Research on Reading Comfort of Office Light Environment Based on Subjective Evaluation

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Abstract. People's requirements for office lighting environment are becoming higher and higher, not only for its comfortable and healthy, but also to ensure that people's work efficiency. Aiming at the problem of visual comfort of office light environment, this study carried out subjective and objective evaluation experiment of lighting comfort of office reading environment. This paper studies the coupling influence of lighting elements on paper reading and VDT reading in the office light environment, conducts experiments on the fixed brightness of the screen, and analyzes and discusses the influence of lighting source on visual fatigue degree of reading. In this study, the visual comfort of paper reading and VDT reading was discussed from the perspective of correlation analysis and multiple regression analysis based on the psychophysical data of 30 observers. The experimental results show that visual comfort of paper reading and VDT reading is significantly correlated with illumination and color temperature. The development of this study will provide effective theoretical reference for the design of the current office light environment and has certain guiding significance for the design of light source in various office places.

Keywords: Visual fatigue · Office lighting · Subjective evaluation

1 Introduction

In the rapid development of China's economic construction, people not only have a higher level of material life requirements, but also gradually pay attention to the spiritual needs. Because of the need to use a lot of eyes, if the long-term work in an uncomfortable light environment is easy to cause visual deterioration and other physiological problems [1]. At the same time, it can cause psychological problems and reduce work efficiency. Comfortable lighting environment can not only ensure good eyesight health, but also provide safeguard for the safe and efficient work and activities. It can not only beautify the office environment, but also ensure people's psychological and physical comfort.

At present, domestic and foreign researchers have explored the influence of lighting source on visual fatigue degree of staff in office. Wu Hong et al. found that eye fatigue is related to light environment [2]. Sivaji et al. conducted an experiment on office lighting with eye tracker, and the results showed that illumination and color temperature

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had a certain influence on reading comfort [3]. Liu Gang et al. conducted an evaluation experiment based on subjective questionnaire. They conducted multivariate nonlinear regression analysis using SPSS software to study the influence of illumination, relative color temperature and illumination uniformity on environmental comfort. The results show that the intermediate color temperature light source and 200–300 lx light environment are more comfortable [4]. Taptagaporn et al. found that reading comfort is better when the horizontal illumination is 500 lx and the computer screen is bright through experiments [5]. Wu Tongyao et al. found that VDT reading comfort of human eyes increased first and then decreased with the increase of illumination through experimental research [6]. Through visual acuity test and heart rate test, Han Zeyang et al. found that color temperature had different effects on visual fatigue under different reading modes [7].

The above studies on the office light environment have mainly focused on the influence of illumination, color temperature and other lighting indicators on the comfort level of one of them. However, the current office materials are a combination of paper and electronic, and the previous studies were only limited to one of them, which does not meet the needs of today.

In view of the above problems, this study combins paper reading and electronic reading, studies the coupling effects of lighting elements on paper reading and electronic reading in the office light environment through subjective evaluation experiment, and analyzed and discusses the impact of lighting source on reading visual fatigue. To provide some technical reference for the design of office light environment under the current epidemic situation.

2 Experimental Design

2.1 Control Variables

Illumination (300 lx, 400 lx, 500 lx) and color temperature (4500 K, 5600 K) were selected as experimental variables in the evaluation experiment of visual comfort of office light environment[8, 9]. In addition, all other lighting parameters are in line with the national standard GB50034–2013[10]. In the experimental process, the illumination and color temperature were arranged and combined according to the experimental purpose. The following 6 experimental conditions of artificial light environment were respectively: 1.300 lx 4500 K; 2.300 lx 5600 K; 3.400 lx 4500 K; 4.400 lx 5600 K; 5.500 lx 4500 K; 6.500 lx 5600 K.

