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Abstract

In office, people perceived higher rated light more attractive, reported more pleasant, and showed greater well-being. Physiological components were also correlated with lighting. The purpose of this paper is to assess appraisal, work performance, physiological components under different office light environment. D2 test was carried out and semantic differential rating scales, PANAS, drowsiness were measured, together with heart rate. This paper laid out 4 lighting conditions, each with different illuminance and CCT. Results suggest that 4000K provided a more integrated and luxurious atmosphere but less brightness than 5000K, together with higher accuracy and less error in D2 test. 750 lx provided a more colorful and luxurious atmosphere than 300 lx, together with high speed but worse accuracy in D2 test. In this study, we obtained an optimum light condition: LED light at 4000K of 750 lx were evaluated the best for short time office work (30 min).

Keywords: Office light, Work performance, PANAS, Heart rate

1 Introduction

Most would agree that lighting does affect performance, physiological components and other parameters. In office, people who perceived higher rated lighting as the space being more attractive, reported more pleasant, and showed greater well-being [1]. Physiological components, including HRV, blood pressure, ERP components etc., were also correlated with lighting.

The illuminance standard value was set in GB50034-2013, based on CIE S008/E-2001, which should be complied with and 300 lx, 500 lx, 750 lx were adjacent grades. GB50034-2013 also listed the recommended illuminance at 300 lx for 0.75m reference surface, which stand for maintained average illuminance for lighting fixture. Differently, CIE S008/E-2001, IESNA-2011, JISZ9110-2010, DIN 5035-1990, CHиП 23-05-95, EN 12464-1-2011 set different recommended office illuminance, respectively as, 500 lx, 500 lx, 750 lx, 300 lx, 300 lx, 500 lx. Smolders [2] pointed out that the effect of high illuminance on alertness was most obvious at night or under sleep, and the effect during the day was more moderate. Melatonin is suppressed when exposed to high illuminance light at night, which enhances the ability of one's continuous attention and cognition. Difference between different grade of maintained average illuminance should be further evaluated by various scales aiming at optimization.

CCT were set to be lower than 4000K under long time reading for LED in GB50034-2013. Former studies have focused on the relationship between high CCT and better work performance, such as 3000K, 4000K between 6500K, neglecting the span between 4000K and 6500K.

This paper is to assess lighting appraisal, performance and physiological components under different office lighting conditions. We laid out 4 lighting conditions, each with different illuminance and CCT, aiming at figuring out the difference between different standards – 300 lx and 750lx, together with 4000K and 5000K. By evaluating the emotional change, physiological indicators and other scales, we found an optimum condition for short time (30 min) office work.

2 Methods

The experiment took place in a 3.2 m x 3 m space with a 2.8m high ceiling with a simulated office inside. The room walls and ceiling were painted matte white and the floor was covered with grey carpet. All the equipment was painted matte white or covered with white cloth.

The light was hanged to the ceiling and created uniform light at work surface, together with 4 lighting conditions, seeing table 1. We designed light conditions according to simulate office work surface. Standards of different areas have listed the recommended illuminance for 0.75m reference surface, from the lowest 300 lx in GB50034-2013, DIN 5035-1990, СНиП 23-05-95 to the highest 750 lx in JISZ9110-2010 and according to which illuminance were set. CCT were set as 4000K and 5000K for figuring out the difference. Commonly, 300 lx, 4000K was set in office condition and were taken as reference in this study.

Table 1 – Lighting conditions and parameters

Lighting condition	Illuminance/lx	CCT/K
1	300	4000
2	750	4000
3	300	5000
4	750	5000

