The Effect of Exercise on Visual Fatigue Based on Eye Movement

Guilei Sun[✉], Yanhua Meng, and Luyao Wang

School of Safety Engineering, China University of Labor Relations, Beijing 100048, China
sunguilei@culr.edu.cn

Abstract. The wide application of visualization equipment makes people's visual fatigue more and more serious. Correspondingly, the recovery of visual fatigue is a very important topic in the current society. An experiment was carried on the recovery of visual fatigue. 30 subjects in a state of visual fatigue were measured by Tobii Glasses X-30 for 5 min exercise or overlooking. Questionnaire was used to obtain subjects' subjective sensation of visual fatigue. The results showed that both table tennis exercise and overlooking had a good effect on visual fatigue recovery. Questionnaire indicated that table tennis exercise had a little better recovery effect on the visual fatigue than overlooking far away because table tennis exercise caused much more eye movement. Overlooking far away focused more on the rest of eyes so that the physiological parameters caused by visual fatigue can be easy recovered.

Keywords: Eye movement · Number of blinks · Pupil diameter · Visual fatigue recovery · Overlooking

1 Introduction

The problem of visual fatigue has been widely concerned around the world. If visual fatigue can't recover for a long time, it will cause serious adverse consequences for the body. Many kinds of visual fatigue analysis were researched, and eye movement analysis was the more commonly used objective analysis method. Through the analysis of the eye movement data, it can be judged and summarized the visual responses and laws of the subjects in the experiment, thus revealing the basic cognitive processes, comprehension processes and visual processing processes [1]. Through the study of driving simulation with eye tracker, Wang [2] found that the hierarchical ordered discrete selection model can realize the consideration of individual differences and enable the driver to accurately identify different fatigue levels. Chen et al. [3] found that the physiological data of human body is correlated with the degree of visual fatigue, the degree of fatigue is positively correlated with blood oxygen saturation and negatively correlated with heart rate. Zhao [4] showed that the combined classification of ECG and pulse can accurately measure visual fatigue. Shi [5] concluded that there is a significant positive correlation between the degree of visual fatigue and pupil diameter through the fatigue eye movement experiment. Zhang et al. [6] obtained through the eye tracker experiment that when

watching 3D videos, the blink frequency was reduced compared with ordinary videos, and the speed, frequency and amplitude of saccade were improved. And after watching for 40 min, it will gradually approach the degree of watching ordinary videos. Sun et al. [7, 8] used eye tracker, questionnaire survey and flash fusion instrument to study the fatigue caused by the 3D display, the result showed that the pupil diameter of the left and right eyes is not synchronized with Red Blue 3D glasses and 3D visual fatigue lead to a decrease in respiratory frequency.

At present, more and more scholars have studied the visual fatigue based on the relevant parameters obtained by the eye tracker, such as eye blink, gaze, pupil diameter and saccade. However, there is little research on visual fatigue recovery, especially on recovery method.

2 Experiments

2.1 Subjects

30 college students without eye diseases and with corrected vision of 1.0 or above were selected, including 15 males and 15 females, with an average age of 21.2 years old. Before the experiment, all subjects signed informed consent.

2.2 Design of the Subjective Fatigue Survey Questionnaire

The purpose of the questionnaire was to obtain the subjective feelings of the subjects before and after the experiment. The quantification of visual fatigue is divided into 10 grades in the questionnaire, ranging from 1 level to 10 level, in which 1 means completely no fatigue and 10 means severe fatigue. Fatigue level was determined by the subjects themselves before and after the experiment.

2.3 Experimental Methods

30 subjects were in a visual fatigue state (above 5 points) through watching 60 min VR video. Then, the subjects were divided into two groups: one for 5-min overlooking (named group of overlooking the distance, GOD) and the other for 5 min playing table tennis (named group of table tennis, GTT). The real-time eye movement parameters of the subjects were measured through TOBII GLASSES X 30, and the subjective feelings of visual fatigue were obtained through questionnaire.

3 Data Analysis

3.1 Questionnaire Analysis

Apparently improved means equal to, or more than 3 levels reduced while a certain degree improvement is less than 3 levels. As shown in Table 1, the results of the questionnaire showed that the number of subjects significantly improved in the GTT is more than GOD, which means that the subjects had better subjective feelings after the exercise in reducing visual fatigue than overlooking far away. The reason is that table tennis exercise caused much more eye movement which alleviate visual fatigue.

