Comparison of Visual Comfort and Fatigue Between Watching Different Types of 3D TVs as Measured by Eye Tracking

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Abstract. An eye movement study was conducted to make clear whether different types of 3D TVs would help to relieve visual fatigue after watching films for a long time. 64 undergraduates and ordinary researchers were measured to compare the difference of watching different 3D TVs by Eye-tracking. 64 participants were divided into four groups after being matched, and the four matched groups were separately arranged to watch Switched 3D TV, polarized 3D TV, naked 3D TV and 2D TV. They watched the same video contents which were scenery video and a film, while eye movement data were recorded. The results showed that: (1) with the increase of watching time, participants' fatigue also increased. The blink frequency, blink counts, blink total duration, saccade angle and saccade velocity of the four group participants who watched different types of 3D TVs remarkably increased in the overall trend with time; (2) There was a remarkable difference between the participants watching polarized 3D TV and others watching 3D TV and 2D TV in average saccade duration, saccade duration peak, average saccade angle and saccade total angle, which might indicate that the principle of polarized 3D TV would affect users' saccade duration and saccade distance during watching videos. (3) The saccade amplitude of switched 3D TV was significantly higher than that of other three conditions, which might indicate a greater influence of saccade amplitude in switched 3D TV.

Keywords: Visual fatigue · Visual comfort · Eye-tracking · 3D TV

1 Introduction

The human brain gets most of the information from the visual system. With the continuous development of the Internet and the advance of 3D display technology, the spread of information and the way people access to information are constantly changing. More and more people obtain information from the Visual Display Terminal (VDT). With the expansion of 3D display in ordinary families, visual fatigue problem associated with watching 3D images has aroused the concern of all sectors of society. Visual fatigue shows a series of visual uncomfortable symptoms in physical, such as eye fatigue, dryness, tearing, strain and double vision [1].

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At present, the visual fatigue assessment methods are divided into two categories, subjective evaluation and objective evaluation. Subjective evaluation is mainly a questionnaire, the use of which is simple. But there is no unified standard of quantitative and it is difficult to quantify the level and degree of fatigue. But the development of subjective measurement is more mature. SSQ rating scale is more commonly used, which has 5 point scale, 7 point scale and 13 point scale to choose. There are many subjective evaluation indexes, which can be filtered according to the experiments. Parameters of objective measurement are the eye parameters, event related potential (ERP) and physiological signals, etc. The eye parameters include critical flicker frequency, blinking frequency, the diameter of the pupil and reaction speed, etc. The drop of critical flicker frequency (CFF) reflects the weakening of retinal function. So the change of CFF value can reflect the human eye fatigue to some extent. Objective evaluation usually detects visual fatigue by physiological indexes to determine the level of fatigue, such as pulse waves, brain waves, heart waves, etc. Zou et al. study the condition of eye fatigue after viewing random stereoscopic point figure using brain waves. They found alpha wave is a sensitive index to represent visual fatigue [2]. Although the data from this method is more scientific and accurate, it needs participants to contact the measuring instrument probe and the test process is complex. Comparatively speaking, using non-contact way is easier to evaluate visual fatigue for the researchers.

