UNIVERSITI PUTRA MALAYSIA

EFFECTS OF LIGHT'S COLOUR TEMPERATURES ON VISUAL COMFORT LEVEL, TASK PERFORMANCES, AND ALERTNESS AMONG UPM'S STUDENTS

BY
SIA CHEE CHAI

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ABSTRACT

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SIA CHEE CHAI

Introduction: As one of the determinants of lighting quality, the correlated colour temperatures (CCT) of light source plays role in both psychological and physiological needs. Influences of different light's CCT are to be tested and studied among undergraduate students of UPM, Malaysia. **Objective:** The aim of this study is to determine the effects of warm white (WW) light (CCT=3000K), cool white (CW) light (CCT=4000K) and artificial daylight (DL) (CCT=6500K) on students' performances, subjective alertness level, visual comfort level and preferences. **Methodology:** A controlled experiment was conducted on total of 47 volunteer undergraduate students under three coloured light sources in a windowless room. FrACT software was used to assess visual task performance, modified OLS questionnaire was used to evaluate subjective comfort level and preferences, typing test and KSS alertness level monitoring was performed. **Result:** The results showed that there were significant increases of subjective alertness level ($p=0.041$) and computer-based performances ($p=0.001$) under DL condition in relative to WW condition. In term of typing performances, subjects performed significantly better in term of typing speed under CW light than DL and WW light. Least typing errors were made under DL, followed by CW light and WW light. CW is the most preferred ($p=0.001$) and most comfortable ($p=0.011$) colour for subjects, and subjects indicated that they can perform longer works in this coloured-lit environment. **Conclusion:** The study concludes that the CW light and DL light were more beneficial for alertness level and academically activities including both computer-based and paper-based activities.

KEYWORDS: Lighting, correlated colour temperatures, visual comfort, alertness level, visual task performance.

ABSTRAK

PENGARUH WARNA CAHAYA PADA PERINGKA KESELESAAN DAN KEGEMARAN, PRESTASI TUGAS DAN KEPEKAAN DI KALANGAN PELAJAR UPM.

SIA CHEE CHAI

Pengenalan: Sebagai salah satu daripada penentu kualiti pencahayaan, suhu warna berkorelasi (CCT) sumber cahaya memainkan peranan dalam kedua-dua keperluan psikologi dan fisiologi. Pengaruh CCT cahaya yang berbeza adalah diuji dan dikaji di kalangan pelajar ijazah UPM, Malaysia. **Objektif:** Tujuan kajian ini adalah untuk menentukan kesan cahaya *warm white* (WW) (CCT=3000K), *cool white* (CW) cahaya (CCT=4000K) dan *daylight* (DL) (CCT=6500K) ke atas prestasi tugas, tahap kepekaan subjektif, tahap keselesaan dan kegemaran. **Kaedah:** eksperimen terkawal telah dijalankan ke atas sejumlah 47 orang pelajar sarjana muda sukarelawan di bawah tiga sumber cahaya berwarna dalam sebuah bilik tanpa tingkap. Perisian FrACT telah digunakan untuk menilai prestasi tugas visual, soal-selidik OLS telah digunakan untuk menilai tahap keselesaan dan kegemaran yang subjektif, ujian menaip dan pemantauan tahap kepekaan KSS telah dilakukan. **Keputusan:** Hasil kajian menunjukkan bahawa terdapat peningkatan tahap kecerdasan subjektif ($p=0.041$) dan prestasi berasaskan komputer ($p=0.001$) di bawah keadaan DL relatif kepada keadaan WW. Dalam ujian menaip, subjek mencapai prestasi yang jauh lebih baik dari segi kelajuan di bawah cahaya CW daripada DL dan cahaya WW. Kesilapan menaip terkurang telah dibuat di bawah DL, diikuti oleh cahaya CW dan cahaya WW. CW adalah warna yang paling digemari ($p=0.001$) dan yang paling selesa ($p=0.011$) bagi subjek, dan mereka berpendapat bahawa mereka mampu melakukan kerja-kerja yang lebih panjang dalam persekitaran sedemikian. **Kesimpulan:** Kajian ini menyimpulkan bahawa cahaya CW dan DL lebih bermanfaat daripada cahaya WW untuk tahap kewaspadaan dan akademik aktiviti yang termasuk kedua-dua aktiviti berasaskan komputer dan berasaskan kertas.

