeballs which are not convergent but slightly accommodate (Figure 1) [17]. The required prism degree could be acquired by the relation of distance difference and diopter between distance pupillary distance and near pupillary distance, Eq. (1).

$$\Delta = \frac{(\text{FPD} - \text{NPD}) \times \text{D}}{10} \qquad (1)$$

Δ: prism degree, D: diopter, NPD: near pupillary distance, FPD: distance pupillary distance.

Figure 2 shows the ray path after adding small prism lenses, and α is the vertex angle of the prism. When the ray is vertically incident to the first surface of the prism, the ray does not refract, while i angle appears between the incident ray and the normal line and γ angle appears between the emergent ray and the normal line when being incident to the second surface. The angle of deviation therefore appears δ. According to the included angle relation, $\delta = \gamma - i, i = \alpha, \gamma = \alpha + \delta$. When the ray goes
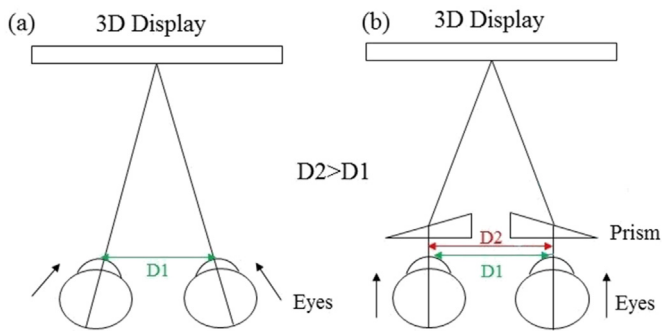

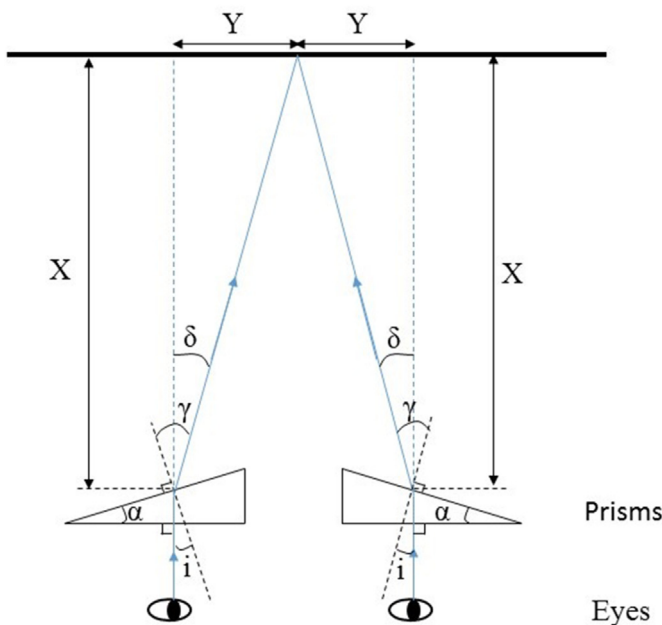**Figure 1.** Optical path (a)without small prism lens (b)with small prism lens.
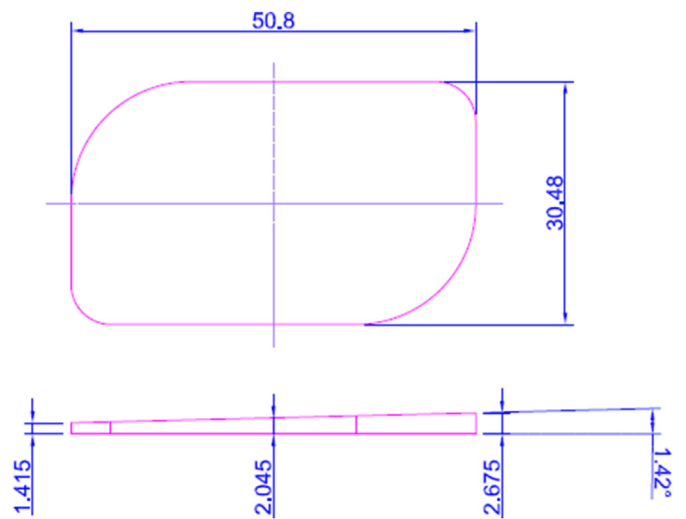

Figure 2. Optical path.

