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Lighting does matter: Preliminary assessment on office workers

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Abstract

Correlated color temperatures (CCT) of light play an important role in human psychological and physiological needs. This study aims is to find out the effects of warm white (WW), cool white (CW) and artificial daylight (DL) on worker's performances, alertness, visual comfort and preferences. With the use of eye tracker and modified Office Lighting Survey, we have conducted a preliminary controlled experiment with 10 office workers. Result reveals significant increases of alertness levels when using WW lighting. We conclude that CW and DL lights were more beneficial in office setting for computer-based tasks and recommend future comprehensive study undertaken.

Keywords: lighting; visual comfort; alertness level; visual task performance

1. Background

Good lighting is required for good visibility of the environment and should provide a luminous environment that is human-friendly and appropriate for the visual task performed. Various studies have been conducted in order to identify the effects of lighting towards human health, productivity, and well-being and alertness level [1, 2, 3, 4]. In regards of human perception, two of the most important characteristics of lights are illumination and correlated color temperature (CCT) [5, 6]. Recently, studies have proven that different CCT provided by different lighting are important in affecting human beings psychologically and physiologically, through their visual and non-visual processes [7]. CCT is found to have effects on visual and mental fatigue. The right selection of CCT in an office environment will benefit its occupants in terms of visual comfort and reduction of daytime sleepiness. This will lead to an increase in productivity and prevention of health effects associated with inappropriate light CCT, such as eye strain or the effects towards emotion and human circadian rhythm [8].

1.1 Objective

The main objective of this study is to determine the visual and non-visual effects of light color temperature (2700K (warm white), 4000K (cool white) and 6200K (Day light)) among office workers. In order to achieve this,

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this preliminary study involves measuring the performance of dependent variables such as alertness, visual performance, typing and visual comfort across three different CCTs, namely WW, CW and DL with 10 subjects.

1.2. Scope

The scope of this study is to identify the differences in participants' alertness level, visual task performance, typing performance and subjective visual comfort and preferences among office workers when being exposed to different light CCT (WW 2700K, CW 4000K and DL 6200K). Furthermore, this study focuses only on the subjects' performance while using a computer, therefore all the test instrumentation are in digital form, such as the use of Microsoft's Word 2007, Paint, and Adobe's Reader (pdf files). Since this is a preliminary study, it has been confined to only 10 subjects who were selected based on the Malaysian demography.

1.3. Methodology

The study was conducted in a controlled environment, the MIMOS UX Lab [9], that is equipped with an eye tracker. The experiments were conducted in daytime from 21 until 29 January 2013 and each subject was tested on different days for each lighting condition. The subjects were made up of 10 office workers from MIMOS Berhad with age ranging from 20 – 45 years old. The study involves measurement of alertness level, visual comfort and subjective preference assessment, number of fixation, typing performance and visual performance. Table 1 shows the demography of the subjects for the three lighting conditions.

Table 1. Demography of subject used for this study

Demographics Data	No of respondents.	Percentage (%)
Age		
20-25	5	50
26-30	3	30
36-40	1	10
41-45	1	10
Hours spent daily on computer (Light On)		
2-4 hours	1	10
6-8 hours	7	70
>8 hours	2	20

Fig. 1. Light setting of the Usability Testing Laboratory in MIMOS Berhad (a) 2700K; (b) 4000K (c) 6200K

1.4. Environment Setup

The experiment was performed in MIMOS UX Lab, MIMOS Berhad located at Bukit Jalil, Malaysia. With a dimension of 14ft x 13ft, the room is illuminated with 8 ceiling bulb Philips TL-D 36W/827 (warm white, 2700K) for the first lighting condition, 8 ceiling bulb PHILIPS TL-D 36W/840 (Cool white, 4000K) for the second lighting condition and 8 ceiling bulb PHILIPS TL-D 36W/865 (Day Light, 6200K) for the third lighting condition. The environmental variables were controlled based on recommended indoor environmental [10]; this is achieved by setting an illuminance of 400 lux, temperature of 28°C and maintaining a consistent ergonomic sitting position.