KATA KUNCI: Lampu, warna cahaya, keselesaan visual, tahap kepekaan, prestasi tugas.

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LIST OF ABBREVIATIONS

CCT	Correlated colour temperature
CIE	Commission Internationale de l'Eclairage
CW	Cool White
WW	Warm White
DL	Daylight
FPSK	Faculty of Medicine and Health Sciences
FrACT	Freiburg Vision Test
K	Kelvin
UPM	Universiti Putra Malaysia

CHAPTER 1

INTRODUCTION

1.1 The Background of the Study

Light is defined as electromagnetic radiation that is visible to human eyes, and it is responsible for the sense of sight (CIE, 1987). Light is very critical for human to see things and perform activities. Physiologically, when the radiation enters the eyes through pupil, it is focused by the lens, and then detected by photoreceptive cells on the retina, thus stimulating vision (Veitch, 2006).

In current practice, most buildings are lit by a combination of sunlight entering through windows and artificial-light sources. Sunlight, the natural source of light, is electromagnetic radiation in the wavelength range that can be absorbed by the photoreceptors of the eyes; whereas artificial electric-light are composed of wavelengths of lights that are concentrated in limited areas of the visible light spectrum (Joseph, 2006).

The main purpose of lighting is to supply a comfortable and an efficient environment that meet requirement of the users' vision from physical to psychological aspects (Sanaz, 2011). This is also important to improve occupants' well-being, motivation and morale, thus leading to a higher or better performance (Boyce, Veitch, Newsham, Myer & Hunter, 2003; Manay, 2007). Also, the right lighting of a workplace can positively influence the health of office personnel, improve efficiency, reduce unnecessary sick leave and result in greater productivity (Altomonte, n.d.).

Good and suitable lighting quality is one of the main determinants of healthy indoor environment. Generally, lighting quality is much more than just providing an appropriate quantity of light (Halonen, Tetri, & Bhusal, 2010). In regards of human perception, two of the most important characteristics of light are illuminance and correlated colour temperature (CCT) (Barkmann, Wessolowski & Schulte-Markwort, 2011; Veitch & Newsham, 1998). Recently, studies proved that different CCT provided by the various types of lighting are important in affecting human beings psychologically and physiologically, as well as visual and non-visual processes (Halonen, Tetri, & Bhusal, 2010; Edwards & Torcellini, 2002; Joseph, 2006; Górnicka, 2008).

CCT is an essential factor in the physical learning environment because it supports and enhances the impact of lighting on users (Sanaz, 2011). Right use of CCT can be beneficial to occupants, such as improving attention span of students during classes. In opposite, improper light's CCT has effects on human health, such as eyes strain, or effects to the emotion and human circadian system (van Bommel & van den Beld, 2004; Halonen, Tetri & Bhusal, 2010).

Undergraduate students are expected to spend most of the time in indoor environment such as lecture hall and library. They are usually exposed to different types of lighting setting under various circumstances. Researches on effects of lighting to students in school have been conducted, but the effects across parameters such as mood, distractibility, visual comfort and performances of students were inconsistent (Barkmann, Wessolowski, & Schulte-Markwort, 2011). Up to date, there is a still a doubt on which CCT of light is the most suitable for students' activities, including use of video display unit, and the use of printed documents.

1.2 Problem Statement

Since the widespread availability of electricity, artificial lighting has become the main medium of lighting within the work and home settings (Frost & Gifford, 2011). For over 50 years of research and practice, the focus of study on lighting was slowly shifted from mere lighting comfort and task activities towards lighting and health (Bluyssen, 2010). Moreover, the need for lighting to improve alertness and performance became the focus point. However, the concept of ergonomic is not commonly associated in general awareness with lighting, and it seems to take a long period before academic research affects day-to-day lighting practice (Stephenson, 2004).

Most people nowadays spend more than 90% of their time indoors, often in school or offices (Altomonte, n.d.), where they expose to different settings of light. Even though colour of light is found to be related to visual fatigue, visual operation of the human eye, well being and comfort, but there is still little was known about its effects on visual task performances (Lin, Feng, Chao, & Tseng., 2008; Stephenson, 2004). In 2010, Sanaz stated that lighting has common adverse exhibits on students, such as itchy eyes after reading and decreased productivity and accuracy in academic activities. This is to say that the lighting technology has not yet been optimized to support students with their studies.