In recent years, with the development of computer technology, more and more people use the technology of image processing and eye movement parameters to evaluate fatigue of eyes. Eriksson monitored fatigue state through tracking, positioning and recognizing the state of eyes [3]. Grace developed a system to monitor the drowsiness of heavy duty truck driver combined the method of percentage of eyelid closure (PERCLOS) [4]. Guo established a set of fatigue test system through PERCLOS value of fatigue judgment [5]. At present, the mainstream eye-movement apparatus uses the high speed infrared camera to record eye movement trajectory. Represent visual fatigue using the blink of eyes, gaze, pupil size and saccadic indexes [6–8]. Studies have shown that the blink of eyes, pupil size and other indexes can reflect the fatigue status of humans. A number of researchers have shown the relationship between the change of blink frequency and saccadic parameters and the fatigue of eyes. Zhang, Lee, Sakamoto, Kim all use blinking frequency to reflect the degree of visual fatigue caused by watching different VDT. Frequency increased with the extension of time [9–12]. Schleicher and other scholars studied the subjects' behavior of blinking eyes with eye movement apparatus in a simulated driving process. The blink frequency increased with the evolution of the four state of consciousness, awakening, alert reducing, tired and sleepy [8]. At the same time, with the transition to the serious drowsiness, duration of blinking eyes extended. Similarly, some researchers also found the relationship between saccadic parameters and visual fatigue. When Zou studied visual fatigue of 3D display, he found the ratio of peak velocity and twitch amplitude is an effective visual fatigue index produced by watching the 3D display screen. The larger twitch amplitude is and the greater the distance of moving the eyes is, the more difficult of information processing will be. Changes of twitch amplitude shows the humans have fatigue [2]. Not only the eye movement parameter can be used as a visual fatigue index, the parameter of the eye itself can also show the eye fatigue.

As some researchers put forward the method of judging eye fatigue degree of watching free stereoscopic display by measuring the pupil diameter, and the pupil diameter measuring device is developed. The device can record the viewer's pupil diameter when continuously playing stereo video. According to the subjective evaluation of the viewer, the degree of visual fatigue was increased with the increase of viewing time. The pupil diameter of the viewer also increased with the increase of viewing time. There was a positive correlation between visual fatigue and pupil diameter, pupil diameter could be regarded as a simple index of visual fatigue measurement [13, 14]. The study of Zhang et al. found that watching 3D video will make blink frequency decrease, saccade speed, saccade frequency and amplitude increase. The pupil diameter in watching 2D and 3D video showed no significant difference [15].

The above studies have shown that the eye tracking method can be used to test the visual fatigue of the user, but there are inconsistencies between the studies, which need further verification. The purpose of this study is to evaluate the difference of visual fatigue caused by three different production principles of 3D TV monitor to the users by eye tracking method. Compare the effects of different types of 3D TV monitors on visual fatigue and comfort.

2 Method

2.1 Experimental Design

This study is 4 * 2 mixed design, which the between-group factor was three different types of 3D and 2D TV. The within-group factor was before and after watching the film. The evaluation indexes included blink frequency, saccade velocity, saccade amplitude, average saccade time, and average saccade angles etc. Use the subjective fatigue assessment scale to assess the fatigue degree. Subjective evaluation was used to evaluate the comfort, fatigue and satisfaction of the subjects to different types of 3D and 2D TV.

2.2 Subjects

There were 64 college students or researchers participating in the experiment in 18–35 years old. The average age was 24.48 years old, male 33, female 31. All subjects were normal or corrected visual acuity above 0.8 and physical and mental health, no stereopsis blindness, no eye disease, neurological or psychological disease. The four groups were matched for demographic variables such as gender, age, and the time to use the visual display terminal (VDT). All the subjects had not seen the film recently.

2.3 Experimental Material

The test samples were different brands of 47 or 48 Inch 3D LCD TV. Each sample was set to the standard state of its own. Switched 3D TV sample was tcll48f3500a-3D; polarized 3D TV sample was lg47la6200-cn TV; naked 3D TV sample is TCL self-research as3Dp, 2D TV was mainly based on lg2d (14:16).

2.4 Experimental Instruments and Environment

The experimental instrument was SMI RED eye tracker. The sampling rate was 60 Hz. Experimental environment was the normal lighting environment (about 100lx).

2.5 Experimental Procedure

The experiment was carried out in a soundproof laboratory simulated home environment. Subjects were asked to relax for 10 min or more before the experiment, then read the informed consent of the experiment and filled in the demographic information. The object explain the test process considerations and requirements to the subjects. The subjects were divided into four groups, each group respectively watched switched 3D TV, polarized 3D TV, naked 3D TV and 2D TV. Before the experiment, adjusted the height of the table and the position of the display, so that the eyes of the subjects were flush with the center of the display. The distance of the test was about 250 cm. The distance between the eye and the eye tracker was about 70 cm, and the range of the head movement was 40 * 40 cm. The experiment was first calibrated, and then began a formal experiment. Require the subjects to watch scenery video in their own natural state for 10 min. Then watch the 90 min movie “the lightning dog” and watch the same scenery video again for the next 10 min.