Figure 3. Parameters of the optical small prism (unit: mm).

to the second surface, the refraction law reveals $n \sin i = \sin \gamma$, $n \sin \alpha = \sin(\alpha + \delta)$.

3. Methods

This research method is divided into two parts. First, the optical small prism lenses is designed by using *Zemax*. Second, real experiments are applied to prove the optical small prism lens being able to improve the discomfort of users when viewing 3D films.

3.1. Optical design

Based on above principles, the prism degree value suitable for viewing 3D films could be acquired. The 1.0Δ lenses are utilized in this study for calculating the heights of a (thin end) and b (thick end) 1.415mm and 2.675mm, the lens width 50.8mm, and the angles of tilt 1.42° (Figure 3). For manufacturing a comfortable and easy-wearing prism devise, the prism devise is made as a glasses type. Figure 4 shows the entitative graph of the devised with optical small prism lens. For reducing the dispersion of this optical small prism lens, the higher Abbe number of the optical element is required [18, 19, 20]. Here, the information of the proposed prism is as follows. The Abbe number of the lens is 57.9, the index of refraction is 1.499, and the density of the lens is 1.32 g/cm³.

Figure 4. The devise with optical small prism.

Figure 5. Experimental environment.

3.2. Experiments

3.2.1. Participants

30 participants, including 23 males and 7 females aged 22.6 ± 2.3 [21] are in this study. Before implementing the experiment, the visual acuity of all subjects were corrected near/distant VA. All subjects were checked their visual acuity with their contact lens and the vision correction is above 1.0. In addition, the binocular vision tested was also implemented with a Randot Stereo test for confirming all subjects can see 3D image well. When watching the 3D film, subjects in experimental group (with small prism lenses)wore their contact lens and the proposed prism devise (shown as Figure 3) and subjects in control group (without small prism lenses)only wore their contact lens. Each participant is requested to have sufficient sleep, not to have food with caffeine and alcohol 8 h before the test, and understand the experimental process. The test design conforms to the requirements of Declaration of Helsinki in 1975.

3.2.2. Environment

In order to simulate the public viewing 3D films indoors, a bright room with the indoor temperature 25 ± 2 °C is used for the test [22]. The distance between the participant and the screen is fixed 40 cm, Figure 5. 15.6" Naked-eye 3D Display is utilized for playing the 3D film.

3.2.3. Process

In this study, each participant has to participate in two experimental groups, without small prism lenses and with small prism lenses. The experimental process is shown in Figure 6. In the two experiments, each participant is requested to put on +3.00D glasses for Fogging [23] to relax the accommodation for 5 min. In the control group (without small prism lenses), the participants, after the relaxation, put on "vision correction glasses" for measuring eye accommodation with an open computer refractometer (SHIN-NIPPON vision-K 5001) and view the 3D film for 10 min. The eye accommodation is immediately measured after finishing the film, and the questionnaires are filled. In the experimental group (with small prism lenses), a participant has to put on vision correction glasses for measuring eye accommodation before viewing the 3D film. The proposed prism devise is then put on to view the 3D film for 10 min. The same eye accommodation is measured, and the questionnaire is filled.

The questionnaire evaluation will be the subjective physiological fatigue index. The detail of the questionnaire is shown as Table 1. In the experimental process, when the participants feel hotched, dyspnea, looked pale, lightheaded, or dizzy, or a participant intends to stop the experiment, the research is immediately stopped.

3.2.4. Statistical analysis

Stat v2.03 (SPSS) statistical software is used for analyzing the accommodation variability. Regarding the in-group statistics, the data of the groups without/with small prism lenses before and after viewing the film and the questionnaire evaluation are analyzed with pair t-test, in which the significance is 0.05.