In addition, there was no consistent study comparing the visual and non-visual effects of different colours of light among undergraduate students. There is still a doubt on which CCT of light (3000K, 4000K and 6500K) is superior for academic activities. More importantly, rarely there are studies done to correlate between lighting and health in Malaysia setting, reflecting there is lack of awareness of potential effects of lighting towards occupants exposed to it.

Therefore, research has to be done to answer on what extend of CCT of light sources to affect task performance, alertness level, individual visual comfort level and subjective preferences of people in an indoor environment, such as in school or office.

1.3 Study Justification

Influences of coloured lighting on human are needed to be determined because of its importance in visual and non-visual processes (Górnicka, 2008). Finding of the effects on the variation of colours of light sources were inconsistent, and some were contradictory to one another. Therefore, study like the present one is expected to generate more input for achieving better indoor quality.

There were studies related to the use of lighting in relation to well being of occupants such as school, college and university students (Lin et al., 2008; Shieh & Lin, 2000; Linhart & Scartezzini, 2011; Barkmann et al., 2011). Yet, not much have been emphasised on the outcomes of raising numbers of coloured lighting application on the exposed occupants. Thus, the question to be answered in this study is to what extent CCT of light source can influence alertness, task performances and visual comfort level of people in the office work situation.

An important question concerns the role of the CCT of light is which would be more effective for both visual and non-visual processes during the day. In general, this study is expected to contribute to the community or industry by determining the effects of commonly used colours of lighting (which are bluish light, yellowish light and white light) on visual task performance, visual comfort level, and alertness among the students.

By the time when the study is conducted, the yellowish light sources (CCT=3000K) is used in most places in Faculty of Medicine and Health Sciences (FPSK), Universiti Putra Malaysia (UPM). By conducting this study, it will to provide opportunities to design better lighting conditions optimized for students' performance and well being. The results of exploring these effects of coloured light in this experimental study should be important for defining new reference for lighting installation, serving both occupants' visual and non-visual needs.

1.4 Conceptual Framework

Figure 1.1 shows the conceptual framework which is used to outline and explain the relationship between chosen variables and study problems in the experiment. This study is aimed to single out the most suitable colour temperature for undergraduate students in an indoor environment, for the purpose of academically activities in particular.

In this experiment, the independent variable of this study is the CCT of light source, while the dependent variables are both visual and non-visual effects on the respondents. The variables include visual comfort level, participants' preferences, subjective alertness level, computer and paper-based task performances, and typing performances.