2.6 Data Statistical Analysis

The eye movement data of watching the same scenery video before and after seeing the film and subjective evaluation data with different TVs were analyzed by IBM SPSS 22 Statistics software (IBM-SPSS Inc. Chicago, IL) and other professional software. The method of repeated-measure ANOVA analysis were applied to the experiment data.

3 Result Analysis

3.1 Results of Subjective Evaluation of Visual Fatigue

Comfort, Fatigue and Satisfaction Evaluation of Watching Different Types of TV. The results showed that there was no significant difference among users’ comfort and satisfaction by viewing different TVs ($F = 0.01$, $p = 0.96$), but there was a significant difference in the subjective fatigue ($F = 3.88$, $p = 0.01$). The post hoc test showed that the fatigue degree of naked 3D was the most serious, followed by polarized 3D. Switched 3D and 2D had no significant difference. The fatigue feeling of switched 3D, polarized 3D and 2D was significantly less than naked 3D ($ps < 0.05$) (Table 1).

Subjective Fatigue Assessment of Watching Different Types of TV. The subjective fatigue evaluation results of each subscales were shown in Table 2. The data were analyzed by repeated measures ANOVA. The statistical results showed that there was

Table 1. Evaluation of comfort, fatigue and satisfaction of different types of TV

	2D (SD)	Polarized 3D (SD)	Naked 3D (SD)	Switched 3D (SD)
Comfort	51.73 (4.45)	51.88 (4.67)	49.88 (3.98)	49.31 (4.52)
Fatigue	50.13 (3.91)	55.35 (3.81)	66.94 (3.00)	51.19 (4.64)
Satisfaction	65.13 (2.46)	71.71 (2.22)	68.13 (2.57)	64.88 (4.90)

Table 2. Subjective fatigue perception evaluation results of watching different types of TV

	2D	Polarized 3D	Naked 3D	Switched 3D	F	Sig.
Burning	30.27 (4.81)	22.94 (3.22)	34.00 (4.03)	20.63 (2.57)	2.85	0.04
Strain	36.20 (3.88)	34.71 (3.34)	42.63 (3.87)	25.69 (3.05)	0.62	0.01
Tearing	22.40 (4.50)	19.18 (2.90)	28.06 (3.69)	12.63 (2.28)	3.60	0.02
Double vision	18.80 (3.38)	19.82 (3.27)	24.06 (4.78)	11.44 (1.72)	2.30	0.08
Dryness	38.73 (3.94)	32.53 (3.02)	45.31 (4.87)	26.31 (3.14)	4.63	0.00
Headache	36.87 (4.45)	43.76 (4.67)	29.00 (3.98)	29.06 (4.52)	2.66	0.05

significant differences among the subscales of subjective fatigue (ps < 0.05). The post hoc test showed that the burning, strain, tearing, double vision, dryness and other problems caused by switched 3D were significantly lighter than those of naked 3D (ps < 0.05). The blur degree of polarized 3D was significantly lighter than that of naked 3D (ps < 0.05). The headache and dryness degree caused by switched 3D were significantly lighter than those of polarized 3D (ps < 0.05). The dryness degree caused by polarized 3D was significantly lighter than that of the naked 3D, but the headache caused by polarized 3D was greater than that of naked 3D and switched 3D.

3.2 Objective Measurement Result of Visual Fatigue

The Saccade Amplitude Changes of Viewing the Same Scenery Video Before and After Seeing the Film with Different Types of TV. The saccade amplitude data of viewing the same scenery video before and after seeing the film with different TVs was analyzed by the repeated measurement ANOVA. The results showed that the time effect was not significant ($F = 0.329$, $p > 0.05$), the differences among the four types of TV were significant ($F = 3.009$, $p < 0.05$), see Table 3. The post hoc test showed that the saccade amplitude of switched 3D was significantly greater than that of three other types of TV (ps < 0.05).