Light room should meet the following requirements: easy to install adjustable light sources, no interference from daylight; able to emit even and stable light. We used aluminium as main material for experimental framework. We used plastic foam board in the framework, with lighting fixtures installed at the top of each room and computers used to control the light.
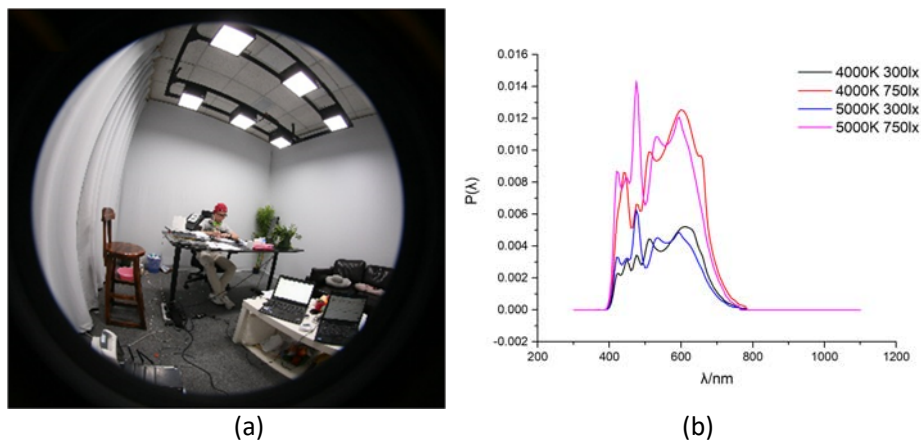

(a)   (b)

Figure 1 – Photograph of experiment and the spectrum distribution

The participants were randomly selected between ages of 18-30 years old, with total number of 10 including 4 males and 6 females, average age at 22.9±(std)1.97. All with no intake of psychotropic drugs before and during the experiment.

The experiment was carried out in the July of 2018, with the temperature and humidity of the laboratory controlled at 25℃ and 44.3±(std)6.82%.

2.1 Experimental process

The experiment time under one condition is 22 min, including 1 min dark adaptation, 5 min in filling semantic difference scale, psychological scale (PANAS and KSS), 5 min in measuring physiological parameters (heart rate), 3 min light adaptation, 5 min in filling D2 test, 5min in measuring physiological parameters (heart rate). Each participant need to take part in 4 experiment conditions randomly. Thus, the total experiment time for one participant is 88 min.
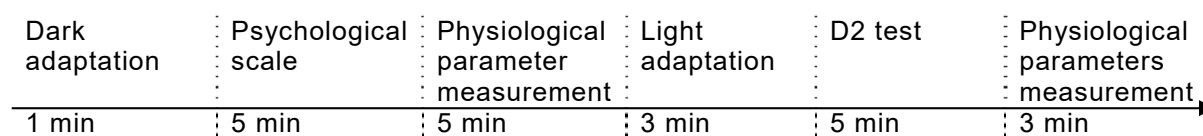
Dark adaptation	Psychological scale	Physiological parameter measurement	Light adaptation	D2 test	Physiological parameters measurement
1 min	5 min	5 min	3 min	5 min	3 min

Figure 2 – Experiment process

2.2 D2 test

D2 test was carried out in this study. The D2 is a one-page A4 paper and pencil test for selective attention, which consists of 14 row, (trials) and each with 47 randomly mixed "p" or "d" letters (character size 12) [6-9]. The target symbol is a "d" with 2 dashes. The participants' task is to cancel out as many target symbols as possible, moving from left to right with a time limit of 20 seconds/trial.

The subscores were calculated for D2 test, which including total number (TN), accuracy (A), omissions (E1), commissions (E2), error (E).TN is a quantitative measure of performance of all items that were processed. A is the accuracy of the crossed out items. E1 occurs when relevant items are not crossed out. E2 occurs when irrelevant letters are crossed out in violation of the instructions. The raw score E is the sum of all mistakes.

2.3 Psychological evaluation

We used the semantic differential rating scales for environment perception. Semantic difference scale (Appendix A), PANAS (Positive and Negative Affect Schedule) [3-4] and Karolinska Sleepiness Scale [5] were filled by participants once entering the light room. PANAS (Positive and Negative Affect Schedule) [3-4] was used to measure one's emotion, scoring from 0 to 40, and people with higher score of PANAS have more positive emotion. KSS was used to evaluate one's drowsiness.