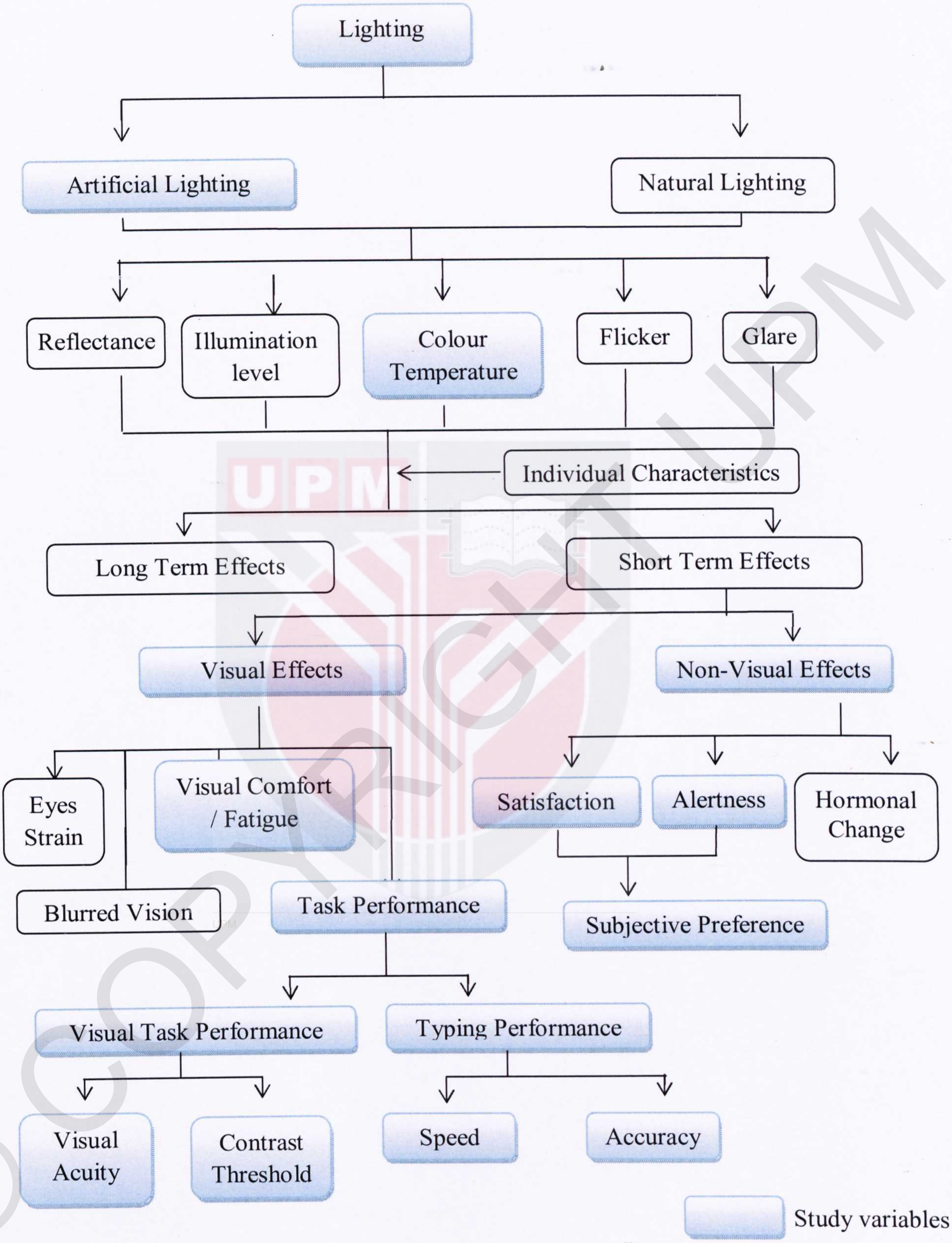

Figure 1.1 : Conceptual framework of the variables affected by CCT of light

1.5 Objectives

1.5.1 General Objective

To determine the effects of light's colour temperatures on task performances, visual comfort level, preferences and alertness level among undergraduate students of FPSK, UPM.

1.5.2 Specific Objectives

1) To determine the socio-demographic status of undergraduate students of FPSK, UPM.
2) To compare the visual comfort level and preferences among the undergraduate students of FPSK under different CCT of light.
3) To determine the significant difference of alertness level changes among the undergraduate students of FPSK under different CCT of light.
4) To compare the visual task performance among the undergraduate students of FPSK under different CCT of light.
5) To compare the contrast threshold level among the undergraduate students of FPSK under different CCT of light.

6) To compare the typing speed and accuracy among the students under different CCT of light.
7) To determine the optimum CCT of light for various tasks for undergraduate students of FPSK.

1.6 Research Hypothesis

1) There is significant difference of visual comfort level and preferences among the undergraduate students of FPSK under different CCT of light.
2) There is significant difference of alertness level among the undergraduate students of FPSK under different CCT of light.
3) There is significant difference of visual task performance among the undergraduate students of FPSK under different CCT of light.
4) There is significant difference of contrast threshold level among the undergraduate students of FPSK under different CCT of light.
5) There is significant difference of typing speed and accuracy among the undergraduate students of FPSK under different CCT of light.
6) There is one CCT of light optimum for visual and non-visual effects for undergraduate students of FPSK

1.7 Definition of Terms

1.7.1 Correlated Colour Temperature

Conceptual Definition

Correlated colour temperature (CCT) is the evaluation for the colour appearance of the lamp itself and the light emit from it (Halonen et al, 2010), and it is expressed on the Kelvin scale (K). CCT is used to indicate how cool or warm the light source appears. If the light source has high CCT, the amount of blue light in the spectrum increases, and thus the appearance of that light is cooler. (Manay, 2007; Altomonte, n.d.). It is used together with colour rendering index to describe the colour of light sources.