2.2 Lighting Environment Design

The experiment was carried out in a dark, enclosed laboratory. A set of tables and chairs, lighting equipment, illuminometer, VDT equipment (laptop computer) and reading materials required for the experiment are placed in the laboratory, as shown in Fig. 1. The lighting device used a Huawei desk lamp, which can adjust the required illumination and color temperature through mobile phone software. Before the experiment, the illumination, color temperature and color rendering index of the subjects were measured with a color illuminance meter. After the lamp was turned on and stable for 30 s, the lighting parameters in each light environment met the requirements of the experimental design. Record debugging data for debugging in formal experiments. The measurement results of lighting parameters in six light environments are shown in Table 1.

Fig. 1. Simulated experimental environment

Table 1. Test results of lighting parameters in six light environments

Number	Color rendering index	Illumination	Color temperature
1	95	296 lx	4487 K
2	95	302 lx	5624 K
3	95	407 lx	4499 K
4	95	399 lx	5612 K
5	95	502 lx	4505 K
6	95	499 lx	5602 K

2.3 The Experimental Method

A total of 30 college students were invited to participate in this experiment, including 18 males and 12 females. Thirty subjects had normal visual acuity, no ocular diseases, and no ocular acid, dry eye, dizziness and blurred vision before participating in the experiment. Because the experimental space was limited, two people in a group participated in the experiment and filled in the questionnaire. The content of the questionnaire is about the degree of visual fatigue scale and record of the reading time of the subjects. The visual fatigue scale scores the degree of eye acid, eye dryness, blurred vision, dizziness and inattention to judge the degree of visual fatigue of subjects. The questionnaire is divided into five grades according to their degree, of which the first grade is not at all, the second grade is low, the third grade is moderate, the fourth grade is deep, and the fifth grade is the deepest.In this study, the effects of illumination and color temperature on visual comfort of paper reading and electronic reading were studied by recording reading time and subjective evaluation results[11, 12]. Electronic reading comfort was evaluated by typing speed and subjective questionnaire.

At the beginning of the experiment, the parameters of the light environment were modulated by software according to the data recorded in the dimming process. After each adjustment of the light environment parameters, one of the subjects was asked to apply the light environment 30 s later and fill in the questionnaire. After finishing the paper reading, the other subject was switched to the paper reading experiment, and the other subject took a rest during this period.After resting, the first participant read electronically and completed the questionnaire after completing the typing task. Then, the second participant was given the electronic reading experiment. After all experiments in each light environment were completed, turned off the experimental light source and turned on the basic lighting to prevent glare caused by dark adaptation which was caused by turning on the light source after rest. Since it was an evaluation experiment on visual comfort, in order to avoid the effects of long-term reading on visual fatigue[13], two people took a rest for 2 min after the experiment in each light environment. Two subjects rested for 20 min after completing the three light environment experiments, and then completed the follow-up experiments.After the experiment, SPSS software was used for statistical analysis of reading time and questionnaire results.

The experiment was divided into two parts, one for paper reading and the other for electronic reading. Prepare a text for each light environment with the same number of words for each text. Before starting the experiment, arrange the reading material and the cell phone used for timing. Then, the subjects got used to the light.When the subjects are ready, they can click the start timer button and start reading the material. After finishing, click the timing button and record the reading time on the questionnaire. Finally, fill in the subjective questionnaire and score the content according to the reading experience. After taking a break from paper reading, start e-reading. For the same reading text content in the same light environment, use a laptop to edit the text printed on A4 paper with song Type-4 character on Word, and punctuation marks also need to be edited. Just like paper reading, subjects clicked the start timing button and began to edit the text. After finishing, they recorded the editing time and scored the content of the questionnaire. The same operation is performed in all six light environments.

3 Analysis of Experimental Data

3.1 Reliability Analysis

The data obtained from the subjective evaluation experiment were summarized and sorted out by Office Excel software, and one-way analysis of variance and multiple linear regression analysis were conducted by IBM SPSS software.

