Effect of Red Blue 3D Videos on Visual Fatigue

Guilei Sun[1](✉), Yun Lin[1], Linghua Ran[2], and Yanhua Meng[1]

[1] School of Safety Engineering, China University of Labor Relations, Beijing 100048, China
sunguilei@culr.edu.cn
[2] China Standardization Institute, Beijing 100191, China

Abstract. In order to analyze the visual fatigue caused by Red Blue 3D videos, a combination of subjective questionnaire survey and objective experimental data was adopted. Questionnaire investigation for visual fatigue and eye movement data were collected in the process of viewing with human machine environment synchronous platform. Three segments of 0–15 min, 15–30 min and 30–45 min were intercepted, and the normality of physiological signal data was detected by SPSS 23.0. Kruskal-Wallis test and multiple tests were used to compare the differences between the groups. The results show that the fixation time of eyes on the screen decreases and the number of blinks increases gradually with the increase of watching time. And the pupil diameter gradually decreases while the right pupil diameter is larger than the left one. The subjects are more comfortable with blue lens than red one.

Keywords: Red and blue 3D display · Physiological signals · Multiple test · Pupil diameter · Left pupil

1 Introduction

With the improvement of living standards, 3D display has become a mature and common technology. When watching movies, the left and right eye images are completely separated. In order to maintain the fusion function, the brain is always in a state of high tension, which leads to the appearance of visual fatigue [1]. Therefore, 3D display brings people a real visual experience, followed by the problem of visual fatigue. Color difference 3D technology, combined with the use of passive red-blue (or red-green, red-cyan) filter color 3D glasses [2]. The use of 3D glasses ensures that the viewer's two eyes can see different images, which makes the viewer feel immersive. However, a problem of visual fatigue appears.

At present, some scholars have carried out research on fatigue on 3D display. Sun [3] researched respiratory signals for visual fatigue caused by 3D display. Wang et al. [4] selected the common double parallax 3D stereo image as the research object. Chen et al. [5] used EEG and VEP in the study of VDT visual fatigue measurement, in which the change of EEG reflected fatigue closer to mental fatigue, but the VEP did not change significantly. The eigenvalues of blink frequency and pupil regulation were also used. Li [6], Sakamoto [7], Kim [8] and some other scholars reflected the degree of visual fatigue caused by watching different VDT by blinking frequency, which showed that

D. Harris and W.-C. Li (Eds.): HCII 2021, LNAI 12767, pp. 427–437, 2021.
https://doi.org/10.1007/978-3-030-77932-0_33

the blinking frequency increased with the extension of time, while Wang [9] and Cai [10] used pulse signal in the study of VDT visual fatigue, which shows the pulse value decreased significantly with the deepening of visual fatigue.

In this research, the relationship of Red Blue 3D display and visual fatigue were studied and the questionnaire investigation, the fixation time, blinking times and pupil diameter were used to analyze characteristic of the subjects.

2 Experiments

2.1 Experiment Equipment

Tobii X2-30 screen-based eye tracker; Workstation (NVIDIA Jetson Xavier NX Developer Kitrefresh rate 120 Hz); Display (AOC, 23.8 in., 165 Hz/1 ms/2k); Red Blue 3D glasses (left red and right blue); Flash fusion frequency meter (BD-11–118, red light as the test light source, the background light intensity is 1, the light black ratio is 1:1, and the bright light intensity is 1).

2.2 Subject Selection

30 subjects were selected, including 15 males and 15 females, with an average age of 21.8 years. Before the experiment, the subjects were reminded to get enough sleep, and during the experiment, the subjects were voluntary and had no other emotional influence.

The informed consent was signed before the experiment and the experiment was completed according to the instructions.

2.3 Experimental Design

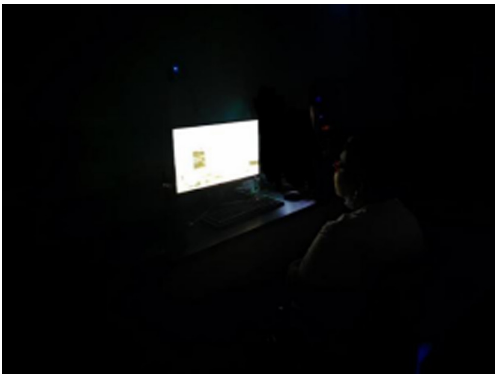

Fig. 1. Scene of the experiment

The subjects were given a questionnaire survey for visual fatigue before watching the video, and the flash fusion frequency meter was used to measure the critical fusion frequency (CFF) in order to obtaining the baseline data. Tobii x2–30 was used to collect the eye movement data during the watching process which lasting for 45 min. After watching the video, questionnaire survey and flash fusion frequency measurement were conducted again. The experiment was carried out in the dark which was shown in Fig. 1.