Operational Definition

There are three types of lights with different CCT to be tested in current study, which are warm white (WW) light (3000K), cool white (CW) light (4000K), and cool daylight (DL) (6500K) (CIE, 1987).

Nine ceiling light tubes of Philips' MASTER PL-L 36W/830/4P are used to supply WW light, while eight light tubes of Tian He's Tricolour (36W) and Liyoda's PLL*36W/EX-D are used to supply CW light artificial DL, respectively.

1.7.2 Subjective Preference and Visual Comfort

Conceptual Definition

Subjective preference is defined as the satisfaction level of occupants on whether the lighting conditions are appraised against expectations (Boyce, Veitch, Newsham, Jones, Heerwagen, Myer, & Hunter, 2006). In simpler words, it is how an occupant like or dislike the lighting condition.

Visual comfort is a state of consciousness evolved as a result of physiological and psychological effects. It expresses satisfaction with the visible environment. Visual comfort may be assessed using the feature belonging to a person such as eyestrain, blurred vision, drowsy, headache, etc. On the other hand, visual comfort may be described with the features belonging to lighting, such as too cold light, too bright, glares, and reflectance (Górnicka, 2008)

Operational Definition

Modified version of Office Lighting Survey (OLS) is used to assess how satisfied and comfortable the occupant feels towards the tested lighting scenarios (Linhart & Scartezzini, 2011; Akashi & Boyce, 2006). Standard score will be given for both comfort level and preferences. The calculation of comparable scores will be detailed out in Chapter 3.

1.7.3 Alertness

Conceptual Definition

Alertness is the state of readiness to detect and respond to certain specified small changes occurring at random intervals in the environment, which requires a person to pay close and continuous attention (Liu & Wickens, 1992).

Operational Definition

Karolinska Sleepiness Scale (KSS) will be adopted and used to test subjects' sleepiness and alertness. It is a 9-stage scale going from "extremely alert" to "very sleepy, great effort to keep awake, fighting sleep", where the person has to state their subjective perception on alertness under specific lighting scenarios, before and after the experiment.

1.7.4 Visual Task Performance

Conceptual Definition

Visual task performance is defined by the visibility speed and accuracy of performing a visual task (CIE, 1987) and its model is used to evaluate the interrelationships between visual task and visual performance, visual target size and contrast and luminance level (CIE, 2002).

Operational Definition

Both computer-based and paper-based task performances will be evaluated by using Freiburg Vision Test (FrACT). To measure computer-based task performance, speed and accuracy of responses made by occupants are the important determinants. Visual performance can be measured by the total number of correct responses over total duration of a trial. The formula is as below:

$$\text{Computer} - \text{based Task Performance} = \frac{\text{Total numbers of correct responses}}{\text{Duration to complete the trial (sec.)}}$$

Paper-based task performance will be evaluated by calculating the numbers of wrong responses made on paper task given within 5 minutes. The fewer errors made, the better is the performance for this variable.

1.7.5 Contrast Threshold Level

Conceptual Definition

Contrast is defined as a product of different reflectance between a subject of view and its background (Stephenson, 2005). The contrast threshold is defined as the amount of contrast a person needs to see a target. Typically the detection limit for a target is the lowest contrast threshold, where it is reciprocal to contrast sensitivity. Thus, persons with low thresholds are said to have high sensitivity, and those with high thresholds have low sensitivity (Owsley, 2003).

Operational Definition

To evaluate the contrast threshold level of students, computerized software, FrACT again will be used. Weber Contrast is used to express the contrast threshold in the experiment because it is commonly used in cases where small features are present on a large uniform background. Normal Weber contrast of a person is 1.0 percent to 2.0 percent (Lueck, 2004).

The software will automatically calculate the contrast threshold of subjects after each trial. Also, the developer of this software has included the formula of Weber Contrast in the manual as below:

$$Contrast_{Weber} = 100\% \times (L_{max} - L_{min}) / L_{max}$$

1.7.6 Typing Task Performance

Conceptual Definition

Typing speed and typing accuracy are the indicators for typing performance in this study.