At the end of the experiment, the reliability of the questionnaire was analyzed by SPSS software to test the reliability of the questionnaire. Reliability is used to verify the stability of the definition of the evaluation scale and ensure the reliability of subsequent data analysis. In the reliability analysis of SPSS software, Cronbach's Alpha coefficient was used to evaluate the internal consistency of the whole visual fatigue scale.Its calculation formula is as follows:

$$r_{tt} = \frac{n}{n-1}\left[1 \frac{\sum_{i=1}^{n}(SD_t^2)}{SD_t^2}\right] \quad (1)$$

where, r_{tt} is the reliability coefficient of evaluation scale; is the number of items on the scale; SD_i^2 is the variance of the score of item i; SD_t^2 is the variance of the total score of the scale[14]. When Cronbach's Alpha coefficient is greater than 0.8, the reliability of the experimental scale is high.

The Cronbach's Alpha coefficient of the experimental data in this study was 0.868 for paper reading and 0.892 for electronic reading, which showed high internal consistency, and the experimental data could be further analyzed and processed.

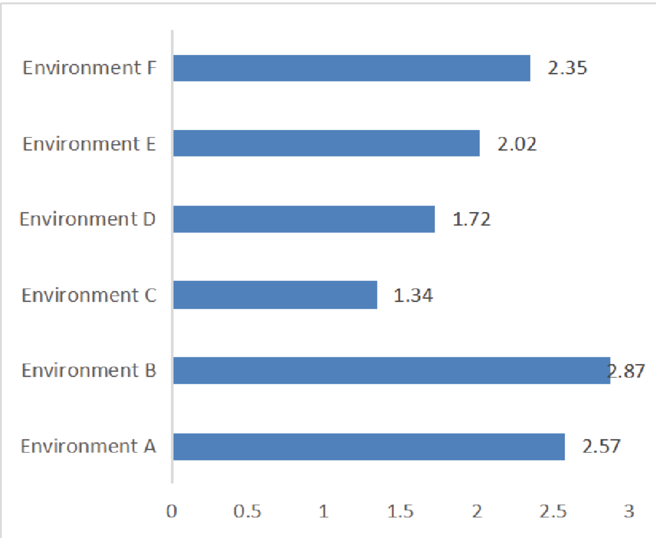

Fig. 2. Average score of paper reading for the six lighting schemes

3.2 Data Summary

The data obtained from the summary of experimental results were sorted out, and the average scores of the subjective questionnaire under six light environments were obtained by Office Excel software, as shown in Fig. 2 and Fig. 3. In the figure: Environment A. 300 lx,4500 K; Environment B. 300 lx,5600 K; Environment C. 400 lx, 4500 K; Environment D. 400 lx, 5600 K; Environment E. 500 lx, 4500 K; Environment F.500 lx, 5600 K.

It can be seen from Fig. 2 that the average score of Environment B in paper reading is the highest (AVG = 2.87), while the average score of Environment C is the lowest (AVG = 1.34). The average scores of Environment C and Environment D were lower than 2 (1.34 and 1.72, respectively), and the illuminance of these two environments was 400 lx.. The average scores of Environment A and Environment B and the average scores of Environment E and Environment F were more than 2 points, which were 2.57, 2.87, 2.02 and 2.35 respectively. The illuminance of Environment A and Environment B was 300 lx, and the illuminance of Environment E and Environment F was 500 lx.At the same time, it can be seen that the average scores of Environment A, Environment C and Environment E are smaller than those of Environment B, Environment D and Environment F. It can be seen that the scores under light environment of 4500 K color temperature are significantly lower than those under light environment of 5600 K color temperature, but the difference between the average scores of the two color temperatures is small, and the best environment is 400 lx 4500 K.