1.5. Alertness Level

In each experiment, the respondent's alertness was monitored using the established Karolinska Sleepiness Scale (KSS). Linhart & Scartezzini (2011) have validated the KSS against electroencephalography (EEG) data by Akerstedt and Gillberg (1990) [11, 12] and found that median reaction time, number of lapses, alpha and theta power density and the alpha attenuation coefficients (AAC) showed highly significant increases with increasing KSS. The same variables were also significantly correlated with KSS, with a mean value for lapses ($r = 0.56$). The KSS was closely related to EEG and behavioral variables, indicating a high validity in measuring sleepiness [13]. KSS is a questionnaire for subjects to rate their actual alertness level on a 9-stage scale from being "extremely alert" (=1) to "very sleepy, great effort to keep awake, fighting sleep" (=9). It is deemed suitable in this study as one of the objectives is to measure subject's alertness level before and after performing tasks to gauge the impact of the various lighting condition on subjects while performing the relevant task that was selected to simulate the practices of office workers.

1.6. Visual Comfort and Preferences

Office Lighting Survey (OLS) is a questionnaire-based assessment method for occupant satisfaction regarding office lighting. It is generated by Eklund and Boyce in 1996, and consist of 10 questions in agree-disagree format [3]. As for this study, a modified version of OLS is used consisting of 13 questions. The reliability of this modified OLS was determined statistically (Cronbach's Alpha = 0.928). In the questionnaire, a mix of general and artificial lighting-specific statements were asked. Subjects were asked to rate their agreement with each statement by using the 7-point Likert scale (Table 2).

Subjects' preferences were assessed from Question 1 to 6, while visual comfort level was assessed from Question 7-12 onwards. Scores were given for every response made. For Question 1 to 4 (positive statements), +6 points were given for response of 'Strongly Agree', +5 for 'Agree', +4 for 'Somewhat Agree', +3 for 'Neutral', +2 for 'Somewhat Disagree', +1 for 'Disagree' and +0 for 'Strongly Disagree'. While for negative questions ranging from 5 to 12, +6 points were given for response of 'Strongly Disagree', +5 for 'Disagree', +4 for 'Somewhat Disagree', +3 for 'Neutral', +2 for 'Somewhat Agree', +1 for 'Agree' and +0 for 'Strongly Agree'. Hence, the eye tracking technology that was used yielded no recommendations regarding optimal lighting in office conditions.

1.7. Typing performance test

To determine the optimum CCT for typing performance, subjects were required to type an article using Microsoft Word 2007 by referring to a printed document within the duration of 10 minutes. Three different articles (approximately 400 words) were prepared using similar levels of difficulty. The automatic spelling and grammar checking functions were disabled, as we wanted to measure the accuracy of the subject's typing performance under various lighting conditions. For each lighting condition, the typing speed (total numbers of words typed) and typing accuracy (percentage of typing errors) were recorded.

1.8. Eye Tracker in measuring numbers of fixation

Tobii T60 Eye Tracker was used to measure number of points of fixation on the computer screen. The aim was to observe the impact of different light color temperature on subject performance by measuring the number of points of fixation on the screen while performing tasks. The number of points of fixation is a measure of total gazes (fixations) captured by the eye tracker from the start to the end of performing a specified task. Similar studies performed by subjects on a web interface has shown high levels of correlation between the fixations (gaze plot) and the subject's think- aloud or feedback capture after task (FCAT) [15]. The heat maps generated from the eye tracker is able to reveal important information such as the crucial design consideration in developing an e-Commerce website [14]. In our study, both the heat map and gaze plot was useful to show subject's level of alertness while performing task of different level of difficulty. For each lighting condition, the number of fixations and the accuracy of task performance were recorded.

Table 2. Modified Office Lighting Survey (OLS)

No.	Questions
1	I like the lighting in this office.
2	In general, the lighting in this office is comfortable.
3	This color of light allows me to carry out the different tasks.
4	My skin looks natural under the light.
5	The lighting in this office is too warm (yellowish).
6	The lighting in this office is too cold (bluish).
7	I feel eye strain when working under this lighting scenario.
8	I find my eye lids are heavy when working under this lighting scenario.
9	I find my eyes feel dry when working under this lighting scenario.
10	I have burning eyes.
11	I have a headache working under this lighting scenario.
12	I have difficulties in seeing objects on the screen.