Operational Definition

Typing speed is defined as total numbers of words typed in 10 minutes, while the typing accuracy is defined as the percentage of correctly typed words over total words typed in 10 minutes.

The formula for typing accuracy is as below:

$$\text{Typing Accuracy} = \frac{\text{Numbers of correctly typed words}}{\text{Total numbers of words typed in 10 minutes}}\ X\ 100\%$$

CHAPTER 2

LITERATURE REVIEWS

2.1 Physiology of Eyes

Physiologically, when the light, in the form of radiation, enters the eyes through pupil, it is focused by the lens, and is detected by photoreceptive cells on the retina, thus stimulating vision (Veitch, 2006). There are 3 types of photoreceptors that have been identified responsible to vision of human.

2.1.1 Cone Photoreceptor

The cone system is responsible for sharpness, high visual acuity and detail and colour vision (Górnicka, 2008). For all indoor lighting situations, the cones are to a very large extent decisive (van Bommel, & van den Beld, 2004). Also to say that, cones are not as sensitive to light as rods and they work optimally under daylight conditions (photopic vision).

2.1.2 Rod Photoreceptor

The rods contain the visual pigment rhodopsin and are sensitive to blue-green light with peak sensitivity around 500 nm. Rods have a low threshold for detecting light, in other words they are highly sensitive to light (Górnicka, 2008). In other words, the rods operate in extremely low-level light situations (scotopic vision) and do not permit colour vision (van Bommel, & van den Beld, 2004).

2.1.3 Novel Photoreceptor

The novel third photoreceptor, intrinsically photoreceptive retinal ganglion cell (ipRGC), was discovered in 2002. It has been found to be the main photoreceptor responsible for entraining humans to the environmental light/dark-cycle along with other biological effects, or more commonly known as non-visual effects. It represents a missing link in describing the mechanism of biological effects as controlled by light and darkness (Halonen, Tetri, & Bhusal, 2010). However, the discussions about the working of the novel photoreceptor, their specific location, parallelism with the visual system and the transformation of the light signals, are still ongoing (Górnicka, 2008).

2.2 Mechanism of Light Entering Eyes

The photoreceptor cells in the retina of the eye, the cones and rods, regulate the visual effects. When light reaches these cells, it is transformed into electrochemical signals followed a complex chemical reaction occurs (van Bommel, & van den Beld, 2004; Górnicka, 2008). The chemical that is formed (activated rhodopsin) creates electrical impulses in the nerve that connects the photoreceptor cells with the back of the brain (visual cortex). In the visual cortex of the brain the electrical impulses are interpreted as "vision". Information to the visual cortex about color, contrast, shape, and movement are interpreted.

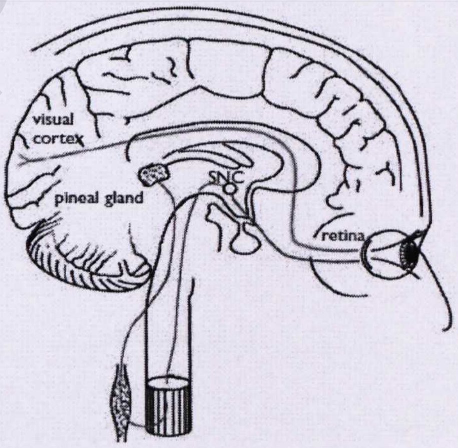

Figure 2.1: Visual and biological pathways in the brain

Figure 2.1 shows the nerve connections between the retina of the eye, with its cones and rods, and the visual cortex on the one hand (in red). Also, the connection between the retina, with the novel photoreceptor cell, and the suprachiasmatic nucleus (SNC) and the pineal gland are illustrated in blue (van Bommel, & van den Beld, 2004).

2.3 Lighting Quality

One of the most important features in indoor environment is lighting. Both natural and artificial light is needed in a proper and adequate amount to carry out normal activities of everyday office work (Hameed & Amjab, 2009). The main purpose of office lighting is to provide a comfortable and an efficient working environment. With the presence of visual and psychological comfort conditions, ergonomic lighting will not only ensures user's well-being, but also increases motivation that will lead to a higher performance and improved productivity (Ozdemir, 2010).