4. Results

4.1. Optical simulation result and image quality analysis

Before manufacturing the proposed the prism devise, the small prism lenses are added on both eyes for the optical simulation to confirm the image quality including the imaging position, lateral magnification, Modulation Transfer Function (MTF) and the distortion. After the calculation, the actual imaging position is 489.626mm when the
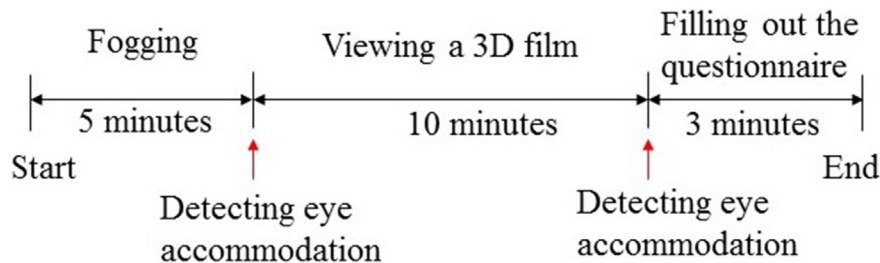

Figure 6. Experimental process.

Table 1. The self-questionnaire in this study.

| When watching the 3D film, did you have the following symptoms?	Strongly disagree	Disagree	Partly disagree	Partly Agree	Agree	Strongly agree
1. Was the image burred?	1	2	3	4	5	6
2. Did you need more attention to watch the 3D film?	1	2	3	4	5	6
3. Were you impatient when you watched the 3D film?	1	2	3	4	5	6
4. Did you feel uncomfortable when you watched the 3D film?	1	2	3	4	5	6
5. Did you get tired eye when you watched the 3D film?	1	2	3	4	5	6
6. Were you dizzy when you watched the 3D film?	1	2	3	4	5	6
7. Did you have headaches when you watched the 3D film?	1	2	3	4	5	6
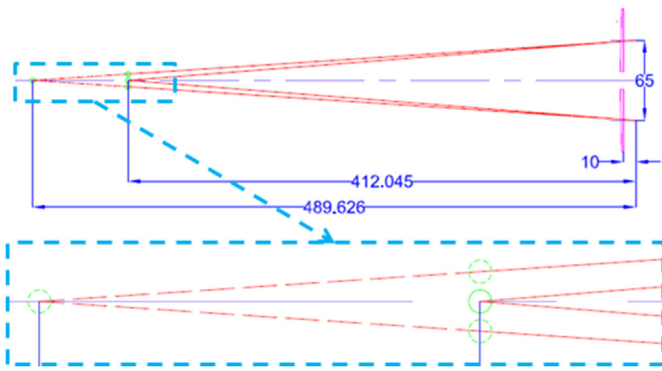
Figure 7. Imaging position with both eyes and 1.0△ small prism lens (unit: mm).

binocular pupillary distance is set 65mm and 1.0△ small prism lenses are added on both eyes with the distance 10mm (Figure 7). The imaging position is 412.045mm without the small prism lenses. The optical simulation results show that the lateral magnification of the image appears 1.008 after adding the small prism lenses, when the depth of field of the image is changed and moves backwards with magnification. The distortion is -0.18% and MTF remains 0.4 at 5.6 lp/mm, shown as Figure 8 and Figure 9.

4.2. Efficiency of wearing the prism device

In this study, participants in groups without/with small prism lenses are measured the accommodation reaction changes before and after viewing the 3D film. After the experiments without/with small prism lenses, each participant has to fill in the questionnaire evaluation for the subjective physiological fatigue index. The scores of the questionnaires from low to high stand for the subjective perception of the participant from slight to severe.

