Visual Comfort and Fatigue Between Watching Linear Polarized and Circular Polarized LCD TVs as Measured by Eye Tracking

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Abstract. An eye movement study was conducted to make clear whether the new technique of circular polarized LCD display would help to relieve the visual fatigue after long duration viewing films. 60 undergraduates and ordinary researchers were measured to assess and compare the difference of blink frequency and duration time between viewing linear polarized and circular polarized LCD displays by Eye-tracking. 60 participants were divided into two groups after matching, and the two matched groups were separately arranged to viewing linear polarized and circular polarized LCD displays. They watch the same video content (scenery video and a film), while recording the eye movement data. The results shows that the blink frequency of the two group participants which viewed linear polarized and circular polarized LCD displays first decreases and then increases in the overall trend with prolonging of the viewing time, and there is remarkable difference between the participants of viewing linear polarized and circular polarized LCD displays in blink frequency and duration time indexes. As a conclusion, circular polarized LCD causes less visual fatigue.

Keywords: Visual fatigue · Eye-tracking · Circular polarized · Linear polarized · LCD display

1 Introduction

It is well believed that about more than 95 % of information obtained by the human brain is from the vision system [1, 2]. With the coming of the information era, the way of information communication has greatly depended on the visual display terminal (VDT). As a kind of visual display terminal, liquid crystal display is essential in our daily working and life. And for people who engaged in computer work for a long time, the visual fatigue problem by using visual display device is very common. Researches show that, using VDT for a long time has easily made the risk of muscle and eye injured high [3–8]. It is important to reduce visual fatigue that we should not only use the visual display terminals in a correct way, but also improve the quality of visual display terminals. Therefore, the research of visual fatigue evaluation methods is particularly important.

At present, studies on the evaluation methods about visual fatigue include subjective evaluation methods and objective evaluation methods. Subjective evaluation methods mainly include questionnaire survey which is simple, but not any unified

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standard and difficult to quantify the degree of fatigue. Objective evaluation methods generally consist of the physiological indexes to detect the visual fatigue, such as EEG, heart rate, which could quantify the degree of fatigue. Although this method is more scientific and accurate to obtain the data, but require participants contact the measuring instrument probes and the test process is complex. Morever, the method is not suitable for some occasions of electromagnetic interference [9]. Therefore, the evaluation of visual fatigue by non-contact method is necessary. In recent years, with the development of computer technology, image processing technology and eye movement parameters are more and more applied to evaluate the visual fatigue. Eriksson [10] monitored visual fatigue through tracking, positioning and recognition the state of eyes. And the eye blink, fixation, pupil size, saccade and other eye tracking indicators have been increasingly applied to the study of the visual fatigue [11–13].

It is showed that eye movement information can reflect a person's mental fatigue and other physiological condition. The relationship between eye blink frequency and visual fatigue has been proved in some studies. Stern [8] and other psychologists believe that eye blink frequency is faster, more fatigue. Lee [14], Sakamoto [15], Kim [16] thought that blink frequency could reflect the visual fatigue degree caused by watching different VDT, which blink frequency increase with the time extension. Schleicher [13] studied blink frequency has increased gradually among awakening, reduced vigilance, fatigue and sleepy four consciousness state in a simulated drive process, and at the same time, the transition from sleep to the serious sleepy is accompanying blink duration extension. Victor [17] also confirmed that blink frequency increase associated with the degree of fatigue, and blink frequency loss associated with the brain's cognitive activity, which the blink frequency decreased significantly in the high concentration driving process.

The manufacture principle of Liquid crystal display is that the liquid crystal molecules is a light control switch, which the brightness of the display screen, flashing and reflecting would cause visual fatigue. People have adopted various methods to reduce the influence of these factors. From optical properties, light is a transverse wave, the plane consisted of the vibration and advance direction of the electric vector called vibration plane. If light vibration plane is not evenly distributed, it is known as the polarized light. If light vibration plane is limited to a fixed direction, it is called linear polarized light; if the light vibration plane rotated around the advance light direction, it is called a circular polarized light. Most natural ambient light (such as sunlight) is natural light, which vibration plane in all directions is uniformly distributed. Usually, liquid crystal molecules of the liquid crystal display screen control the emitting light is polarized light. At present, liquid crystal display products in markets is generally mainly linear polarized light. From the principle of the polarized light, the circular polarized light is closer to natural light with respect to linear polarized light on the optical characteristics [18–20]. So, we assume that the circular polarized light is more helpful to retard the visual fatigue.

This study intends to investigate the effect of visual display terminals made by linear polarized light and circular polarized light on people's visual comfort and evaluate people's fatigue for two kinds of manufacturing techniques of the LCD displays by eye tracking experiment. The study is expected to provide design suggestions and evidence for manufacturing techniques of the LCD displays.