The quality of lighting depends largely on people's expectations and past experiences (Halonen, Tetri, & Bhusal, 2010). However, it is generally agreed that the lighting system should be designed to supply appropriate illuminance and colour temperature to meet the requirement of the users' vision form physical to psychological aspects (Sanaz, 2011). In specific, lighting quality is related to objectives like enhancing performance of relevant tasks, creating specific impressions, generating desired pattern of behaviour and ensuring visual comfort.

Halonen, Tetri, & Bhusal (2010) indicated that light quality can be discussed from visual and non-visual aspects. For visual aspect, its quality is measured according to the level of visual comfort and performance required for our activities. Besides that, it can also be assessed from the psychological basis, where the pleasantness of the visual environment and its adaptation to the type of room and activity are the focus points.

2.3.1 Historical Aspects

The visual effects of lighting have studied for more than 500 years. The use of artificial electric lighting has increased rapidly over the last hundred years both in daytime and nighttime, allowing humans to adapt to 24 hour active society (Teikairi, 2007). In late 1980s and during the 1990s, the WHO concept of health, became significant for identifying the concept of a ''healthy building'' in terms of building performance, where lighting quality and acoustics became one of the important parameters (Bluyssen, 2010).

Since the introduction of electric lighting, the time people spend inside building during both daytime and night time is greatly increased (Aries &

Zonneveldt, 2004). The common types of lamps used to illuminate the indoor area are incandescent lamps and fluorescent lamps. Incandescent lamps are the lamps most familiar to homeowners and they are commonly used for the majority of residential lighting, both indoor and outdoor. Fluorescent lamps are also seen in residential lighting, and they predominate in indoor retail and office uses.

When moving from incandescent light sources to discharge light source, the issue of colour rendering and colour temperature has been rise. Today, LEDs are entering the lighting market as new light sources and they enable new approaches to lighting design and practice. The new source of light will introduce new possibilities for tuning the colour of light (Halonen, Tetri & Bhusal, 2010).

2.3.2 Safety and Health Issue Related to Quality Lighting

Bluyssen (2010) stated that research and practice was focused at lighting comfort and task activities at first, and then slowly shifted to lighting and health. Designing good lighting or illumination has long been considered as one of the most important industrial workplace design tasks that are associated with productivity and work efficiency (Lin et al., 2007). Lighting should be designed to enable people to have right visual conditions that help them to perform visual tasks efficiently, safely and comfortably.

Beside of providing an appropriate quality of light, illuminance uniformity, colour characteristics of light and glare are factors to be considered (Veitch & Newsham, 1998). A well designed illumination system, or good lighting, increases productivity creates a lively atmosphere and reduces fatigue while inappropriate lighting can increase visual fatigue, decrease task performance and even result in many health and hygiene problems, such as eyes strain and affecting human circadian system (Aries & Zonneveldt, 2004; Lin et al., 2007; Juslen & Tenner, 2005; Stephenson, 2004; Walawalkar, 2001).

Up to date, the need for lighting that does not cause health and comfort problems, and the need for lighting to improve alertness and performance have became the focus point of research and practices.

2.4 Colour Characteristics of the Light

Besides of providing an appropriate quality of light, colour characteristics of light is important factors to be considered and received higher attention (Veitch & Newsham, 1998; van Bommel & van den Beld, 2004).

The colour of light sources is usually described by two properties, namely general color rendering index (CRI) and the correlated color temperature (CCT) (Halonen, Tetri, & Bhusal, 2010).

2.4.1 Color Rendering Index (CRI)

For CRI, it is used to measure how well a given light source renders a set of test colours. The maximum value of CRI is 100, where the higher CRI, the better is the colour rendering of a light source (Halonen, Tetri & Bhusal, 2010).

2.4.2 Correlated Colour Temperature (CCT)

CCT is a quantitative evaluation or measurement for the actual colour appearance of the light emitted by a light source (Boyce, 2003). It is expressed in Kelvins (K). The CCT of light can also influence how we perceive the surrounding space: cool or warm. Typically, low CCT implies warmer (more yellow/red) light while high CCT implies a colder (more blue) light. Also, the amount of blue light in the spectrum of light sources increases with increasing colour temperature (Manay, 2007).