Table 3. The variance analysis results of saccade amplitude of watching different types of TV

	SS	df	MS	F	Sig.
TV types	35168189352.29	3	11722729784.10	3.009	0.038
Time	235898954.34	1	235898954.34	0.329	0.568
TV types *time	36867625.94	3	12289208.65	0.017	0.997

The Average Saccade Time Changes of Viewing the Same Scenery Video Before and After Seeing the Film with Different Types of TV. The average saccade time data of viewing the same scenery video before and after seeing the film with different TVs was analyzed by the repeated measurement ANOVA. The results showed that the time effect was significant ($F = 7.510$, $p < 0.01$), the TV types effect was significant ($F = 4.426$, $p < 0.01$), see Table 5. The results of multiple comparison showed that the average saccade time of polarized 3D was significantly greater than that of 2D and switched 3D ($ps < 0.01$). Afterwards, The post hoc test showed that the average saccade time of viewing the scenery video after the film with polarized 3D was significantly greater than that of viewing the scenery video before the film ($p < 0.01$) (Table 4).

Table 4. The variance analysis results of average saccade time of watching different types of TV

	SS	df	MS	F	Sig.
TV types	61130.38	3	20376.79	4.426	0.007
Time	6321.33	1	6321.33	7.510	0.008
TV types *time	2486.85	3	828.95	0.985	0.407

The Saccade Peak Changes of Viewing the Same Scenery Video Before and After Seeing the Film with Different Types of TV. The saccade peak data of viewing the same scenery video before and after seeing the film with different TVs was analyzed by the repeated measurement ANOVA. Results showed (see Table 5) that the time effect was significant ($F = 4.821$, $p < 0.05$), the difference of saccade peaks among the four types of TV was significant ($F = 3.219$, $p < 0.05$). The multiple comparison results showed that the saccade peak of polarized 3D was significantly greater than that of 2D and switched 3D ($ps < 0.05$). Afterwards, The post hoc test showed that the saccade peak of viewing the scenery video after watching the movie had great changes. The saccade peaks of viewing the scenery video after watching the movie with polarized 3D and naked 3D were significantly greater than that of viewing the scenery video before watching the movie ($ps < 0.05$).

Table 5. The variance analysis results of saccade peak of watching different types of TV

	SS	df	MS	F	Sig.
TV types	7146106.31	3	2382035.44	3.219	0.029
Time	1547040.62	1	1547040.62	4.821	0.032
TV types *time	1760723.48	3	586907.83	1.829	0.152

The Average Saccade Angle Changes of Viewing the Same Scenery Video Before and After Seeing the Film with Different Types of TV. The average saccade angle data of viewing the same scenery video before and after seeing the film with different TVs was analyzed by the repeated measurement ANOVA. The results showed that the time effect was significant ($F = 17.933$, $p < 0.05$), the difference of saccade average angle among the four TVs ($F = 2.676$, $p = 0.056$) was critical significant (see Table 6). Multiple comparison showed that the average saccade angle of polarized 3D was significantly greater than that of 2D and switched 3D (ps < 0.01), the average saccade average of naked 3D was significantly greater than that of 2D ($p < 0.05$). The post hoc test showed that the average saccade angles of viewing the same scenery video after watching the film with polarized 3D and naked 3D was significantly larger than that of viewing the same scenery video before watching film (ps < 0.05).