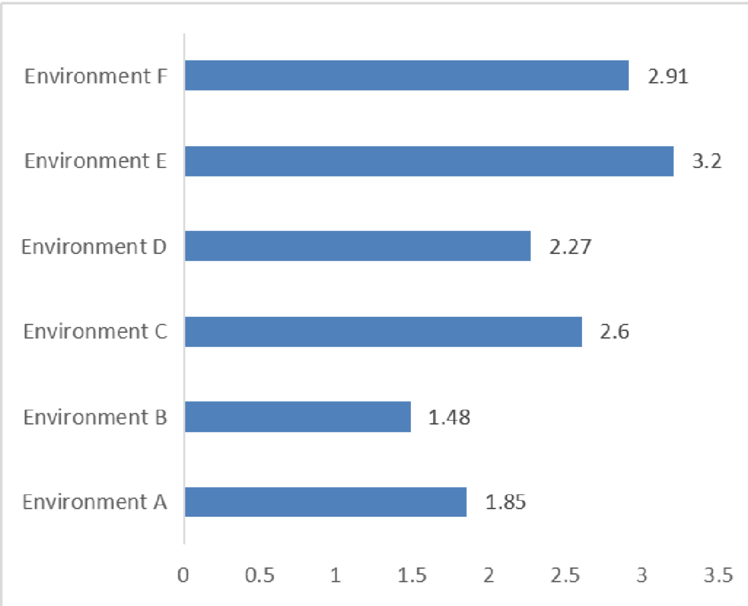

Fig. 3. Average score of electronic reading for the six lighting schemes

It can be seen from Fig. 3 that the average score of Environment E in electronic reading is the highest (AVG = 2.87), while the average score of Environment B is the lowest (AVG = 1.34). The average scores of Environment A and Environment B were lower than 2, which were 1.85 and 1.48 respectively. The illuminance of these two environments was 300 lx. The average scores of Environment C, Environment D and Environment F were all more than 2 points, which were 2.6, 2.27 and 2.91 respectively. The two environmental illuminance of Environment C and Environmen D was 400 lx, and the environmental illuminance of Environment F was 500 lx. At the same time, it can be seen that the average values of Environment A, Environment C and Environment E are higher than those of Environment B, Environment D and Environment F. It can be seen that the scores under light environment of 4500 K color temperature are significantly higher than those under light environment of 5600 K color temperature, and the average scores of the two color temperatures differ greatly, and the best feedback is the environment of 300 lx 5600 K.

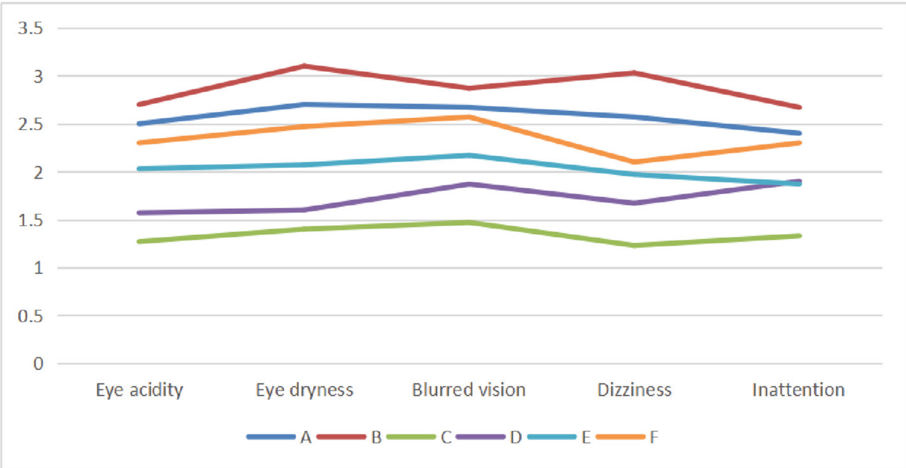

Fig. 4. Average score of five degree words in different light environments of paper reading

As can be seen from Fig. 4, in paper reading, the average scores of the five degree words of Environment C are the lowest, and the scores of each word pair of Environment B are the highest. Among them, six environments showed significant differences in the degree of inattention, with Environment C, Environment D and Environment F showing significant increases, while the other three environments showed decreases. The curves under different light environments differ greatly.