3 Data Processing

3.1 CFF Analysis

The mean value, median value and standard deviation of CFF before and after watching the video tested by flash fusion frequency meter are compared, as shown in Table 1.

Table 1. Descriptive statistics of CFF

Group		Mean	Median	Standard Deviation
Before video watching	Flash frequency	26.763	26.700	4.132
	Fusion frequency	28.280	28.400	3.493
After video watching	Flash frequency	26.517	27.600	3.769
	Fusion frequency	28.190	28.150	3.388

The bigger the CFF, the higher level of the brain consciousness. And when the human body is tired, the CFF is low [11]. It can be seen from the data in Table 1 that the three descriptive statistical data (mean, median and standard deviation) after watching are less than those before watching, which indicate that the visual fatigue after watching is significantly higher than before watching.

In order to analyze these four sets of data, Skapiro-Wilk method is used for normality test, and the test results are shown in Table 2.

Table 2. Normality test of CFF

Group		P-value
Before watching video	Flash frequency	0.826
	Fusion frequency	0.904
After watching video	Flash frequency	0.027
	Fusion frequency	0.481

It can be seen from Table 2, before watching the video, the flash frequency value and fusion frequency value are greater than 0.05, which conforms to the normal distribution. While p-value of fusion frequency is less 0.05 after watching the video and it does not conform to the normal distribution. The fusion value after watching the video is greater than 0.05, which also conforms to the normal distribution. At this condition, the four groups of flash fusion frequency data do not meet the normal distribution, then Kruskal-Wallis test was used.

Table 3. Kruskal Wallis test results of flash frequencies and fusion frequencies

Chi-square	5.1727
Degrees of freedom	3
Pr > Chi-square	0.1596

It can be seen from Table 3 that the chi square value is 5.1727 and $P = 0.1596 > 0.05$, showing that there is no significant difference in flash fusion before and after watching, that is to say, it is not effective to use CFF data to describe visual fatigue.

3.2 Questionnaire Analysis

Blehm [12] has studied that people's visual fatigue includes ten items, such as blurred vision, sore eyes, tingling eyes, drowsiness, dizziness, ghosting, tears, dry eyes, headache and vomiting. The reliability coefficient of the questionnaire is tested, and the result is 0.761, which is greater than 0.7, indicating that the subjective reliability quality of the questionnaire fatigue is very suitable for the experiment. Based on the reliability of the questionnaire, the fatigue of the subjects before and after watching the video was investigated. Each subjective problem was described in five different degrees. The scoring standard is shown in Table 4.

Table 4. Standard of point score

Score	Fatigue degree
0	Not at all
1	A little
2	Feel it
3	It's a little bit strong
4	Feel strong

The statistics for the scores of the questionnaire before and after watching the video were done and shown in Table 5.

It can be seen from Table 5 that the score after watching is significantly higher than that before watching. That is to say, the scores after watching are increased compared with that before watching in ten aspects, and it is more obvious in four aspects: blurred vision, sore eyes, drowsiness and ghosting. Moreover, drowsiness is the most obvious one. These two sets of data are analyzed, and the results is shown in Table 6.

Table 5. Scores for questionnaire before and after watching video

Content	Before watching video	After watching video
Blurred vision	33	46
Sore eyes	29	44
Tingling eyes	22	28
Drowsiness	30	72
Dizziness	24	34
Ghosting	31	40
Tears	22	25
Dry eyes	31	38
Headache	22	33
Vomiting	21	22

Table 6. Analysis of subjective questionnaire data before and after watching the video

Groups	Mean	95% confidence interval of the difference		Standard deviation	95% confidence interval of the difference	
		Lower	Upper		Lower	Upper
Before watching video	36.500	33.140	39.860	4.696	3.230	8.574
After watching video	49.200	38.666	59.734	14.726	10.129	26.883

Table 6 shows that the mean value and visual fatigue store are within the 95% confidence interval, and the mean value and standard error mean after the video watching are significantly greater than those before video watching. Then the two groups of data were tested for normality, the results showed that the p-value before and after viewing were greater than 0.05, in line with the normal distribution. Analysis of variance (ANOVA) was used on the data, and the results are shown in Table 7.