Table 6. The variance analysis results of average saccade angle of watching different TVs

	SS	df	MS	F	Sig.
TV types	1005.93	3	335.31	2.676	0.056
Time	389.17	1	389.17	17.933	0.000
TV types *time	79.16	3	26.39	1.216	0.312

The Total Saccade Angle Changes of Viewing the Same Scenery Video Before and After Seeing the Film with Different Types of TV. The total saccade angle data of viewing the same scenery video before and after seeing the film with different TVs was analyzed by the repeated measurement ANOVA. The results showed that the time effect was significant ($F = 15.879$, $p < 0.001$), the total saccade angle differences between the four TV types were significant ($F = 2.783$, $p < 0.05$), see Table 7. The post hoc test showed that the total saccade angle of polarized 3D was significantly greater than that of 2D and switched 3D (ps < 0.05). Afterwards, the comparison showed that total saccade angle of polarized 3D and naked 3D after watching the film was significantly greater than that of before watching the film (ps < 0.05).

The Blink Counts Changes of Viewing the Same Scenery Video Before and After Seeing the Film with Different Types of TV. The blink response data of viewing the same scenery video before and after seeing the film with different TVs was analyzed by the repeated measurement ANOVA. The results show that the time effect was significant ($F = 22.298$, Ps < 0.001), but the difference among the four types of TV was not significant, see Table 8. The results showed that the blink counts of the four types of TV during watching the movie has an increasing trend, but there was no significant difference among the four types of TV.

Table 7. The variance analysis results of saccade total angle of watching different types of TV

	SS	df	MS	F	Sig.
TV types	349839306.50	3	116613102.17	2.783	0.049
Time	100522228.54	1	100522228.54	15.879	0.000
TV types *time	6164822.55	3	2054940.85	0.325	0.808

The Blink Frequency Changes of Viewing the Same Scenery Video Before and After Seeing the Film with Different Types of TV. The blink frequency data of viewing the same scenery video before and after seeing the film with different TVs was

Table 8. The variance analysis results of blink response of watching different types of TV

	SS	df	MS	F	Sig.
TV types	14344.24	3	4781.41	0.815	0.491
Time	22165.35	1	22165.35	22.298	0.000
TV types *time	77.75	3	25.92	0.026	0.994

analyzed by the repeated measurement ANOVA. The results showed that the time effect of blink frequency was significant ($F = 20.527$, $P < 0.001$), but there was no significant difference of the blink frequency among the four types of TV, as shown in Table 9. The results showed that there was an increasing trend of blink frequency in the four types of TV during watching the movie, but there was no significant difference among the four types of TV.

Table 9. The variance analysis results of blink frequency of watching different types of TV

	SS	df	MS	F	Sig.
TV types	0.176	3	0.059	0.830	0.483
Time	0.265	1	0.265	20.527	0.000
TV types *time	0.005	3	0.002	0.120	0.948

The Average Saccade Speed Changes of Viewing the Same Scenery Video Before and After Seeing the Film with Different Types of TV. The average saccade speed data of viewing the same scenery video before and after seeing the film with different TVs was analyzed by the repeated measurement ANOVA. The results showed that the time effect of saccade average speed among the four types of TV was significant ($F = 32.878$, $p < 0.001$). The post hoc test showed that the saccade speed of viewing the same scenery video after watching the film with 2D, polarized 3D, the naked 3D and switched 3D was significantly greater than that of before watching the film (ps < 0.05), see Table 10.

Table 10. The variance analysis results of average saccade speed of watching different types of TV

	SS	df	MS	F	Sig.
TV types	2993.53	3	997.84	0.735	0.535
Time	5344.95	1	5344.95	32.878	0.000
TV types *time	257.56	3	85.85	0.528	0.665

The Blink Time Changes of Viewing the Same Scenery Video Before and After Seeing the Film with Different Types of TV. The blink time data of viewing the same scenery video before and after seeing the film with different TVs was analyzed by the repeated measurement ANOVA. The results showed that the time effect of total blink time was significant ($F = 25.507$, $p < 0.001$). The results showed that the blink time of the four types of television during watching the movie was increased, the total blink time of viewing the same scenery video before and after watching 2D TV had greatly difference ($p = 0.057$), the degree of fatigue was the most light. See Table 11.