As can be seen from Fig. 5, the average score of five degree words of Environment B in electronic reading is the lowest, and the score of each word pair of Environment E is the highest. Among them, in the degree of dizziness, the average scores of the six light environments were significantly different, and the scores of Environment C and Environment E were significantly different from those of the other four environments. The scores of Environment F and Environment A are very similar.

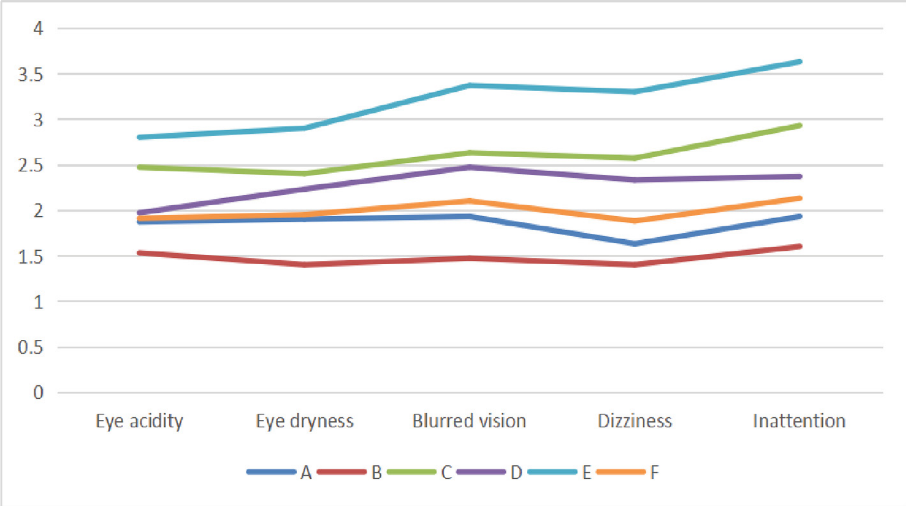

Fig. 5. Average score of five degree words in different light environments of electronic reading

3.3 Correlation Analysis

SPSS software was used to analyze the correlation between illumination and color temperature of electronic reading and paper reading and the degree of eye acidity, eye dryness, blurred vision, dizziness and inattention. The analysis results of Pearson correlation coefficient are shown in Table 1 and Table 2.

3.3.1 Correlation Analysis of Paper Reading

The results showed that the degree of eye acid, dry eye, blurred vision, dizziness and inattention were negatively correlated with illumination ($P < 0.05$), and positively correlated with color temperature ($P < 0.05$). The Pearson correlation coefficient between the degree of dizziness and illuminance was $r = -.366^{**}$, and the closer its value was to -1, the more significant the negative correlation was, and the change of illuminance had the greatest impact on the degree of dizziness. However, the absolute values of Pearson's correlation coefficients of the five words were all greater than 0.2 and less than 0.4, so the degree of eye acid, dry eye, blurred vision, dizziness and inattention were weakly correlated with the degree of illumination. There was a significant negative correlation between the five visual fatigue degree quantifiers and illuminance, and the significance was the degree of dizziness > the degree of dry eye > the degree of inattention > the degree of acid > the degree of blurred vision.

The Pearson correlation coefficient between the degree of inattention and color temperature is $r = .285^{**}$. The closer its value is to 1, the more significant the positive correlation is, and the change of color temperature has the greatest impact on the degree of inattention. Among them, the Pearson correlation coefficient of the degree of blurred vision, the degree of dizziness and the degree of inattention was greater than 0.2 and less than 0.4, so the degree of visual blur, the degree of dizziness and the degree of inattention showed significant weak correlation with color temperature. However, the correlation coefficient of the degree of eye acid and the degree of eye dryness was less than 0.2 but close to 0.2, showing a very weak correlation with color temperature. There was a significant positive correlation between the five visual fatigue degree quantifiers and the color temperature, the significance of which was the degree of inattention > the degree of blurred vision > the degree of dizziness > the degree of dry eye > the degree of acid.