Table 7. ANOVA of data before and after watching video

Method	Numerator degrees of freedom	Denominator degrees of freedom	F-value	Pr > F
F-test	9	9	9.83	0.002

Table 7 shows $Pr > F = 0.002 < 0.05$. That is, the variances are homogeneity. T-test is carried out and the result is shown in Table 8. It can be seen that p-values are all less than 0.05 whether the variances are homogeneity or not. If the hypothesis is established, it means that the fatigue test scores by questionnaire before and after watching the video are statistically significant.

Table 8. T test results

Method	Variance	Degrees of freedom	T-value	P-value
Pooled	Equal	18	−2.60	0.018
Satterthwaite	Not equal	10.812	−2.60	0.025

3.3 Eye Movement Data Analysis

Due to the difference between the left and right lenses of Red Blue glasses, the eye movement test data were divided into three periods, 0–15 min, 15–30 min and 30–45 min, in order to analyze the fatigue and changes of the left and right eyes in different time periods.

Proportion of Fixation Time. Descriptive statistics of the total fixation time of the three periods are given, as shown in Table 9.

Table 9. Descriptive statistics of fixation time proportion

Time period	Mean	Standard deviation	Median	Variance	Range
0–15 min	0.482	0.188	0.511	0.036	0.741
15–30 min	0.423	0.188	0.511	0.029	0.741
30–45 min	0.302	0.147	0.270	0.022	0.526

As shown in Table 9, the average value of the data of three groups decrease gradually, indicating that the proportion of total fixation time in the total time shows a downward trend, and the total fixation time becomes less and less with the increase of viewing time. It also indicates the fatigue performance of the subjects are increasing. Among the data of three groups, the mean, standard error, median, variance and range are the smallest in the 30–45 min viewing time, which indicates that the dispersion degree of this group is the smallest. In other words, the total fixation time of 30 subjects in the period of 30–45 min viewing time has different decline, and tends to a certain value.

Skapiro Wilk test was performed on the data of the three groups. It showed that the p-values of fixation time data were all greater than 0.05, which conformed to the normal distribution. The data of three groups were analyzed by ANOVA, as shown in Table 10.

Table 10. ANOVA of the fixation time

Source	Degrees of freedom	Quadratic sum	Mean square	F-value	P-value
Fixation Time	2	0.457	0.229	7.86	0.0007

In Table 10, 0.05 is taken as the test level of hypothesis test, to the three groups of data, $p < 0.05$. It indicates statistical significance. $F = 7.86$, indicating that there are differences among the data of three groups. To sum up, the viewing and fixation time of the three time periods were different and statistically significant. It shows that with the increase of viewing time, the degree of visual fatigue increases, and the fixation time on the screen decreases gradually.

Eye Blinks. Through the analysis of the number of eye blinks recorded by the eye tracker when watching video, the number of blinks in three periods are carried out, as shown in Table 11.

Table 11. Descriptive statistics of blink times

Time period	Mean	Standard Deviation	Median	Variance	Range
0–15 min	291.50	165.00	276.00	15643	477.00
15–30 min	305.83	172.00	287.00	20407	574.00
30–45 min	316.70	181.00	265.00	14376	433.00

It can be seen from Table 11 that the mean value and inter quartile range increased with the increase of watching time. The data of the period 30–45 min is the maximum value in three periods. It indicates that the period of 30–45 min is the most discrete in the data of three periods, and the increase of blinking times is the most significant. That is to say, with the increase of viewing time, the subjects have to relieve the fatigue caused by watching video through the increase of blinking times.

The data of three time periods were tested for normality, and the results are shown in Table 12. In the period of 30–45 min, it does not follow the normal distribution. And then Kruskal Wallis method of multiple rank sum test was used. The results are shown in Table 13.