Table 11. The variance analysis results of total blink time of watching different types of TV

	SS	df	MS	F	Sig.
TV types	890417248.90	3	296805749.63	0.872	0.461
Time	1489926846.25	1	1489926846.25	25.507	0.000
TV types *time	110786433.96	3	36928811.32	0.632	0.597

The Saccade Count Changes of Viewing the Same Scenery Video Before and After Seeing the Film with Different Types of TV. The saccade count data of viewing the same scenery video before and after seeing the film with different TVs was analyzed by the repeated measurement ANOVA. The results showed that the saccade count before and after watching movies with four types of TV was significantly different ($F = 15.262$, $p < 0.001$). The post hoc test showed that in addition to the 2D effect, the saccade times of viewing the same scenery video after watching movies polarized 3D, naked 3D and switched 3D were significantly less than those of viewing the same scenery video before watching the film ($ps < 0.05$) (Table 12).

Table 12. The variance analysis results of saccade count of watching different types of TV

	SS	df	MS	F	Sig.
TV types	140177.47	3	46725.82	0.899	0.448
Time	174122.25	1	174122.25	15.262	0.000
TV types *time	7562.29	3	2520.76	0.221	0.881

The Saccade Frequency Changes of Viewing the Same Scenery Video Before and After Seeing the Film with Different Types of TV. The saccade frequency data of viewing the same scenery video before and after seeing the film with different TVs was analyzed by the repeated measurement ANOVA. The results showed that the time effect of the saccade frequency was significant ($F = 13.206$, $p < 0.01$). Afterwards, the post hoc test showed that saccade frequency of viewing the same scenery video after watching the film with 3D polarization and naked 3D was significantly less than that of before watching the film ($p < 0.05$), the saccade frequency of viewing the same scenery video with switched 3D before and after watching the movie had critical significant difference ($p = 0.075$) (Table 13).

Table 13. The variance analysis results of saccade frequency of watching different types of TV

	SS	df	MS	F	Sig.
TV types	1.75	3	0.58	0.956	0.420
Time	1.81	1	1.81	13.207	0.001
TV types *time	0.11	3	0.04	0.268	0.848

3.3 Discussion

The subjective evaluation results showed that there was no significant difference between the 4 conditions in terms of comfort and satisfaction. In terms of fatigue, naked 3D was the most serious, followed by polarized 3D, switched 3D and 2D. The results showed that the degree of comfort and satisfaction was difficult to be distinguished by subjective evaluation. But the fatigue could be quantified by subjective evaluation. The fatigue of different TVs watching movies was mainly manifested in eyes dryness, eyes strain, tearing, burning, headache and double vision. The difference was not the same pattern. Naked 3D in dryness, tearing, strain, burning and double vision is significantly greater than the switched 3D. The dryness and blur of naked 3D was significantly greater than polarized 3D. The headache and dryness by Polarized 3D was significantly greater than the switched 3D. The degree of headache caused by polarized 3D was significantly higher than that of switched 3D. Therefore, naked 3D was more likely to lead to the user's tearing, dryness, strain, burning, blur and double vision, polarized 3D was more likely to cause a headache. Because the other parameters of the sample were not strictly controlled, these differences were influenced by many factors of the sample itself. In this study, the technique of naked 3D sample was not mature, the difference between polarized 3D and switched 3D was not significant in many aspects. Therefore, the advantages and disadvantages of polarized 3D and switched 3D could not be determined.