Table 2. The Pearson correlation coefficient between illumination and color temperature and visual fatigue degree in paper reading

		The degree of eye acidity	The degree of eye dryness	The degree of blurred vision	The degree of dizziness	The degree of inattention
IllumInation	Pearson correlation	-.222**	-.301**	-.204**	-.366**	-.248**
	Significance (two tails)	.003	.000	.006	.000	.001
	The case number	180	180	180	180	180
Color temperature	Pearson correlation	.160*	.194**	.208**	.202**	.285**
	Significance (two tails)	.032	.009	.005	.007	.000
	The case number	180	180	180	180	180

Continue to Table 2:

3.3.2 Correlation Analysis of Electronic Reading

In electronic reading, the degree of eye acid, dry eye, blurred vision, dizziness and inattention were positively correlated with illuminance ($P < 0.05$), and negatively correlated with color temperature ($P < 0.05$). The Pearson correlation coefficient between the degree of dizziness and inattention and illumination was r = .637**, and the change of illumination had the greatest effect on the degree of dizziness and inattention. The Pearson correlation coefficient of the degree of visual blur, dizziness and inattention was greater than 0.6, which was strongly correlated with the color temperature. The Pearson correlation coefficients of the degree of eye acid, dry eye and visual blur were greater than 0.4 and less than 0.6, which were moderately correlated with color temperature. There was a significant positive correlation between the five visual fatigue degree quantifiers and illuminance, the significance of which was the degree of dizziness = the degree of inattention > the degree of blurred vision > the degree of eye acid > the degree of dry eye.

The Pearson correlation coefficient between the degree of eye acid and color temperature was r = −.1.97**, and the change of color temperature had the greatest effect on the degree of eye acid. The Pearson correlation coefficient of the degree of visual blur, dizziness and inattention was less than 0.2 but close to 0.2, showing very weak correlation. There was a significant negative correlation between the five visual fatigue degree quantifiers and color temperature, and the significance was the degree of eye acid > the degree of inattention > the degree of dizziness > the degree of dry eye > the degree of blurred vision.

According to Pearson correlation value of data analyzed by SPSS software, multiple factors in visual fatigue degree have certain correlation with illumination and color temperature. Therefore, the reading comfort of paper and electronic reading can be improved by adjusting the illumination and color temperature (Table 3).

Table 3. Pearson correlation coefficient between illumination and color temperature and visual fatigue degree in electronic reading

		the degree of eye acidity	the degree of eye dryness	the degree of blurred vision	the degree of dizziness	the degree of inattention
IllumInation	Pearson correlation	.515**	.504**	.621**	.637**	.637**
	Significance (two tails)	.000	.000	.000	.000	.000
	The case number	180	180	180	180	180
Color temperature	Pearson correlation	−.197**	−.163*	−.149*	−.171*	−.182*
	Significance (two tails)	.008	.028	.046	.021	.015
	The case number	180	180	180	180	180

3.4 The Analysis of Multiple Linear Regression

Firstly, illumination and color temperature have significant differences with he degree of eye acidity, eye dryness, blurred vision, dizziness and inattention,and there is a significant relationship through the correlation analysis. Then, the overall visual fatigue of the subjects was defined as the average score of each subject's five visual fatigue states.

SPSS software was used to process the dummy variables of the sorted experimental effective data. Then, the scores of visual fatigue degree were analyzed by multiple linear regression to test whether the different levels of illumination and color temperature had an effect on the degree of visual fatigue[15].