2.4 Measurement and data analysis

The illuminance was measured by KONIKA MINOLTA CL-200A. We measured the edges and the centre of work surface and calculated the average illuminance. The CCT and distance of departure from the blackbody locus (duv) were measured by KONIKA MINOLTA CL-500A.

The analytic hierarchy process (AHP) is applied for analysing complex decisions. [10-12] By decomposing problems into a hierarchy of sub-problems (element), each element can be analysed independently by systematically evaluating its various elements by comparing them to each other. In this study, judgments were acquired by inquiry and numerical weights has been derived for each element, representing the alternatives' relative ability to achieve the decision goal.

3 Analysis

3.1 Analysis of light exposure on psychological scale and physiological parameter measurement

Factor analysis (FA) for semantic difference scale yielded 3 main components for office light. Comparing atmosphere terms in each factor, we could learn some underlying dimensions in atmosphere perception. Under different CCT, participants have "integrated-separated" in Factor 1, "bright-dim" in Factor 2 and "luxurious-simple" in Factor 3. Under different illuminance, participants have "natural-unnatural" in Factor 1, "colorful-colorless" in Factor 2 and "luxurious-simple" in Factor 3. Though multivariate analysis of variance (MANOVA) also yielded no significant differences for 3 factors between 4000K and 5000K. Multivariate analysis of variance (MANOVA) also yielded significant differences for scale "luxurious" between 300 lx and 750 lx (F=4.532, p=0.006). The average score and error bar (95% confidence intervals) for the scales "integrated", "brightness", "luxurious" under different CCT and "natural", "colourful" and "luxurious" under different illuminance were illustrated in Figure 3.

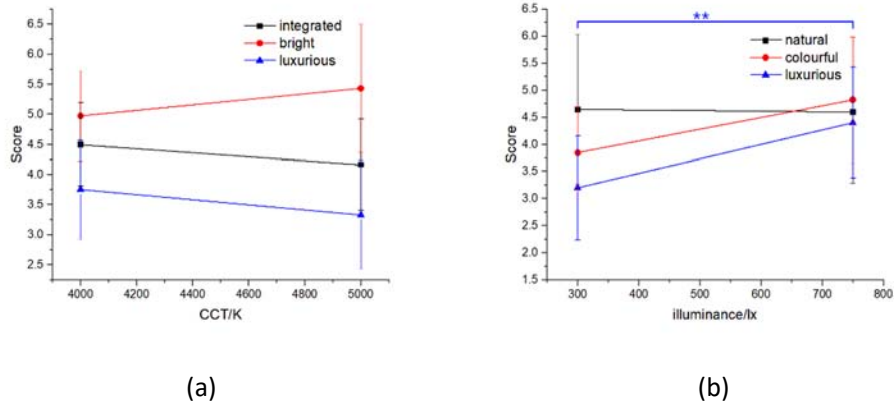(a)   (b)

Figure 3 – Plots of (a)integrated, bright, luxurious under different CCT, (b)natural, colourful, luxurious under different illuminance, * labelled p<0.05 and ** labelled p<0.01.