It can be seen from Table 13 that the difference in the total number of blinks among the three groups is statistically significant (Chi-square = 0.7032, $P = 0.0036 < 0.05$). From Fig. 2, it can be seen that 30–45 min is the most significant data. It indicates that the visual fatigue and the blink times increase with the increase of viewing time while the medium has a little decrease.

Pupil Diameter of Left and Right Eyes. To analyze the data of left and right pupils, the corresponding relationship between visual fatigue and pupil diameter, the descriptive statistics of the pupil diameters in three time periods are shown in Table 14.

Table 12. Skapiro Wilk test

Time period	Statistic		P-value	
0–15 min	W	0.958	Pr < W	0.270
15–30 min	W	0.952	Pr < W	0.189
30–45 min	W	0.915	Pr < W	0.020

Table 13. Kruskal-Wallis test

Chi-square	0.703
Degrees of freedom	2
Pr > Chi-square	0.004

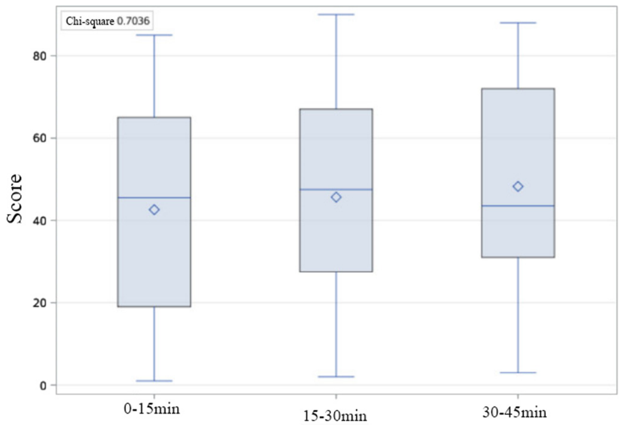

Fig. 2. Kruskal-Wallis test result

It can be seen from Table 14 that the mean value and the pupil diameter of both eyes decreases with the increase of watching time, which indicates that the pupil diameter gradually decreases with the increase of eye fatigue. The mean, standard deviation, variance and interquartile distance of pupil diameter in the right eye were greater than those in the left eye in the three periods of 0–15 min, 15–30 min and 30–45 min. It was assumed that the fatigue degree of the right eye was lower than that of the left eye. Then the normality of pupil data of left and right eyes in three periods is tested, as shown in Table 15.

It can be seen from Table 15 that the p-value of the left pupil is less than 0.05 at the period of 0–15 min, which does not conform to the normal distribution. The P values of the other five groups are greater than 0.05. Therefore, the average pupil diameter data of

Table 14. Pupil diameters of left and right eyes in three period

Descriptive statistics	Left eye			Right eye		
	0–15 min	15–30 min	30–45 min	0–15 min	15–30 min	30–45 min
Mean	4.636	4.317	4.032	4.650	4.347	4.058
Std	0.819	0.941	0.964	0.898	0.977	0.978
Standard deviation	0.671	0.885	0.928	0.807	0.954	0.957
Range	3.530	3.900	3.740	3.570	4.400	3.440
Inter quartile range	0.800	1.240	1.510	0.845	1.470	1.660

Table 15. Normality test for two pupils at different period

P-value	Time/min		
	0–15	15–30	30–45
Left pupil	0.038	0.563	0.467
Right pupil	0.210	0.218	0.420

the six groups do not meet the normal distribution. Kruskal Wallis test is used and the results are shown in Fig. 3 and Table 16.