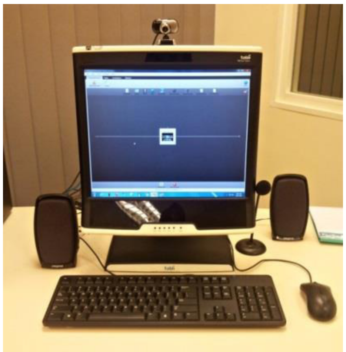

Fig. 2. Tobii Eye Tracker T60 used to capture fixation, heat maps and gaze plots [9, 14, 15]

1.9. Visual Performance

1.9.1 Proofreading Task (PT)

The subjects were given 2 sets of 10-word string articles (using Acrobat Reader's pdf format) that were called Set A and Set B which are displayed in two columns. Set A consisted of the original set of strings while Set B was modified from Set A to contain few differences to enable the proofreading. Subjects were required to identify the differences in Set B by referring to Set A. When a difference was spotted, subjects were required to highlight the discrepancy. This was used to assess the visual performance of respondents while using computers. The visual performance scores for the PT for each subject were calculated using equation 1:

$$PT= (T-E)/100/ (S+10) \quad (1)$$

where T is number of trial (always 20 rows), E is the numbers of error and S is time in seconds.

1.9.2. Numerical Verification Test (NVT) Task

Similar with the proofreading task, 2 sets of 10-digit strings that consisted of 20 lines on each column were prepared. The left column displaying Set A contained the original or reference numerical strings set while Set B displayed on the right column contained few differences. The subjects were again required to identify and highlight the differences. The visual performance scores for the NVT for each subject were calculated using equation 2:

$$NVT= (T-E)/100/ (S+10) \quad (2)$$

where T is number of trial (always 20 rows), E is the numbers of error and S is time in seconds. The formula is a modified version of Rea (1981) (NVT = (T-E)/100/(S+5) where a 5-digit string was used [16]. It was found to be a very easy task for subjects of this study, given that all subjects were office workers. Therefore, it was modified accordingly to the use 10-digit string instead.

1.9.3. Matching Task (MT)

While performing the sanity test, it was found the PT and NVT tasks were indeed simple and thus had a low level of difficulty. In order to increase the complexity of the task in stages, a more difficult matching task was added. In this task, two sets of Animal Lists were given. Set A is the original list of animals while set B contained extra animals that were not in Set A. Additionally unlike the PT and NVT tasks, the order of items appearing in Set B was different from Set A. Subjects were required to identify and highlight the animals that were found in Set B that did not match those in Set A using the “highlight text” tool in pdf file. This task had a 10 minute time limit. The performance scores were calculated based on the number of correct matches and points were deducted for incorrect answers.

1.9.4. Study procedure

Initially 10 subjects were recruited from an organization. Before study was started, subjects were briefed in detail with regards to the flow (Fig.3) and purpose of this study. Subjects were required to sign a consent form to indicate their willingness to participate in this study. During the experimental phase, we randomized the sequence of lighting scenarios to measure alertness, visual comfort and preference, and task performance. Each trial was expected to be completed in 45 minutes. The detailed process of our study is shown in Fig. 3.

At the start of the study, the subjects were allowed to adapt to the lighting condition for 5 minutes. They were also advised to sit in an ergonomic position. Subjects began the experiment with the typing task. Within 10 minutes, the subjects were required to type as many words as they could. Next, the Tobii T60 Eye Tracker was set up and a 9 –point calibration was performed. This eye tracker monitored the eye gaze patterns of the subjects as they performed the tasks set before them.

Since the procedure involved many manual tasks which are time consuming and error prone, we used a user research gathering tool known as URANUS [21], which automated the data gathering, testing and analysis. With a total of 4 tasks for 10 subjects across 3 lighting conditions, URANUS enabled us to add the task and questionnaire related to Karolinska Sleepiness Scale measurement [11], demography, and modified Office Lighting Survey (OLS), which ensured efficient and high data integrity for this study. Subjects filled a demographic questionnaire together with the KSS before the starting the study using URANUS. Then subjects then proceeded to complete Tasks 2 to 4. The subjects were required to complete the proofreading task within 5 minutes, followed by the NVT task also within 5 minutes. The fourth task was to be completed within 10 minutes. Towards the end of the study, the subjects would fill up the OLS and second KSS.

