Effection of Luminance on Visual Fatigue in 3D Mode Under Dark Environment

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Abstract. In order to study the effect of 3D mode on visual fatigue under different luminance, the values of 58.24cd/m^2, 101.15cd/m^2, and 119.17cd/m^2 were used as low, medium, and high brightness for the experiment. 30 subjects watched science fiction video of 3D mode lasting for 90 min under dark environment. Subjective fatigue test and objective fatigue test were carried on by questionnaire survey, critical flicker frequency(CFF) test and pupil diameter measure. SPSS was used to analyze the differences of the visual fatigue under different luminance. The results indicated that the subjects got the lowest fatigue at the luminance of 101.15 cd/m^2 when the viewing time was less than 45 min, and when the viewing time was more than 45 min, the luminance leading to the lowest fatigue was 58.24 cd/m^2. With the increase viewing time, the higher the luminance, the more serious the visual fatigue. The subjective fatigue test index is relatively lagging behind the objective fatigue test index result. K-Means clustering algorithm was used to predict the fatigue of the subjects which indicated that the pupil diameter and CFF value could be used to assess the subject's visual fatigue and the accuracy rate was about 94.0%.

Keywords: visual fatigue · luminance difference · critical flicker frequency (CFF) · pupil diameter

1 Introduction

3D can give people an immersive experience, but it also could cause visual fatigue. Zou [1] pointed out that the measurement of stereoscopic visual fatigue includes ocular measurement, brain activity measurement and autonomic nervous system measurement. Hsu et al. [2] used flash fusion frequency, adjustment of near point and subjective measurement to evaluate the level of eye fatigue. Kim et al. [3] found that participants blinked more times when watching 3D TV.Cong et al. [4] showed that the pupil diameter reacts significantly to fatigue, and the diameter of the pupil becomes smaller as the degree of fatigue increases in dark environment. Wu [5] found that the human eye was usually inconsistent with the adjustment distance, and as the parallax increases, the inconsistency increases. Brain activity measurement and autonomic nervous system measurement are

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also used in the study of visual fatigue. Lihco et al. [6] found that the beta frequency of EEG is stronger than 2D when watching 3D videos, and the P700 potential generated by 3D is later than 2D. Shen et al. [7] indicated that 3D display had greater impact on people than traditional 2D display, and the amplitude of N200 and P300 components in the fatigue state decreased significantly while the incubation period increased slightly. Wang et al. [8] found that subjective scoring and heart rate increased with the duration of viewing time, and the proportion of intervals with RR interval difference of more than 50 ms decreased with the increase of viewing time. In addition, Wang et al. [9] proposed the statistical method of multiple linear regression to process subjective evaluation data and evaluate the degree of predicted visual fatigue. In the study of visual fatigue on luminance, Bullough et al. [10] showed that various factors such as the type of light source, the distribution of brightness and color temperature may have impact on visual fatigue. Jing et al. [11] found that excessive brightness may produce glare, which can cause distraction and cause visual fatigue. Chen et al. [12] found that 200lx ~ 500lx ambient lighting had no significant effect on visual fatigue or visual performance. However, no relevant results have been found on the influence of 3D display brightness on visual fatigue. Subjective and objective analysis methods were adopted to study the change of visual fatigue with viewing time and the impact of different display brightness.

2 Experiment

2.1 Experimental Equipment

PR-670 SpectraScan, Tobii Glasses (sampling frequency 50Hz), BD-II-118 flash fusion frequency meter(red light wase used as the test light source, light intensity was 1, bright-to-black ratio was 1:1, and background light was 1), Konka TV (LED42MS11PD, recommended viewing distance 3.1–4.0m).

2.2 Experimental Settings

According to the method of display brightness measurement in SJ/T11541–2015 “Stereoscopic TV Image Quality Test Method” [13], the brightness test of the 3D display was carried out with a luminance meter, and the brightness values were taken as low brightness 58.24 cd/m^2, moderate brightness 101.15 cd/m^2 and high brightness 119.17 cd/m^2, and the viewing distance was set to 3.5 m. Because watching the same film is easy to lead to psychological fatigue and affect the test results, in order to ensure the consistency of the test conditions, the 3D video material uses a number of popular science fiction films, each experimental film is selected by the participants independently, the video resolution is 1920 $\times$ 1080; before the different brightness test, the TV display displays a black picture at the corresponding brightness, and the adaptation time of the participant is 20min; The overall test environment is dark.