The eye accommodation changes of the participants in both experiments are shown in Figures 10 and 11. In the experimental process, during the accommodation reaction changes of the group without small

prism lenses before and after viewing the 3D film, the right eye presents statistically meaningful rise ($P < 0.05$), as the accommodation reaction increases from 0.30D to 0.39D. The left eye does not reach the statistics, but the accommodation reaction increases from 0.38D to 0.56D. Regarding the accommodation reaction changes of the group with small prism lenses before and after viewing the 3D film, the right eye does not achieve the statistics, with the accommodation reaction dropping from 0.22D to 0.14D, and the left eye also does not reach the statistics, with the accommodation reaction decreasing from 0.28D to 0.17D.

Aiming at the accommodation reaction parameters between the groups without/with small prism lenses before and after viewing the 3D film (Figures 12 and 13), both eyes without/with small prism lenses before viewing the 3D film does not reach the statistics, while they show statistically meaningful decrease after viewing the 3D film. The accommodation reaction of the right eye drops from 0.40D to 0.14D, and it of the left eye decreased from 0.56D to 0.17D.

Figure 14 shows the analysis of the self-report questionnaires. It is found that participants without small prism lenses are more easily perceive the blurred image, generate visual fatigue, spend more attention, and feel dizzy and headache than those with small prism lenses. The above indices reveal remarkably statistical differences.

5. Discussion

The presentation of 3D images aims to create the perception of virtual reality for viewers. However, in addition to improper contents which would generate negative effects on human bodies, the feelings of visual fatigue, dizziness, sickness, and headache would appear when viewing general 3D films [24].

Current binocular parallax 3D display techniques display the 3D effect with 2D flat screens that the presented 3D images show the initial light source on the flat screen either before the screen (smaller depth of field) or after the screen (larger depth of field). In this case, the eye convergence and accommodation at fixed viewing distance would be inconsistent. From the aspect of physiological mechanism, human eyes generate the stereo perception with parallax stereoscopy when viewing 3D movies, allowing the convergence of human eyes appearing the perception of far and near. The extraocular muscle accommodation
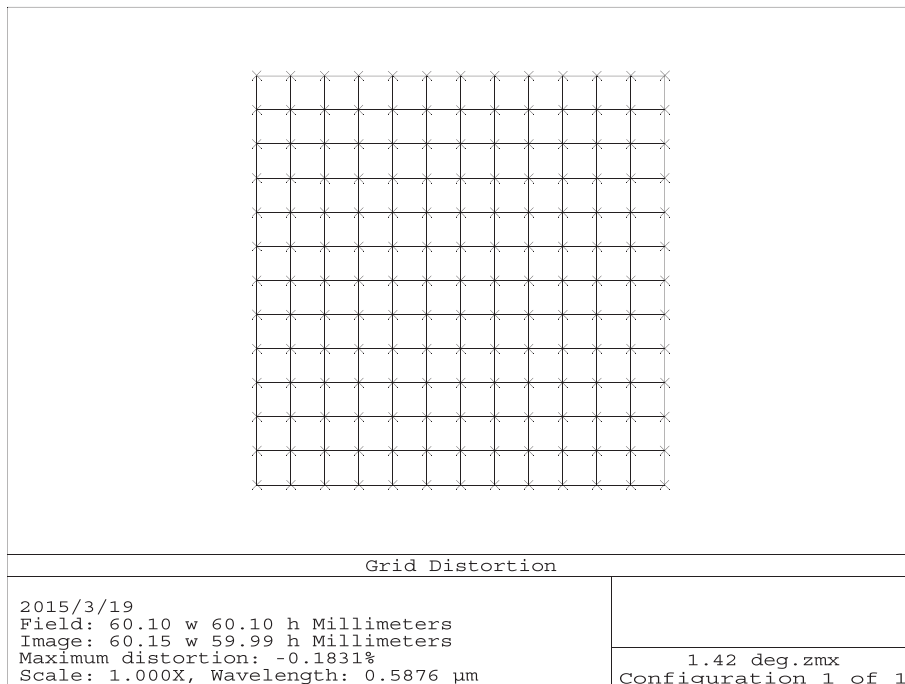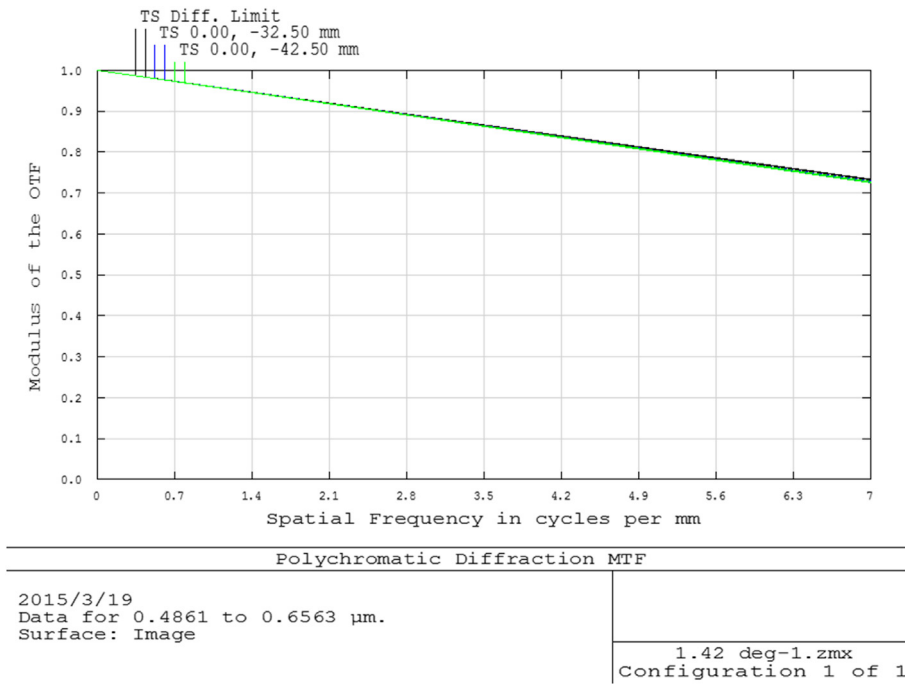