2 Method

2.1 Participants

Sixty undergraduates and ordinary researchers from 20 to 36 years old (25 male and 35 female, mean age = 25.7, standard deviation of age = 3.95) were recruited and paid to participate in the experiment. Sixty participants were divided into two same number groups after matching and the gender rate is roughly matched (the linear polarized group men: women = 13:17, the circular polarized group men: women = 12:18). All had normal or corrected-to-normal visual acuities and healthy physical conditions, without ophthalmic diseases. They did not have any history of neurological and mental diseases. And all participants were divided into two groups after matching according gender, age and job category etc. The two matched groups were separately arranged to viewing the same film and videos on linear polarized or circular polarized LCD displays.

2.2 Experiment Design

A between-subject factorial design was used in this experiment. The independent variable of the experiment is TV types which include circular polarized LCD display and linear polarized LCD displays. In this experiment, the difference of blink frequency and blink duration time between viewing the same video before and after seeing the film on the linear polarized or circular polarized LCD displays were measured by Eye-tracking to assess and compare which TV is better. The subjective questionnaire was used to investigate the visual fatigue after watching the films. Participants reported their perception and evaluations by filling in a questionnaire. All the questions in the questionnaire were measured by a eleven-point scale from none to strongly serious (0 = “none” and 10 = “strongly serious”).

2.3 Apparatus

Experiments were conducted in a laboratory environment which simulated home condition. It was installed in the laboratory in the Institute of Human Factors and Ergonomics in China National Institute of Standardization. The video display terminals are 40 inch modified L409HBD FHD TV (the exit light is linearly polarized light or circularly polarized light, respectively), made by Chinese TCL Corporation. After a Photo Research PR650 spectrophotometer calibration, two television sets exactly the same in addition to polarized incident light of different characteristics, other properties such as brightness, contrast, hue, color saturation and sharpness.

2.4 Procedures

After arriving at the laboratory, participants signed the informed consent and completed a general survey about their demographic information. The participants were asked to

sit into the simulator to get ready for the test. Then we had an eye movement calibration for the participants. After that, the participants were asked to follow their own natural state to watch the plotless scenery "mountains and rivers" and the film "Jurassic Park". Before the experiment, participants were asked to relax 10 min or more, and told the testing process and requirements. And the participants were divided into two groups, one group used linearly polarized light LCD TV to watch video (referred to as the line-partial group, the same below), the other group used a circularly polarized liquid crystal TV watching video (referred to as the circular-partial group, the same below). The video display terminal are vertically arranged in the height adjustable special experimental table. Before the experiment, the height of the table and display position were adjusted to make the participants' eyes and display center on a line. The viewing distance is about 250 cm. The eye and the eye tracker distance is about 70 cm, and the head tracking range is 40 * 40 cm. Before viewing the first scenery video, an eye move calibration was done to ensure data precisely. The experiment task is watching a scenery video for about 5 min, then seeing a film for about 110 min and again watching the same scenery video for about 5 min. During viewing the film and videos, the participants' eye movement data were recorded. After viewing the last scenery video, the participants were required to fill out the visual fatigue questionnaire. Each participant spent about two hour finishing the experiment.

2.5 Data Analysis

Eye movement of original data were exported from the SMI BeGaze software. The changes value of the blink frequency and blink time between watching the first and last scenery were analyzed by IBM SPSS 20 Statistics software (IBM-SPSS Inc. Chicago, IL). The method of independent samples T test was applied. In order to reduce the interference from the plots, the study mainly analyzes the data of viewing the same scenery video experimental, and calculates the difference of blinking frequency and blink duration variation, and compare visual fatigue between viewing different polarized light TV.

3 Results

3.1 T-Test of Blink Frequency and Blink Duration Time Before Watching Movie

Eye-tracking test was conducted to compare the effect of the two types of LCD TVs on participants' visual fatigue and comfort preference. Blink frequency and blink duration time data were analyzed. Before the experiment data analysis, we need check if there is difference in blink frequency and blink duration time data between the two groups of participants who viewed different LCD TVs. So, an independent samples T-test was conducted to the blink frequency and blink duration time data of the linear/circular polarized group during viewing scenery video before watching movie. The results indicated that the difference of eye blink frequency and duration time between linear polarization group and the circular polarization group was not significant ($ps > 0.05$)

(see Table 1). It means that the linear polarization group and the circular polarization group were matched well before watching movie.

Table 1. Comparison of blink frequency and blink duration before watching movie

Item	Linear-partial group	Circular-partial group	T value	Sig. (two-tailed)
The first blink frequency	15.83(1.815)	13.93(1.707)	.762	.449
The first blink duration time	2271.60(299.038)	2001.37(290.468)	.648	.519

3.2 T-Test of Blink Frequency and Duration Variation After Watching Movie

An independent samples T-test was conducted to compare the effect of the two types of LCD TVs on participants' visual fatigue and comfort preference. Blink frequency and blink duration time data were analyzed. The results show that blink frequency and duration time increasing proportion of linear-partial group after watching movie is far higher than those of circular-partial group. An independent samples T-test was conducted to blink frequency and blink duration time variation data of the linear/circular polarized group after watching movie. The results shows that there is a remarkable difference between linear polarized group and circular polarized group in blink frequency and duration variation (ps < 0.05) (See the Table 2).