3.4.1 The Analysis of Multiple Linear Regression in Paper Reading

It can be seen from Table 4 that the visual fatigue degree at 400 lx and 500 lx in paper reading is significantly lower than that at 300 lx ($P < 0.05$). The visual fatigue degree at 500 lx was significantly higher than that at 400 lx. Since the higher the score of visual fatigue,the deeper the degree of visual fatigue, paper reading under 400 lx light environment has the highest visual comfort. It can be observed from Table 5 that the visual fatigue degree of paper reading at 5600 K is significantly higher than that at 4500 K ($P < 0.05$), so the visual comfort degree of paper reading at 4500 K is the highest.

Table 4. Multiple linear regression analysis results of illumination in paper reading

Model		Unnormalized coefficient		Normalization coefficient	t	Significance
		B	Standard error	Beta		
1	(Constant)	2.720	.044		61.542	.000
	400 lx	−1.190	.063	−.945	−19.039	.000
	500 lx	−.537	.063	−.426	−8.586	.000
2	(Constant)	1.530	.044		34.617	.000
	500 lx	.653	.063	.519	10.453	.000
	300 lx	1.190	.063	.945	19.039	.000

a. Dependent variable: degree of visual fatigue

Table 5. Multiple linear regression analysis results of color temperature in paper reading

Model		Unnormalized coefficient		Normalization coefficient	t	Significance
		B	Standard error	Beta		
1	(Constant)	1.976	.060		32.768	.000
	5600 K	.338	.085	.285	3.962	.000

a.Dependent variable: degree of visual fatigue

It can be observed from Table 6 that the visual fatigue degree at 400 lx and 500 lx in electronic reading is significantly higher than that at 300 lx($P < 0.05$). The visual fatigue degree at 500 lx was significantly higher than that at 400 lx. Therefore, the visual comfort of 300 lx is the highest for electronic reading.It can be seen from Table 7 that the visual fatigue degree at 5600 K in paper reading is significantly lower than that at 4500 K ($P < 0.05$), so the visual comfort degree at 5600 K in paper reading is the highest.

Table 6. Results of multiple linear regression analysis of illumination in electronic reading

Model		Unnormalized coefficient		Normalization coefficient	t	Significance
		B	Standard error	Beta		
1	(Constant)	1.667	.063		26.552	.000
	400 lx	.770	.089	.488	8.674	.000
	500 lx	1.387	.089	.878	15.621	.000
2	(Constant)	2.437	.063		38.820	.000
	500 lx	.617	.089	.390	6.947	.000
	300 lx	−.770	.089	−.488	−8.674	.000

a.Dependent variable: degree of visual fatigue

Table 7. Multiple linear regression analysis results of color temperature in electronic reading

Model		Unnormalized coefficient		Normalization coefficient	t	Significance
		B	Standard error	Beta		
1	(Constant)	2.551	.077		33.158	.000
	5600 K	−.331	.109	−.222	−3.042	.003

a.Dependent variable: degree of visual fatigue

3.5 Analysis of Reading Efficiency

Through statistical analysis of reading time of 30 samples in two modes and six light environments, the average value is calculated, and the results are shown in Fig. 6 and Fig. 7.

The shorter the reading time is, the higher the reading efficiency is, that is, the higher the reading comfort is, the longer the reading time is, the lower the reading efficiency is due to the influence of fatigue, the lower the reading comfort is. As can be seen from Fig. 2, from the perspective of color temperature analysis, the reading time of paper at 4500 K between 300 lx and 500 lx is shorter than that at 5600 K, and the difference in reading time at 400 lx is larger than that at 300 lx and 500 lx, indicating that paper reading under the condition of the same illumination, The reading comfort is higher when the