Table 1. Results of the survey questionnaire

	GTT	GOD
All subjects	15	15
Number of apparently improved	9	0
Number of a certain degree improvement	3	12
Number of not obvious improvement	3	3

3.2   Analysis of Eye Movement Data

3.2.1   Eye Blink Times
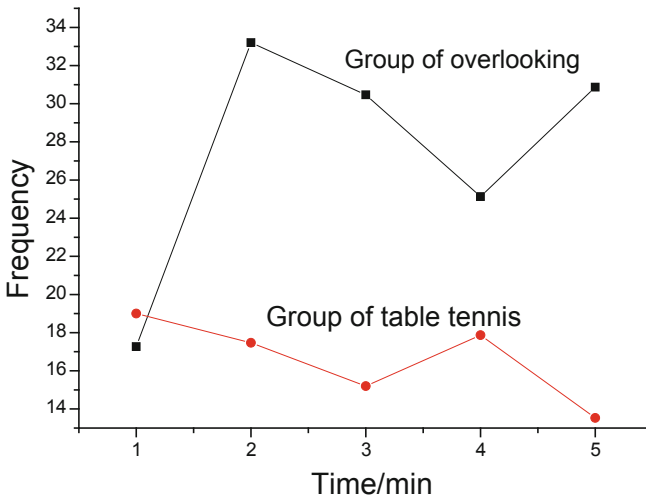
Fig. 1. Descriptive statistics of blink times

Differential analysis indicates that the eye blink times between GTT and GOD showed no significant difference, therefore, the data of two groups can be used for analyzing. Descriptive statistics of the eye blink times for GTT and GOD in the first minute (1st min), the second minute (2nd min), the third minute (3rd min), the fourth minute (4th min) and the fifth minute (5th min) are shown in Fig. 1.

The average blink times of GTT showed a downward trend while the blink number of group of overlooking increased significantly in the 5 min experiment. However, GTT were less than the blink times at the beginning and GOD were higher than the beginning. Further, the data were tested for normality. Since the sample size was 15 which was a small sample test, the Shapiro-Wilke test was selected, and the test results are shown in Table 2.

Table 2. Blink times Shapiro-Wilke normality test

	Mean value of GTT blink times		Mean value of GOD blink times	
	Statistics	Sig.	Statistics	Sig.
1st min	0.891	0.069	0.879	0.046
2nd min	0.881	0.049	0.880	0.048
3rd min	0.894	0.077	0.946	0.466
4th min	0.916	0.167	0.799	0.004
5th min	0.888	0.062	0.840	0.012

The results showed that GTT was less than 0.05 only at the 2nd min, which did not meet the normal distribution, the Wilkerson signed-rank test was required in non-parametric variables, and the paired t test was used for the remaining groups. The Shapiro-Wilke test indicates that the 1st min, the 2nd min, the 4th min and the 5th min were less than 0.05, which does not conform to the normal distribution rule. Therefore, Wilcokson signed rank test should be used for the difference analysis of the blinking times. The test results are show in Table 3 (Table 4).

Table 3. Test of difference for GTT in eyeblink times

| min-min	Average value	Standard deviation	Sig.	Method of calibration
2nd-1st	2.937	20.134	0.572	Shapiro-Wilke test
3rd-1st	3.800	20.288	0.480	Paired t test
4th-1st	1.133	19.430	0.825	Paired t test
5th-1st	5.467	20.266	0.314	Paired t test

Table 4. Test of difference for GOD in eyeblink times.

min-min	2nd-1st	3rd-1st	4th-1st	5th-1st
Z	−1.875	−2.074	−0.880	−2.160
Asymptotic significance (double-tail)	0.061	0.038	0.379	0.031

The test results showed that the blink times of GOD at the 3rd and the 5th min was statistically different compared with the 1st min data, and the number of blinking would increase in subjects. Although the number of blink times showed a downward trend, the change of blink times still did not show a statistical difference, and the GTT did not show a significant difference in the number of blink times in visual fatigue.

The number of blinking in GTT is on a downward trend and group of overlooking shows an upward trend, which may be caused by the subjects who need to focus on table

tennis, so the number of blinking is less. However, in the group of overlooking far away, the visual fatigue gradually recovers, the eyes rest and the eye muscles are fully relaxed.

Differential Analysis of the Pupil Diameter. Descriptive statistics of mean pupil diameter at each minute for GTT and GOD are shown in Fig. 2.
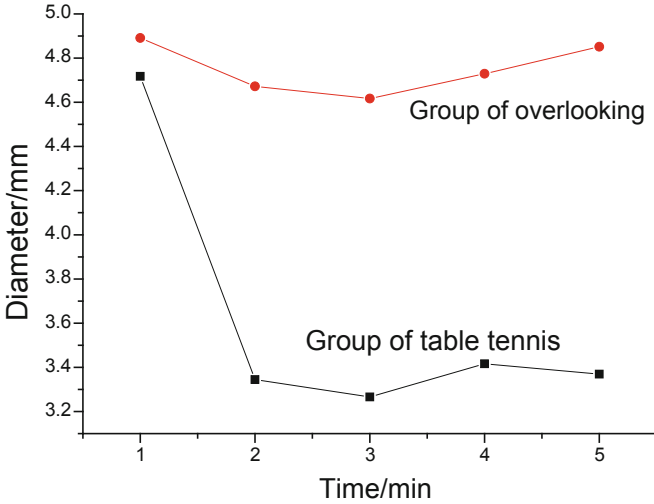
Fig. 2. Descriptive statistics of mean pupil diameter

It can be seen from the description statistical results that the subjects had only a slight decrease in mean pupil diameter of GOD, while the mean pupil diameter of the GTT had a significant decrease. The data were normally tested, and the test results are shown in Table 5.