We measured the mood, drowsiness through scales, so as heart rate, illustrated in Figure 4. T test yielded significant differences for PANAS between 300 lx and 750 lx under 4000K, (t=3.8, df=18, p=0.001) and under 5000K (t=3.769, df=18, p=0.001), illustrated in Fig. 4(a). T test also yielded significant differences for drowsiness between 300 lx and 750 lx under 4000K, (t=2.485, df=18, p=0.023), illustrated in Fig. 4(b). When comparing subjective drowsiness during light exposure to pre-light levels, light at 5000K and 750 lx resulted, respectively, in an increase of 2.564%, and a decrease of 5.076% in comparison to pre-light exposure. Heart rate of light at 5000K and 750 lx resulted, respectively, in an increase of 1.824%, 2.767% in comparison to pre-light exposure.
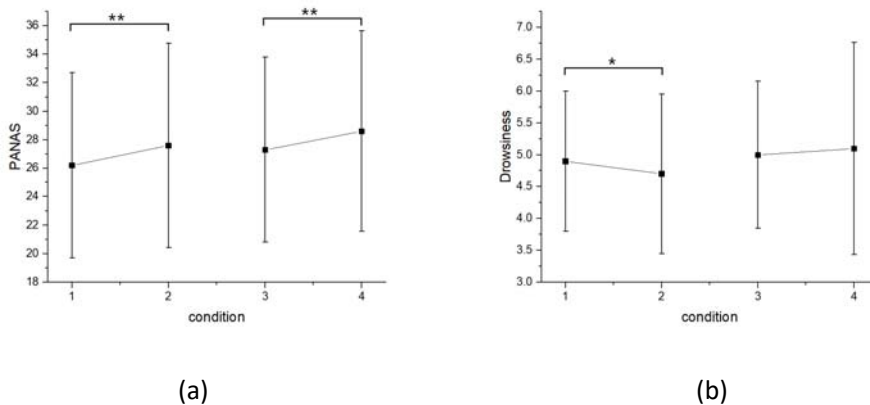

(a)   (b)

Figure 4 – Plots of (a)PANAS, (b)drowsiness under four light conditions, * labelled p<0.05 and ** labelled p<0.01.

3.2 Analysis of light exposure on D2 test

In the results of D2 test, total number and accuracy revealed no significant difference under different illuminance and CCT but an obvious tendency, illustrated in Figure 5(a). Under 4000K, comparison of D2 test's total number across different illuminance indicated that light at 750 lx resulted 3.83% higher than 300lx. Similarly, under 5000K, the total number across different illuminance indicated that 750 lx resulted 1.01% higher than 300lx. Accuracy across different light conditions indicated that light at 300 lx, 4000K resulted, the highest, respectively 4.71%, 1.90%, 2.09% higher than condition 2,3,4.
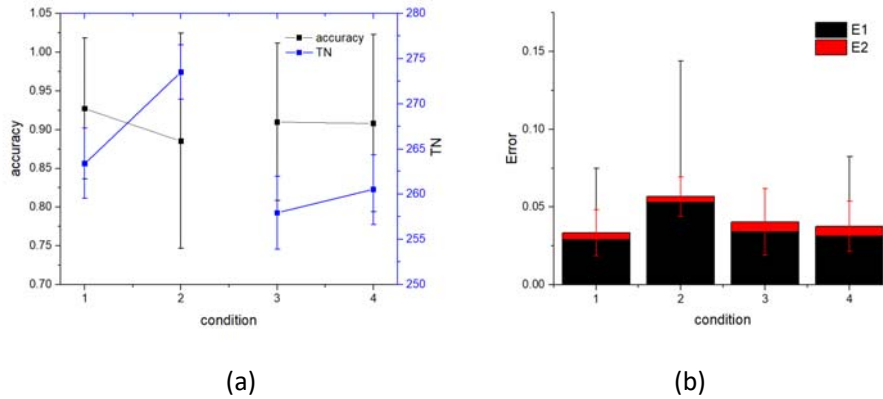
(a)   (b)

Figure 5 – Plots of (a)Total Number (TN) and accuracy, (b) omission(E1) and comission (E2) under four light conditions

The error, including omission and comission, was calculated and plotted in Figure 5(b). E1 (missing items) occurred more frequent than E2 (irrelevant items crossed out). 750 lx, 4000K resulted the highest error (E), 69.7% higher than reference light (300 lx, 4000K). Accuracy under 300 lx was prior to 750 lx under 4000K, while oppositely, the total number were higher under 750 lx rather than 300 lx.

3.3 Analytic Hierarchy Process for office work

Both psychological scale and physiological parameters were measured in this study. Whether there is collation between psychological scale and some of the physiological parameters need to be dig up. Thus, we analysis the correlation between psychological scale, work performance, physiological parameters using analytic hierarchy process.