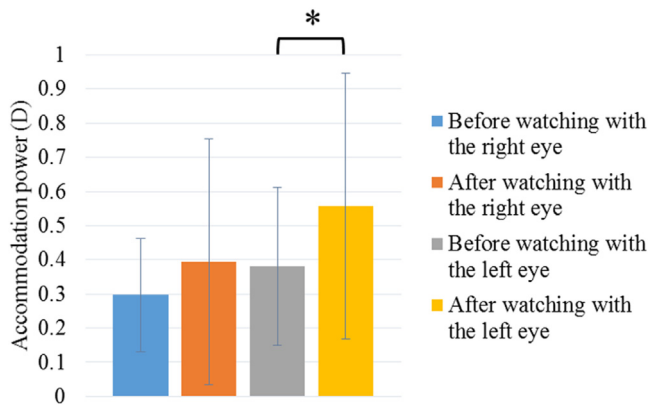**Figure 8.** Distortion analysis.

Figure 9. MTF analysis.

Figure 10. Comparison before and after viewing the film without a prism.
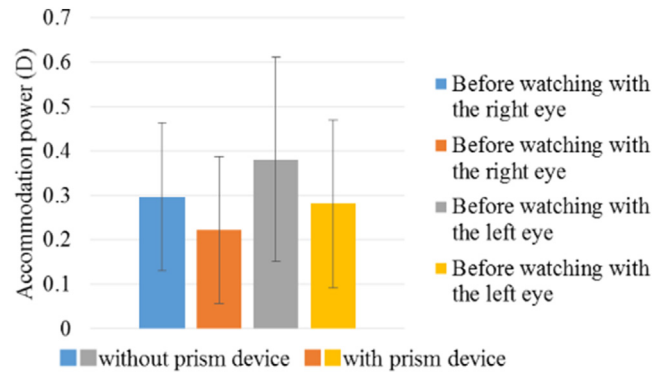