Table 5. Mean pupil diameter by Shapiro-Wilke normality test.

	GTT		GOD	
	Statistics	Sig.	Statistics	Sig.
1st min	0.930	0.270	0.964	0.764
2nd min	0.970	0.864	0.956	0.622
3rd min	0.934	0.318	0.944	0.434
4th min	0.938	0.359	0.913	0.149
5th min	0.932	0.289	0.903	0.106

Shapiro-Wilke normality test was used for the mean pupil diameters of GTT and GOD. The results of sig. were all seems greater than 0.05. With paired t-test, the results were shown in Table 6 and Table 7.

Table 6. Difference test of in mean pupil diameter for GTT.

min-min	Average value	Standard deviation	Standard error mean value	Difference value: 95% confidence interval		t	Sig.
				Lower limit	Superior limit		
2nd-1st	0.21933	0.80650	0.20824	−0.22729	0.66596	1.053	0.310
3rd-1st	0.27467	0.91899	0.23728	−0.23425	0.78359	1.158	0.266
4th-1st	0.16200	10.00435	0.25932	−0.39419	0.71819	0.625	0.542
5th-1st	0.04000	0.94892	0.24501	−0.48550	0.56550	0.163	0.873

The difference test results showed that the slight drop did not have significant difference compared with the 1st min, and the mean pupil diameter could change in subjects with visual fatigue during exercise.

The description of the statistical results showed that the 15 subjects of GOD had a significant decrease in mean pupil diameter during the 2nd min to the 5th min compared to the 1st min, and whether this difference was statistically significant or not, differential analysis is required.

Table 7. Group of overlooking test of difference in mean pupil diameter.

min-min	Average value	Standard deviation	Standard error mean value	Difference value: 95% confidence interval		t	Conspicuousness
				Lower limit	Superior limit		
2nd-1st	1.37267	0.93211	0.24067	0.85648	1.88885	5.704	0.000
3rd-1st	1.45133	0.97660	0.25216	0.91051	1.99215	5.756	0.000
4th-1st	1.30133	1.01707	0.26261	0.73810	1.86457	4.955	0.000
5th-1st	1.34800	1.05006	0.27112	0.76649	1.92951	4.972	0.000

The difference test results showed that the mean pupil diameter of each minute decreased significantly compared with that of the 1st min. This conclusion was statistically significant, indicating that the mean pupil diameter of the visual fatigue person could decrease significantly in the distance, which was because the eyes had a full rest when looking in the distance.

4   Conclusions

1. There was a trend towards decreases in the group of playing table tennis while there was a significantly increase in the group of overlooking the distance.

2. Overlooking the distance can make the visual fatigue of the eye muscles to resume the active state, has a positive impact on the recovery of visual fatigue.
3. The pupil diameter playing the table tennis group becomes smaller because of the fixation while overlooking the distance does not need fixation.
4. The questionnaire survey shows that eye movement will make the subjects have a better subjective feeling.

References

1. Morita, K., Maeda, N., Kawaoka, T., et al.: Effects of the time interval between clamping and linear stapling for resection of porcine small intestine. Surg. Endosc. **22**(3), 750–756 (2008)
2. Wang, X., Li, F.: Eye Indicators and drowsy level analysis based on driving simulator. J. Tongji Univ. (Nat. Scie. Ed.), **43**(02), 226–231 + 264 (2015)
3. Chen, Y., Tu, Y., Wang, L., Shen, L., He, Y.: Study on physiological indicators during visual fatigue state. Electron. Dev. **38**(06), 1245–1248 (2015)
4. Zhao, Z.: Study on the identification method of visual fatigue state based on ECG pulse signal. Lanzhou University of Technology (2010)
5. Zhang, L., Ren, J., Xu, L., Zhang, J., Zhao, J.: Visual comfort and fatigue measured by eye movement analysis when watching three-dimensional displays. Ophthalmol. China **23**(01), 37–42 (2014)
6. Shi, X., Wang, S.: Evaluation of visual fatigue based on eye motion parameters. Technol. Inf. **21**, 172–173 (2012)
7. Sun, G.: Research on respiratory signals for visual fatigue caused by 3D display. In: Long, S., Dhillon, B.S. (eds.) MMESE 2020. LNEE, vol. 645, pp. 663–672. Springer, Singapore (2020). https://doi.org/10.1007/978-981-15-6978-4_76
8. Sun, G., Lin, Y., Ran, L., Meng, Y.: Effect of red blue 3D videos on visual fatigue. In: Harris, D., Li, W.-C. (eds.) HCII 2021, LNAI, vol. 12457, pp. 427–437. Springer, Cham (2021). https://doi.org/10.1007/978-3-030-77932-0_33