2.3 Participant Selection

30 volunteers, 15 men and 15 women, without color blindness, color weakness or eye diseases, with an average age of 26.8 years participated in the experiment. Each participant was only allowed to participate once on the same day, and had a good rest before

the experiment. Before conducting the experiment, all participants signed an informed consent form.

2.4 Experimental Methods

The subjective questionnaire was consisted of 12 questions. Question 1 was about comfort. Question 2 to 11 were about blurred vision, sore eyes, eye tingling, drowsiness, dizziness, double vision, tears, dry eyes, headache, and vomiting. And each subjective question had five different levels of description as shown in Table 1. Question 12 was the amount of time participants paid attention to subtitles.

Table 1. Five-point evaluation table

Score	Degree of fatigue
0	No
1	Slight
2	Moderate
3	Significant
4	Severe

Table 2. Baseline data paired test results

Content	ANOVA Significance	Luminance - Luminance	LSD Significance
Pupil diameter	0.538	58.24cd/m^2–101.15cd/m^2	0.350
		58.24cd/m^2–119.17cd/m^2	0.326
		101.15cd/m^2–119.17cd/m^2	0.962
CFF	0.898	58.24cd/m^2–101.15cd/m^2	0.929
		58.24cd/m^2–119.17cd/m^2	0.662
		101.15cd/m^2–119.17cd/m^2	0.728
Subjective questionnaire survey	0.754	58.24cd/m^2–101.15cd/m^2	0.806
		58.24cd/m^2–119.17cd/m^2	0.463
		101.15cd/m^2–119.17cd/m^2	0.624

3 Data Analysis

3.1 Baseline Data Analysis

Before the comparative analysis of visual fatigue at different luminance, the baseline data of pupil diameter, CFF, and subjective questionnaire survey were analyzed using ANOVA for univariate analysis, and then further perform intergroup analysis. At the test level of 0.05, there is no significant difference between the baseline data measured (Table 2). Therefore, the data which is used for visual fatigue at different luminace can be compared and analyzed.

3.2 Effects of Time on Visual Fatigue

3.2.1 Pupil Diameter

Firstly, ANOVA test and LSD test were used and the data test results were shown in Table 3 and Table 4. The ANOVA results in Table 3 appeared no significant difference among pupil diameter under the three luminance. The LSD test results of pupil diameter in Table 4 indicate that there were significant difference between the baseline data and the data at 30 min at **58.24cd/m^2**, between the baseline data and the data at 75min at **101.15cd/m^2**, and between the baseline data and the data at 15min, 30min, 45min, and 60min. It indicated that high luminance was the most likely to lead to the change of pupil diameter than other two. Followed by low luminance, and medium luminance was not easy to cause significant differences in pupil diameter.

Table 3. ANOVA analysis of pupil diameter at three different luminance

Luminance	F	Sig
58.24cd/m^2	0.956	0.459
101.15cd/m^2	1.126	0.353
119.17cd /m^2	1.294	0.267

Table 4. LSD analysis results of pupil diameter at three different luminance

Baseline /min	Viewing Time/min	58.24cd /m^2		101.15cd /m^2		119.17cd /m^2	
		Mean difference(I - J)	Sig	Mean difference(I - J)	Sig	Mean difference(I - J)	Sig
0	15	0.374	0.199	0.441	0.145	0.527	0.023*
	30	0.609	0.038*	0.369	0.223	0.472	0.042*
	45	0.562	0.055	0.262	0.385	0.518	0.026*
	60	0.443	0.129	0.279	0.356	0.468	0.044*
	75	0.315	0.279	0.740	0.015*	0.440	0.058
	90	0.339	0.243	0.249	0.410	0.351	0.129