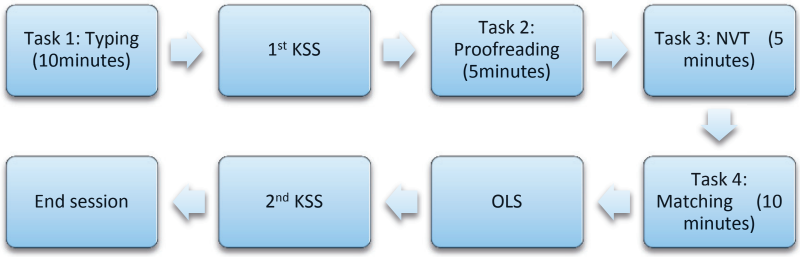

Fig. 3. Experimental process flow

2. Result and Discussion

2.1. Alertness Level

Figure 4 shows the comparison of alertness levels before and after the trial. There is significant increase of alertness levels among subjects under WW (0.7 increase) and CW (0.8 increase) light towards the end of the experiment as compared to DL. A paired Sample T-Test was used to compare the pre-experiment alertness level with the post-experiment alertness level under respective light sources. Statistical analysis shows that there are significant changes in the alertness level of subjects when exposed under WW light (Pair sample T-test, $p=0.025 < 0.05$) whereby their alertness levels increased towards the end of the experiment. In contrast, under CW light ($p=0.07 > 0.05$) and Daylight (0.678) conditions, no significant changes were recorded. This is surprisingly different from findings of previous research that stated DL is meant to increase the alertness level of those being exposed to it. High CCT was associated with better alertness [16]. Our findings is in contrast to the study conducted by Górnicka (2007) [8], where he compared two different CCT of lights condition (2700K & 17000K), and concluded that there were no significant effects between light settings on non-visual processes which was the evening alertness level in his research.

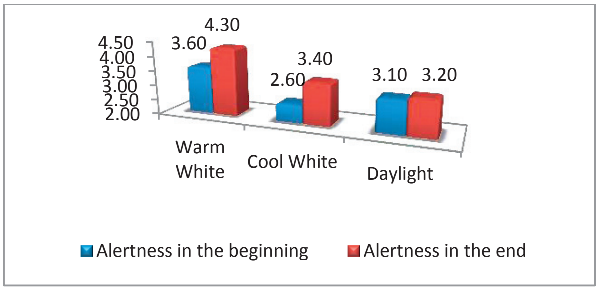

Fig. 4. Comparison of alertness level before and after the trial

2.2. Visual Comfort Level and Subjective Preferences

Fig. 5 shows that subjects were most comfortable under CW light (27.2 points); the difference among the visual level of comfort across three lightings experienced by subjects were found to be significant (r-ANOVA, $p = 0.010 < 0.05$).

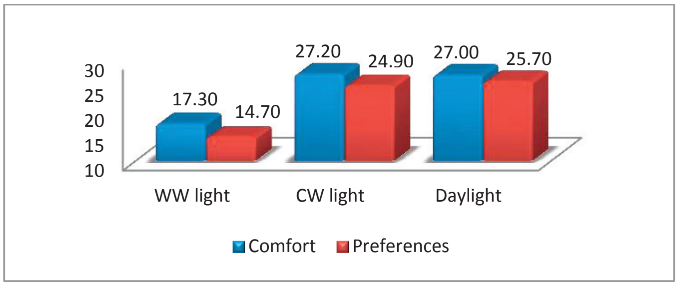

Fig. 5. Comparison of comfort level and preferences between three light CCT exposure

In terms of preference, it was found that the subjects of the study significantly preferred Daylight over WW light ($p = 0.001$, < 0.05). DL was also considered as comfortable light CCT (27 points) as compared to WW (17.5) with the statistical analysis showing a significant difference (r-ANOVA $p=0.006$, <0.05). Furthermore, CW (24.9 points) is also considered more preferable light CCT to WW (14.7 points) whereby statistically, r-ANOVA $p = 0.02$, <0.05.