Table 2. Comparison of blink frequency and duration variation after watching movie

Item	Linear-partial group	Circular-partial group	T value	Sig. (two-tailed)
The variation of blink frequency after watching movie	6.80(1.583)	2.40(1.194)	2.219	.030
The variation of blink duration after watching movie	1812.33(492.084)	594.53(245.949)	2.214	.031

3.3 The Subjective Visual Fatigue Feelings After Watching Videos on Circular Polarized and Linear Polarized LCD TV

Participants' perception about the visual fatigue of viewing film and videos on LCD TVs was measured by ten items (see Table 3), such as "If you have the feeling of dizzy?" 600 ordinal scale data (60 participants × 10 questions) was collected. It is demonstrated in Table 3 that there are more serious visual fatigue feelings of blurred, ophthalmodynia, eye drying in linear polarized group, while there are more serious visual fatigue feelings of dizzy, headache and eye burns in the circular polarized group. As the independent samples T-test results shows, there is no significant difference of subjective visual fatigue report between two groups of participants (ps > 0.05).

Table 3. Comparison of the subjective visual fatigue feelings after watching videos on circular polarized and linear polarized LCD TVs.

Item	Dizzy	Nausea	Headache	Echo	Blurred	Ophthalmodynia	Eye drying	Eye burns	Eyestrain	Eyelids heavy
Circular-partial group	1.23	0.27	0.82	0.77	1.36	1.64	2.09	0.82	3.55	2.64
Line-partial group	0.83	0.26	0.65	0.87	1.78	1.91	2.57	0.52	3.57	2.35

4 Discussion

In this study, the participants' blink frequency and blink duration time exceeds the initial blink frequency and blink duration data after watching movie. Generally speaking, the blink frequency and duration time have increased with the viewing time prolonged, which means that the physiological state of visual fatigue appeared. It is consistent with the past studies of other scholars [13–17, 20–22]. It may be that participants accepted a large amount of information and caused the visual fatigue accumulation with the viewing time prolonged. And the increase of blink frequency and blink duration time may be a self-regulating and protecting function of human body.

The past studies manifested that eye blink is important to maintain the intact of the ocular surface. And the eye blink include active blink, reflex blink and spontaneous blink [21, 22]. Spontaneous blink would distribute the tear uniformly throughout the eyeball surface, and help to remove the lipid secreted by tear and meibomian gland, so as to keep the dynamic balance of the humidity on the ocular surface. The tear evaporation speed is related to blink interval (inter blink interval, IBI). The inter blink interval is longer, which means the blink frequency is reduced, and the ocular surface exposure time is prolonged, then the corresponding evaporation speed is faster. When engaged in focused work or some evoked gaze activities (for example, watching movies), the eye blink would reduce and the eye blink frequency would decrease in the initial stage. But with the viewing time extension, visual fatigue gradually appears, the bad blink caused by too focused on viewing decreases gradually, the tear evaporation speeds up. In order to prevent ocular surface drying, reflex blink increases. Therefore, the eye blink data reflected the visual fatigue degree. Not tired eyes blink is usually very little or not. If the eyes are fatigue, then they can't help to blink or the blink time becomes long.

In this study, there is significant difference of blink frequency and duration time between the linear and circular polarized groups after viewing the movie. Which the blink frequency and blink duration time variation of the linear polarized group are more than those of the circular polarized group after watching movie. It show that, the visual fatigue degree of the linear polarized group is more serious than that of the circular polarized group. The results seems to show that the circular polarized LCD causes less visual fatigue. This conclusion obtained by eye tracking test in this experiment is consistent with the result showed in the experiment done by Xiaolin Yan et al. [20].

But, in the experiment there is no significant difference of subjective visual fatigue report between the linear and circular polarized groups of participants. It may be because that participants are too excited to feel the visual fatigue and distinguish the fatigue difference watching the linear and circular polarized LCD TV. And, it indicated that the subjective testing is not sensitive to visual fatigue comparing with the objective testing in a degree.

5 Conclusion

The study investigated the effect of viewing different LCD TVs on visual fatigue and comfort. It compared the result of the two LCD TV types, and figure out which was better. A compare test was designed and an experiment was conducted to fulfill the study goals. The study indicated that there are significant difference between watching circular polarized LCD TV and linear polarized LCD TV by eye tracking test. Comparing with viewing the linear polarized LCD TV, there are less blink frequency and blink duration time after watching the movie. In a word, the results show that comparing to the linear polarized LCD TV, watching the circular polarization LCD TV caused lighter visual fatigue for a long time viewing.

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