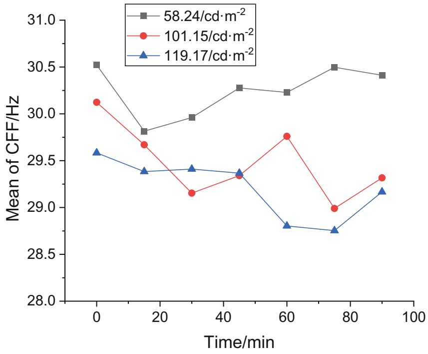

Fig. 1. CFF values under different luminance

3.2.2 CFF

7 sets of CFF values were shown in Fig. 1. In the first 30 min, the CFF value had a significant decrease, which was caused by the process of the subject's adaptation to the environment. As the time spent watching video increases, there is a slight upward trend, but it is always below the baseline data. In addition, the average CFF value of 58.24cd/m^2 was always higher than the CFF value of **101.15cd /m^2 and 119.17cd /m^2**, indicating that low luminance had little effect on the CFF value. 0.05 was used as the test level of hypothesis test, and the results showed that the difference of CFF values were not statistically significant with the change of time.

3.2.3 Questionnaires

The fatigue scores of the questionnaire are summed to get the sum of the fatigue scores at three brightness, as shown in Fig. 2. It can be seen that during the whole experiment, visual fatigue showed an upward trend, and from the beginning of the experiment, the fatigue scores of high brightness 119.17cd/m^2 and low brightness 58.24cd/m^2 have been higher than those of medium brightness 101.15cd/m^2, indicating that too bright or too dark will increase the degree of visual fatigue, and the effect of high brightness is greater than that of low brightness. During the whole process, the subjective fatigue score at high brightness of 119.17cd/m^2 was always the highest, and the fatigue increased sharply between 30-45min at this brightness, indicating that high brightness is more likely to cause fatigue, which is consistent with the analysis of pupil diameter detection results. Under the medium brightness of 101.15cd/m^2, the fatigue increased sharply during the 45-60min period, and exceeded the fatigue score of 58.24cd/m^2 of low brightness, which indicated that if the viewing time was within 45min, the subjective visual fatigue of the participants would be relatively low if the viewing time was within 45min. If the viewing time exceeds 45min, the fatigue at a low brightness of 58.24cd/m^2 is relatively low, although this will make the subject's visual fatigue slightly heavier than the medium brightness at the beginning of the experiment due to low brightness, but the cumulative eye fatigue is the lowest when watching for a long time. In addition, on the composite visual fatigue score of 3 points or more, the brighter the brightness, the earlier the same degree of visual fatigue appeared.

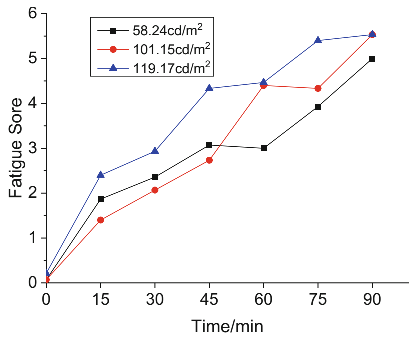

Fig. 2. Subjective questionnaire fatigue score

3.3 Effect of Brightness

The results of pupil diameter, CFF, and questionnaire in the three experiments of 30 participants were compared. The parameters under different brightness were tested for difference. The data were divided into three groups, Group 1 (58.24 cd/m^2 and 101.15 cd/m^2), Group 2 (58.24 cd/m^2 and 119.17 cd/m^2), and Group 3 (101.15 cd/m^2 and 119.17 cd/m^2). The participants participated in each experimentattended each experiment, therefore, the paired-sample t-test was used for conforming to the normal distribution, and the nonparametric test was used for the non-parametric test for the non-normal distribution, and the test results are shown in Table 5.