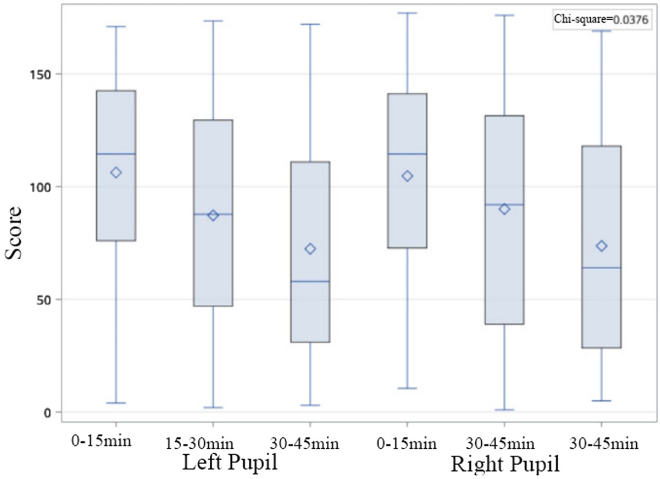

Fig. 3. Kruskal-Wallis test result

In Fig. 3, the scores of left and right eyes are all the highest in the period of 0–15 min, the data is the most significant and the scores of right eye are higher than that the left. Then the previous preliminary hypothesis is verified, the fatigue degree of the right eye is lower than the left, that is to say, under the same stimulation conditions, blue 3D lens in the Red Blue glasses is more comfortable than the red lens. And it are produce less visual fatigue.

Table 16 shows that the average pupil diameter of the six groups is 11.802 and $p = 0.0376 < 0.05$. It indicates that when the visual fatigue is produced, the pupil decreases, and the left and the right eyes are not synchronized. With the external stimulation, the degree of visual fatigue will be different, so the size of the pupil also has different performance.

Table 16. Kruskal-Wallis test

Chi-square	11.802
Degrees of freedom	5
Pr > Chi-square	0.0376

4 Conclusions

1) According to the questionnaire survey analysis, the subjects had obvious feeling of visual fatigue after watching video. Blurred vision, sore eyes, drowsiness and ghosting were more obvious, among which drowsiness was the most obvious one.
2) The visual fatigue and the blink times (mean and quartile) increase with the increase of watching time while the medium has a little decrease.
3) With the increase of viewing time, visual fatigue occurs, the number of blinks increases, the fixation time on the screen, the pupil diameter of the left and the right eyes decrease, and the pupil diameter of the left and right eyes is not synchronized with Red Blue 3D glasses.
4) Under the same conditions, the right eye using the blue lens in 3D glasses is more comfortable than the left eye. That is, the blue lens results in lower visual fatigue than the red one.

Acknowledgments. The presented work has been supported by General project of China University of Labor Relations (21XYJS012) and National key R & D projects (2017YFF0206604).

References

1. Wang, J.H., et al.: 3D Visual Fatigue of Personal Computer Display. Acta Sci. Natur. Univ. Sunyatseni **52**(05), 1–5 (2013)

2. Xu, P.: Analysis on the development and application of 3D TV technology. China Digit. Cable TV, (05), 584–586 (2015)
3. Sun, G.: Research on respiratory signals for visual fatigue caused by 3D display. In: Long, S., Dhillon, B.S. (eds.) Man-Machine-Environment System Engineering: Proceedings of the 20th International Conference on MMESE, pp. 663–672. Springer, Singapore (2020). https://doi.org/10.1007/978-981-15-6978-4_76
4. Wang, F.J.. Research on visual fatigue of 3D video. Beijing University of Posts and Telecommunications (2014)
5. Chen, C.M., Wang, H., Zhou, J., Du, Z.Q.: Review of VDT visual fatigue and its measurement methods. Chin. J. Ergon. **19**(02), 92–95 (2013)
6. Lee, E.C., Park, K.R., Whang, M., Min, K.: Measuring the degree of eyestrain caused by watching LCD and PDP devices. Int. J. Ind. Ergon. **39**(5), 798–806 (2009)
7. Sakamoto, K., Aoyama, S., Asahara, S., Yamashita, K., Okada, A.: Measurement of visual fatigue for large-sized TVs in a home viewing environment. In: The 13th IEEE International Symposium on Consumer Electronics, pp. 738–742 (2009)
8. Kim, D., Choi, S., Park, S., Sohn, K.: Stereoscopic visual fatigue measurement based on fusional response curve and eye blinks. In: Digital Signal Processing (DSP), pp. 1–6 (2011)
9. Wang, Y.T.: Research on VDT visual fatigue state recognition based on real-time pulse signal processing. Lanzhou University of Technology, Gan Su (2010)
10. Cai, H.Y.: Research on VDT visual fatigue based on pulse signal. Lanzhou University of Technology, Gan Su (2012)
11. Hsu, B.W., Wang, M.J.J.: Visual fatigue evaluation of PDP, LCD and CRT TV. In: Proceedings of 17th World Congress on Ergonomics (2009)
12. Blehm, C., et al.: Computer vision syndrome: a review. Surv. Ophthalmol. **50**(3), 253–262 (2005)