Figure 12. Comparison between with and without a prism before viewing the film.
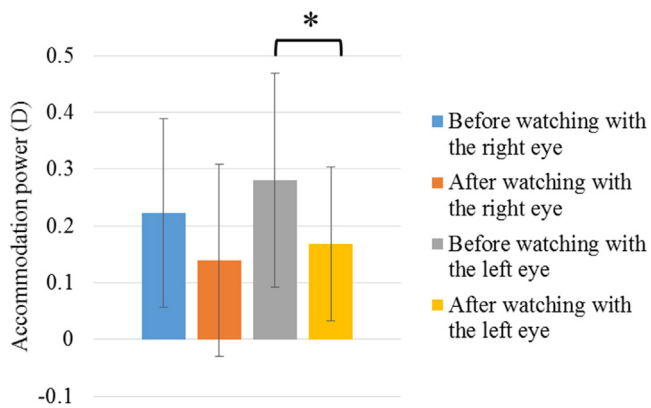

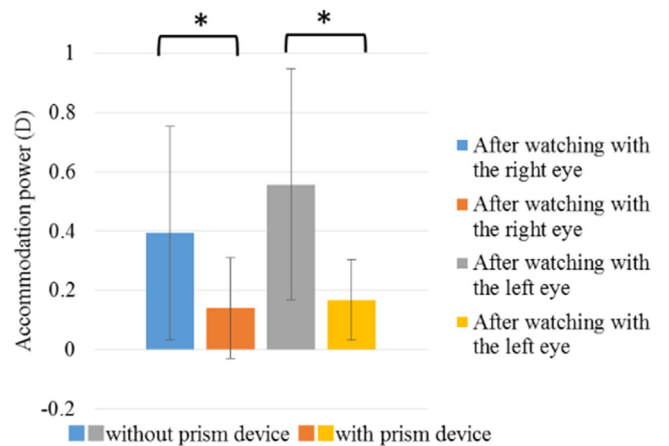**Figure 11.** Comparison before and after viewing the film with a prism.

Figure 13. Comparison between with and without a prism after viewing the film.
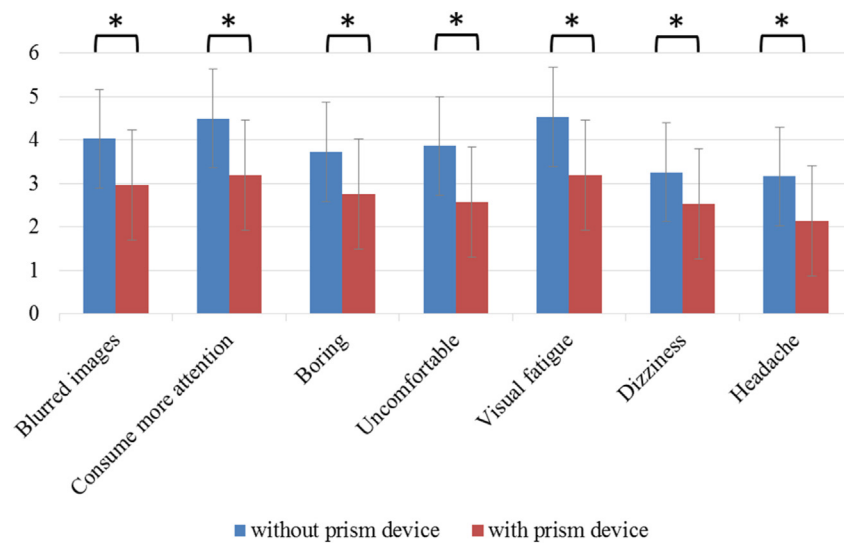
Figure 14. Questionnaire evaluation between groups without small prism lens and with small prism lens (*: $p < 0.05$).