Table 5. Data test of three groups for pupil diameter, CFF, questionnaire

Time/min	Different of pupil dimeter			Different of CFF			Different of questionnaire		
	1	2	3	1	2	3	1	2	3
15	0.108	0.072	0.603	0.750	0.428	0.620	0.359	0.529	0.139
30	0.755	0.582	0.514	0.078	0.316	0.700	0.498	0.622	0.163
45	0.860	0.376	0.250	**0.027***	0.217	0.967	0.243	0.419	0.168
60	0.363	0.078	0.360	0.498	0.110	0.172	0.662	0.833	0.728
75	**0.009***	0.074	0.140	**0.007***	**0.043***	0.715	1.000	0.838	0.325
90	0.152	0.082	0.626	**0.020***	0.190	0.845	0.622	0.969	0.529

0.05 is taken as the test level, it can be seen from Table 5 that none of the three parameters corresponding to the three sets of data showed statistical significance within 30 min. Compared with the data in Fig. 3, the subjective fatigue appeared after 45 min, while the CFF value showed statistical significance at 45 min, indicating that the subjective feeling lagged behind the objective test results. At 75 min, the pupil diameter and CFF value of the first group were significantly different, and the CFF value of the second group also showed a significant difference, indicating that the cumulative fatigue degree at 58.24 cd/m^2 brightness was lower than that at 101.15cd/m^2 and 119.17cd/m^2, that is, when the viewing time of 3D video exceeded 75min, the degree of visual fatigue when viewing with low brightness was lower than that of medium and high brightness. At 90 min, the first CFF was still statistically significant.

In the test results in Table 5, there was no significant difference between the three parameters in Group 3, which shows that the effect of medium and high brightness on visual fatigue is not much different. From the analysis of the difference of subjective fatigue data, it can be seen that the fatigue scores of the subjective questionnaire do not reflect the differences between groups.

3.4 Logistic Regression Analysis

In order to analyze the relationship between brightness, viewing time, pupil diameter, CFF, and eye fatigue, the predictors of fatigue were selected and predicted. The K-Means clustering algorithm was used to divide the subjective fatigue into two groups, representing fatigue and non-fatigue, respectively, and the forward algorithm was analyzed by binary logistic regression, and the Omnibus test and the Hosmer-Remshaw test showed that the model could fit the data well.

Table 6. Variables in the equation

	B	Stand error	Wald	Sig	Exp(B)
ΔD	1.021	0.478	4.558	0.033	2.777
ΔCFF	-0.791	0.134	34.925	0.000	0.454
Constant	-3.480	0.387	80.966	0.000	0.031

Note: ΔD (difference from baseline pupil diameter data) and ΔCFF (difference from baseline flash fusion value)

As can be seen from Table 6, ΔD and ΔCFF have a significant effect on fatigue. ΔD and ΔCFF were statistically significant, and the overall correct percentage of the final fitted equation reached 94.0%, and the equation was:

$$P = \frac{1}{1 + e^{-1.021\Delta D - 0.791\Delta CFF - 3.480}}$$

In the equation, P is the predicted value, greater than or equal to 0.5 indicates that the participant has developed fatigue, less than 0.5 indicates that the participant has not developed fatigue. ΔD is the difference between the pupil diameter and the baseline data.ΔCFF is the difference between flash fusion and baseline data.

4 Conclusions

(1) The fatigue was the lowest at the brightness of 101.15cd/m^2 if the continuous viewing 3D video time was less than 45min. However, when the continuous viewing time exceeded 45min, the display brightness of 58.24cd/m^2 was was the lowest for the cumulative fatigue.

(2) Within 30min of viewing, the brightness of 3D video display has no significant effect on visual fatigue. At 75min, the pupil diameter of 58.24cd/m^2 and medium brightness of 101.15cd/m^2 showed significant differences, and the CFF value of medium and high brightness was significantly different. There was no statistical difference between the parameters of medium and high brightness within 90 min.
(3) The CFF value will show a significant decrease in the first 30min, and there will be a slight upward trend as the video viewing time increases, but it is always lower than the baseline data. The subjective perception of visual fatigue lags behind the objective test data.
(4) The regression equation for the determination of visual fatigue state, in which P is the predicted value, greater than or equal to 0.5 indicates that the participant is close to visual fatigue, and less than 0.5 indicates that visual fatigue has not yet appeared.

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The study was approved by the Logistics Department for Civilian Ethics Committee of China University of Labor Relations.

All subjects who participated in the experiment were provided with and signed an informed consent form.

All relevant ethical safeguards have been met with regard to subject protection.

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