Subjective preference on light color temperature varied between individuals. In a previous study, Miller (2007)[22] found that the preferences of lighting conditions varied between people and even to the extent of the same person preferring different lighting conditions during different times of the day. In contrast, another study suggested that there are no trends of individual preference in choice of light color in an office environment [1].

2.3. Typing Task Performance

For the typing test, subjects working under the CW light responded with the highest typing speed of an average of 298.60 words, followed by Daylight having 280.6 words. Subjects under the WW light had the slowest typing speed of 263.4 words (Table 3). Further statistical analysis using r-ANOVA yield that there was a significant difference between the typing speeds of subjects exposed under CW light ($p=0.08$, <0.05) and Daylight ($p=0.03$, <0.05). Meanwhile subject typing speeds under WW light did not have any significant differences when analyzed by using r-ANOVA ($p=0.14 > 0.05$).Therefore, typing accuracy was said to not be affected by the differences of light CCT (r-ANOVA $p > 0.05$).

Our results show some linkage between speed of typing and visual comfort. As participants felt most comfortable under CW light (Fig. 5), they typed significantly faster than WW (least comfortable perceived). The finding was compatible with another study done by Park et al. (2010), whereby their work performance under CW condition was shown to be higher than WW [18]. In addition, another study also pointed out that WW light was less effective in information processing (looking at paper and reading) and implementation (typing) [19].

For typing accuracy, subjects committed the least amount of errors under WW setting. Typing accuracy was used as an assessment of the subject’s level of alertness. Thus, the significant increase in performance could be related to increased alertness levels under WW as shown in Fig. 4. This result is slightly different from previous studies conducted among university students, whereby the accuracy using DL was higher as compared to WW [20]. The reason behind this difference can be due to the low number of study subjects in this research.

Table 3. Comparison of Typing Performance

CCT	Typing speed (Mean ± S.D.)	Typing accuracy (% of error)
WW light (3000K)	263.40 ± 61.107	0.025 ± 0.011
CW light (4000K)	298.60 ± 60.939	0.031 ± 0.013
DL (6200K)	280.60 ± 58.327	0.028 ± 0.010

2.4. Numbers of Eye Fixation

Fig. 6 shows that CW light had the highest average number of eye fixation (79%) followed by WW light (77.5%) and Daylight (74%). According to statistical analysis using r-ANOVA (yield that p= 0.786 (WW), p=0.647 (CW) and p= 0.178, >0.05), there were no significant differences between the three different light CCT and number of eye fixation. This showed that different CCT of lights did not influence the numbers of eye fixation on the computer screen. Fig. 6. There were few factors associated with using the eye tracker in collecting the numbers of fixation on the computer screen, such as incorrect sitting position and personal characteristics of the study sample. Even though it has been controlled by providing ergonomic sitting position for the study subject, the personal characteristic of the study subject did interfere with the data collection.

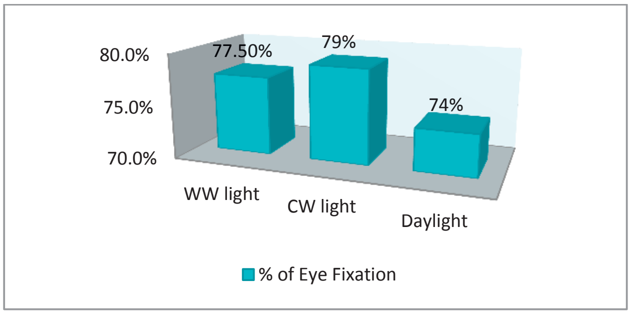

Fig. 6. The comparison of average for number of eye fixation under different light CCT.