convergent angle allows the convergent point of both eyes being ambivalent among "positive parrallax–zero parrallax–negative parallax". However, the image is from the same screen that the accommodation of human eyes in fact focuses on the screen the same as the 2D image position. In other words, the ciliary muscle for accommodating focus does not work. When human eyes view the real world, the radial muscle, which control the zoom of pupils, the ciliary muscle and binocular convergence controlling the zoom of crystalline lens, and the eye-level extraocular muscle present "triad effect". Consequently, when viewing parallax 3D movies, the extraocular muscle applies a force while the ciliary muscle is stationary, which is considered abnormal and would cause the so-called triad mechanism being damaged to result in muscle imbalance. Such a phenomenon would accumulate sarcolactic acid and release heat to cause the perception of sore and fatigue. Accordingly, it is inferred that the changes of eye convergence and accommodation being inconsistent when viewing parallax 3D displays would further damage the triad mechanism and result in extraocular muscle fatigue. Such an innovative inference could be explained as the reason of people often feeling fatigue and discomfort when viewing 3D films.

As mentioned above, vergence-accommodation conflict has been as the main problem to produce fatigue and discomfort while people watch 3D videos. The vergence-accommodation conflict can be described as the difference between distances of the required vergence and the required accommodative. Overall, a change in the vergence cause a change in the accommodation, so, in natural viewing, the distances of vergence and accommodation are coupled. In this study, we design and manufacture a prism devise to help people modifying their eye convergence slightly while watching 3D films. The slight change in vergence can cause a slight accommodation [25, 26].

The image, which is generated by the ray path simulated by Zemax optical software going through the lens with small prism degree, is discussed the quality. Besides, the changes of human eye accommodation when viewing 3D films with small prism degree lenses and self-report questionnaires are analyzed to discuss the objective physiological fatigue and subjective mental fatigue in this study.The optical simulation results show that the lateral magnification of the image appears 1.008 after adding the small prism lenses, when the depth of field of the image is changed and moves backwards with magnification. It proves why the image is slightly magnified and far away from human eyes when viewing 3D films with small prism lenses. The imaging quality after adding the small prism lenses is also discussed. On the other hand, the participants are requested to put on the small prism lenses for viewing the parallax 3D display in order to prove the device being able

to improve the tension of extraocular muscle. The results present that the eye accommodation increases when viewing 3D films without small prism lenses, revealing the extraocular muscle being tense. It proves that human eyes easily appear fatigue after viewing 3D films. Nonetheless, the accommodation of both eyes decreases when viewing 3D images with small prism lenses (compared with those without small prism lenses). The accommodation reaction of the right eye drops from 0.40D to 0.14D, and it of the left eye decreases from 0.56D to 0.17D, proving that viewing 3D films with small prism lenses could relax the accommodation. The self-report questionnaires are also analyzed in this study. The participants more easily feel dizzy and headache when viewing parallax 3D films without small prism lenses, and the eyes more easily perceive fatigue and appear image blur. The results of subjective physiological fatigue index and objective physiological fatigue index are consistent, indicating that people would feel more comfortable when viewing 3D films with small prism lenses.

6. Conclusion

A prism which can modify eye convergence is proposed in this study to relax the muscle of eyeballs. It could also decrease eye accommodation and reduce discomfort in viewing 3D video. With *ZEMAX* optical simulation program, the physiological reaction analysis of eye accommodation and the subjective mental fatigue evaluation in the self-report questionnaire prove that the proposed small prism lenses actually could improve the comfort in viewing 3D films. Moreover, a possible point of view related to eyeball vision and visual triad physiological mechanisms is also inferred to the discomfort in viewing 3D films.

Declarations

Author contribution statement

Chien-Yu Chen: Conceived and designed the experiments; Wrote the paper.

Hsien-Chang Lin: Conceived and designed the experiments; Performed the experiments.

Pei-Jung Wu: Analyzed and interpreted the data; Wrote the paper.

Chih-Hao Chuang: Contributed reagents, materials, analysis tools or data; Wrote the paper.

Bor-Shyh Lin: Analyzed and interpreted the data.

Ching-Huang Lin: Contributed reagents, materials, analysis tools or data.

Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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