Previous studies showed that the extending of blink duration reflects the excitability of the nervous system decreased, physiological process of nervous system inactivation or slow down. The faster of saccade frequency may indicate that the information processing was difficult. The study found that, with the increase of watching time, blink times, blink frequency and total blink time all showed the overall upward trend, the data of blink times, blink frequency and total blink time after watching movies was significantly higher than that of watching movies before, indicating that these indicators can be characterized as fatigue. Under the four conditions, the blink frequency and blink times showed a trend of decreasing and then increasing. It is probably because the video has not been seen before the subject, so that the subjects focused attention by the impact of the story, leading to blink frequency and the number of blinks first showed a downward trend. With the extension of time, the increase of information acceptance caused the increase of visual fatigue, which led to the increase of blink frequency and blink time and had visual fatigue. This was consistent with the Zhang, stern, Lee, Sakamoto, kim [8–11], etc., which reflect the visual fatigue caused by watching different VDT by blink frequency and blink time. Blink frequency was associated with the individual fatigue degree. Blink frequency decreased under the condition of high concentration. Prolonging blink duration reflects the decreasing excitability of the nervous system, physiological process of nervous system inactivation or slow down.

Saccade parameters of eye movements revealed the mental and physical fatigue of subjects. When using the four kinds of TV to watch the movie, the saccade indexes of subjects increase. Watching 3D showed a higher frequency of saccades, greater saccade amplitude, shorter saccade time and faster saccadic speed. This might imply that the subjects were more alert when watching 3D videos because they need to deal with more visual information. Along with the prolonging of viewing time, saccade parameters decreased in end-stage of watching 3D videos, which shows the input of more information to the brain leads to decrease alertness. Previous studies showed that longer saccade time, bigger saccade angle and greater distance of the eye movement could make information processing more difficult and cause more serious visual fatigue. The saccade speed reflected the excitability level of the physiological system. The study found that the saccade average time, saccade peak, average saccade angle, total saccade angle, average saccade speed, number of saccade and saccade frequency of viewing the same scenery video were significantly different before and after watching the films. The number of saccade and saccade frequency decreased significantly and the other saccade indexes significantly increased. These indicators could be characterized as fatigue phenomenon.

The study found that the eye movement indexes like the average saccade time, saccade peak, saccade average angle, total saccade angle and saccade amplitude between different types of TV had significant differences. The differences between the four kinds of TV mainly manifested that the average saccade time, saccade peak time, saccade average angle and total saccade angle of polarized 3D were significantly greater than that of 2D and switched 3D. The saccade average angle of naked 3D was significantly greater than that of 2D. The results of this study showed that saccade time and distance of the users watching video would be affected by the principle of polarized 3D television. Saccade amplitude of switched 3D was significantly greater than that of the other three kinds of TV. This might indicate that the principle of switched 3D was more sensitive to the saccade amplitude. Saccade amplitude of 2D TV was larger than that of the other two types TV, indicating the saccade amplitude could distinguish viewing effect of various televisions. This was consistent with Zou's [2] visual fatigue study. This might indicate that the average saccade time, saccade duration peak, average saccade angles, total saccade angles and saccade amplitude indicators might be sensitive to the differences of different types of TV.

4 Conclusion

The study found that, with the increase of viewing time, the degree of fatigue that subjects feel had increased. The data of the blink times, blink frequency, saccade average speed, blink time, the average saccade time, saccade peak, saccade average angle and total saccade angle was significantly higher than that of viewing the secrecy video before watching movies, which has an upward trend. The data of the saccade number and saccade frequency was significantly lower than that of before watching movies, showing a downward trend. It indicates that these eye movement indicators may reflect the fatigue of eyes, providing more evidence for the study of visual fatigue.

On the visual fatigue evaluation of different types of display TV, in the indexes of average saccade time, saccade peak, average saccade angle and total saccade angle, that of polarized 3D was significantly higher than that of other 2D and 3D television switched TV. It may indicate the principle of 3D polarization television may affect the users' saccade time and distance of watching video. The saccade amplitude of switched 3D TV was significantly larger than that of other three conditions, which may indicate switched 3D TV had a greater impact on the saccade amplitude. From the evaluation method, eye tracking analysis method can be used as a reliable method of visual fatigue evaluation. But for display terminals with different production principles, the sensitive indicators will be different. As for the subjective evaluation method, it is difficult to distinguish the comfort and satisfaction of the monitor by subjective evaluation. But the fatigue could be quantified by subjective evaluation.

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