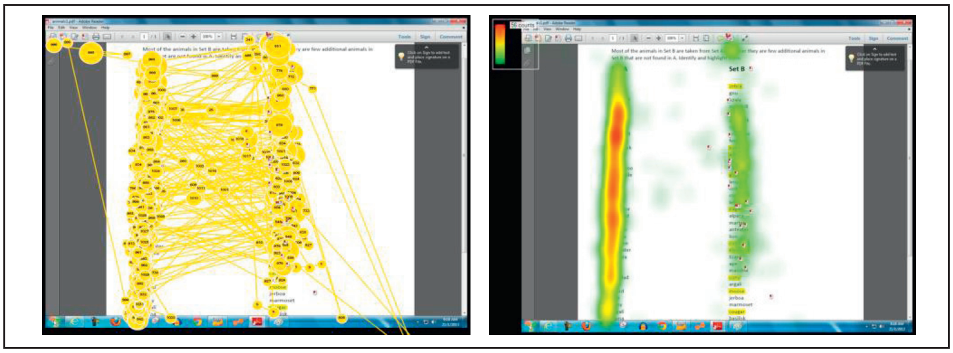

Fig. 7. Gaze Plot and Heat Map for Matching Task

2.5. Visual Task Performance

There are 4 visual tasks that were related to the use of computers. Fig. 8 shows the overview of average scores for each task performed. Further analyses were conducted by using repeated measures by ANOVA and it was proven that there were no significant differences in the visual task performances conducted under different CCT of lights (r-ANOVA p>0.05). This implies that differences in CCT of lights do not affect workers' performance involving the use of computer. This finding supports a previous study conducted among 17 subjects stating that different CCT of light do not significantly affect visual performance [17]. Another study among office workers also indicated that work performance was not related to CCT of lights [18].

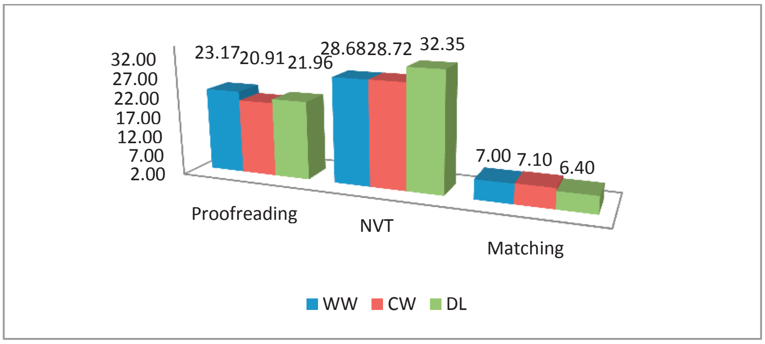

Fig. 8. Comparison mean score of visual task performed under different light CCT.

3. Conclusion

This preliminary study led to few findings. Firstly, CW is the most comfortable CCT of light while DL was found to be the most preferred light CCT. This was proven when the study subjects mentioned that they could imagine themselves working with computer under the specified CCT of light for more than 6 hours. Secondly, subjects working under the WW light recorded the highest increase in level of alertness. This finding differs from previous studies that found WW had led to a reduction of alertness level. Meanwhile, numbers of eye fixation on computer screen was not affected by the difference of light CCT. Hence, the eye tracking technology that was used yielded no recommendations regarding optimal lighting in office conditions. Similarly, for visual task performance, there were no significant differences reported by subjects under different CCT of lights. Finally, regarding typing speed, our study showed that subjects typing under the CW light demonstrated the highest speed. It can be concluded that there is no absolute perfect light color temperature for office workers. However, CW and DL light were found to be more beneficial to office workers than the WW light in terms of being most comfortable and preferred.

Some limitations of the study should be acknowledged. The study had included small numbers of subjects from one office setting only, which makes generalizing the findings somewhat difficult. Also, the study included self-reported perceptions, which might be problematic in terms of the reliability of measurements. Besides that, as with other experiments on the effects of lighting, it is almost impossible to implement a double-blinded design. Therefore, it is unavoidable for the results to be at risk of being influenced by the Hawthorne effect, where participants might perform outstandingly well (sometimes poorly), as they know that they were being observed and assessed. Therefore, advance study should be conducted in order to identify the optimum CCT of light under office settings, as the findings would be beneficial to the wellbeing of workers and lead to an increase in their performance that will lead to higher productivity.

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