We decomposed the decision problem into sub problems, including semantic difference scale, PANAS, KSS, D2 test, heart rate. A numerical weight is derived for each element of the hierarchy, allowing diverse elements to be compared. The weights are listed as following:

Table 2 – Analytic Hierarchy Process and weights for office work

Sub problem	Semantic difference scale	PANAS	KSS	D2 test	Heart rate
Weights	0.188901	0.056484	0.0745	0.497145	0.18297

With analytic hierarchy process, the evaluation under each light condition was calculated, illustrated in Figure 6. In this paper 4 lighting conditions were laid out, each with different illuminance and CCT.
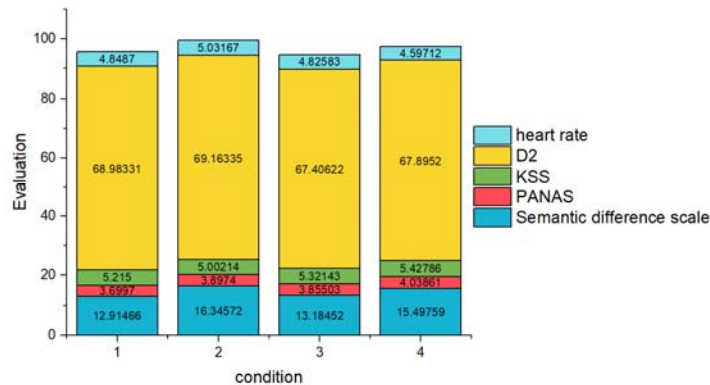

Figure 6 – Plots of analytic hierarchy process evaluation under four light conditions.

For different illuminance, 750 lx resulted in higher evaluation than 300 lx under both 4000K and 5000K, mainly corresponding to the contribution of higher evaluation in semantic difference scale. For different CCT, difference revealed in D2 test, which participants performed better under 4000K rather than 5000K.

The study of assessing lighting appraisal, work performance, physiological components in office environment offered that lighting appraisal, work performance, physiological components were influenced by both CCT and illuminance. Condition 750lx, 4000K provide respectively better mood (PANAS), feeling (semantic difference scale) and performance (D2 test) comparing with reference light, leading to higher total evaluation through AHP.

4 Conclusion

From this study, we found that:

Different CCT could lead to different feeling in office as commonly accepted, while also result in difference for work performance. 4000K provided a more integrated and luxurious atmosphere but less brightness than 5000K, together with higher accuracy and less error in D2 test.

Illuminance affects the mood, performance and psychological parameters for people with 300 lx recommended for office surface. The exploration for high illuminance (750 lx) and comparison between reference (300 lx) lead to the results that 750 lx provided a more colourful and luxurious atmosphere than 300 lx, together with high speed but worse accuracy in D2 test.

Lighting appraisal, work performance, physiological components were analysed through analytic hierarchy process and weight coefficients were calculated, which could be applied in further studies under office environment. Work performance yielded the highest importance.

Condition 750 lx, 4000K provide respectively better mood, feeling and work performance comparing with recommended illuminance 300 lx, leading to higher total evaluation through AHP. Though it was evaluated the best and most suitable for an approximately 30 min's office work in this study, the effect of time duration so as fatigue etc. should be explored in future research.

Acknowledgments

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Appendix A

The 25 atmosphere perception scales used in the experiment in English

No.	Scales in English	Literature sources	No.	Scales in English	Literature sources
1	Comfortable-Uncomfortable	a,b,c	10	Dangerous-Safe	b
2	Harmonious -Incongruity		11	Unfamiliar-Familiar	b
3	Restless- Tranquil	a,b	12	Suitable-Unsuitable	b
4	Bright-Dim	b	13	Integrated-Separated	b
5	Dislike-Like	b	14	Luxurious-Simple	a,b
6	Lifeless-Lively	b	15	Active-Repressed	b
7	Unnatural-natural	b	16	Colourful-Colourless	b
8	Soft-Glazing	b	17	Tense-Relax	a,b,c
9	Clear-Blurred	b	28	Lethargic-Alert	a,b

Note: a is Vogels 2008[14], b is Liu 2015[15], c is Wang 2014[16]