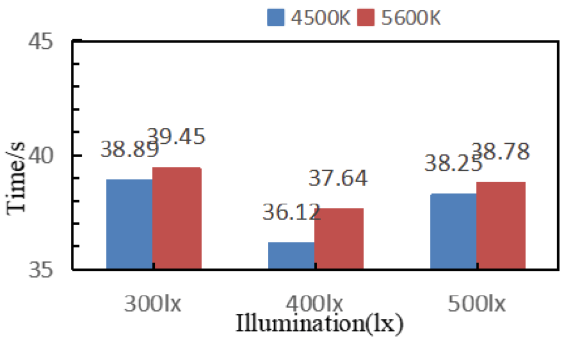

Fig. 6. Average reading time of paper reading

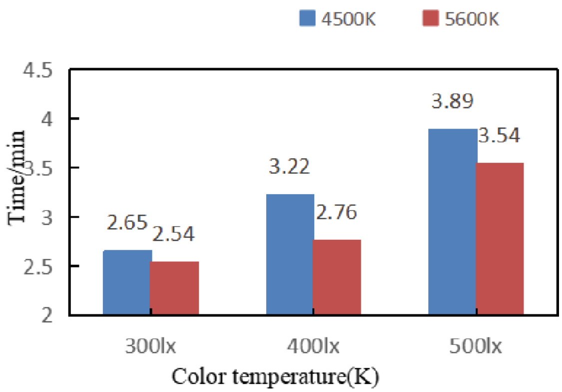

Fig. 7. Average reading time of electronic reading

light environment is 4500 K. From the perspective of illumination, at 4500 K and 5600 K, the reading time under 400 lx electronic environment is shorter than that under 300 lx and 500 lx environment, and the reading time drops significantly between 300 lx and 400 lx, while the change between 400 lx and 500 lx is little, indicating that paper reading under the same color temperature, When the light environment is 400 lx, the reading comfort is the highest, followed by 500 lx and 300 lx. Therefore, the lighting design applied to office needs can choose a light source with a color temperature of 4500 K under the condition of uniform illumination. When the color temperature increases, the change of visual comfort of reading is not obvious. Therefore, from the perspective of green, environmental protection and energy saving, the intermediate color temperature light source can be selected and the intermediate illumination applied to the paper reading office needs.

As can be seen from Fig. 3, from the perspective of color temperature, the e-reading time between 300 lx and 500 lx at 5600 K is slightly shorter than that at 4500 K, and the difference is small. Especially when the illumination is 300 lx, the electronic reading time at the two color temperatures is basically the same, indicating that the electronic reading time at the same illumination level is similar. The reading comfort is slightly higher than 4500 K when the light environment is 5600 K. According to the analysis from the perspective of illumination, at 4500 K and 5600 K, the reading time under 300 lx electronic environment is shorter than that under 400 lx and 500 lx, and the difference is obvious, indicating that the reading comfort of electronic reading under low illumination is the highest under the same color temperature, and the reading time increases slightly at 400 lx. The reading time was significantly different from that at 500 lx. Therefore, in the need to complete electronic reading tasks such as typing, low color temperature and light source can be selected to meet people's visual comfort needs. Because the comfort gap between the intermediate color temperature and light source and the high color temperature and light source is not obvious, so from the perspective of energy conservation, you can also choose the medium color temperature and light source. However, due to the limited text content and short reading time, the reading time is relatively close, which may have a certain impact on the result.

4 Conclusion

A psychophysical experiment was carried out using a subjective questionnaire to obtain the subjective evaluation data of reading time and reading feeling in paper and electronic reading under six light environments.

Through experiments, it can be found that illuminance and color temperature can have a certain impact on people's reading comfort, and the effects are different in paper reading and electronic reading. Whether it is paper reading or electronic reading, reading in a medium-color temperature light environment is more comfortable.At the same time, considering factors such as green energy saving, it is recommended to use an intermediate color temperature light source.It can also be found that the higher the illuminance, the higher the visual comfort of paper reading is, while the lower the visual comfort of electronic reading.From the analysis of the influencing factors of illuminance, people's needs for the light environment in different reading modes are significantly different.

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