Figure 2.2 shows the scale of CCT range from 1500K to 8000K, with own colour description. For example, light with CCT of 2700K have a yellowish colour appearance and it is described as 'warm', while light with CCT of over 6000K with bluish appearance is described as 'cool'.

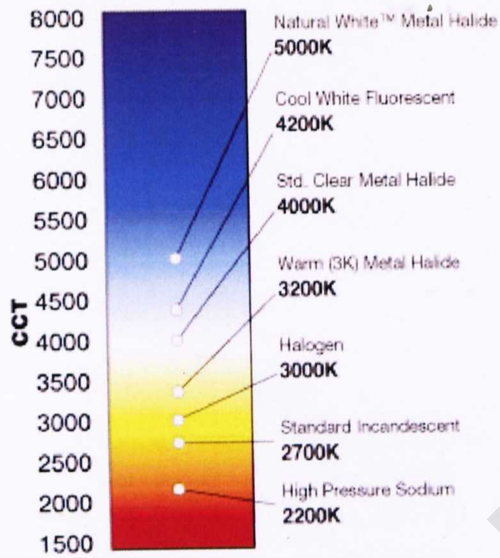

Figure 2.2 : The scale of CCT of light with its colour appearance

The CIE (Commission Internationale de l'Eclairage) recommends the CCT for interior lighting in the range of 3000-6500K (Górnicka, 2008).

2.4.3 Application of Coloured Lighting

As colour temperature can support light and enhance the impact of lighting on users, Sanaz (2011) has mentioned that colour is an essential factor in the physical learning environment, and it is one of the most important elements in interior design. More importantly, various CCT has effects on human health, which are related to the strain of eyes caused by bad lighting, or to the emotion and human circadian system (van Bommel & van den Beld, 2004; Halonen, Tetri & Bhusal, 2010).

However, as mentioned in study of Altomonte (n.d.), Aries and Zonneveldt (2004), current electric lighting installations are only adjustable in output level, but not in colour temperature even though people are comfortable at different colour temperature. This might be resulted from fair understanding of optimum lighting colour temperature for indoor environment (offices) which is necessary to achieve high levels of visual performance and to avoid visual discomfort (Boyce et al., 2006).

2.5 Subjective Preferences and Visual Comfort Level

Preferences on light's colour temperature are very individual. Miller (2007) in his study pointed out, the preferences are varied among the people and for the same person at various times during the day. Similarly, studies on the preferred colour of light in an office environment have shown that there is no trend in preference between individuals in this respect: everyone has their own personal preference (van Bommel & van den Beld, 2004). This means that even a same person might prefer lighting with lower CCT at one time, and change his interest to higher one at another time. To explain more, the preferences of CCT are very much related to mood, culture and climate, as well as dependant of the prevailing lighting practices in different regions (Aries & Zonneveldt, 2004; Miller 1998).

Causes of visual discomfort can be too little light and too much light, too much variation in luminous distribution, too uniform lighting, annoying glare, veiling reflections, too strong shadows and flicker from light sources (Halonen, Tetri, & Bhusal, 2010). Similar to subjective preferences, occupants have own perception towards visual comfort due to exposure to different types of lighting system. This is because of the different application of light with different CCT. For instance, lighting that is considered comfortable in an entertainment setting may be disliked and regarded as uncomfortable in a working space (Boyce 2003).

2.6 Subjective Alertness Level

Besides of visual comfort, effect of light on alertness level of occupants is one of the qualities of light to be considered. Recently, it has been suggested that high CCT of light could be used in increasing human alertness (Halonen, Tetri, & Bhusal, 2010). Generally, the higher the CCT, the bluish like will be the light, and the more activating it will lead to exposed occupants. In opposite, yellowish light, as in red sky in the early evening has a relaxing effect (van Bommel & van den Beld, 2004).

In addition, Mills, Tomkins & Schlangan (2007) pointed out studies have demonstrated that higher CCT (7500 K versus 3000 K) are more activating from the viewpoint of mental activity level. And therefore, drowsiness has been observed to be higher under lower CCT lighting when comparing 3000 K with 5000K. More interestingly result was found in the experiment among students during lecture hall environment by Rautkylä, Halonen & Lehtovaara (2008), the correlated colour temperature of light did prove to be associated with the alertness of the subject.

It was expected that in cooler CCT, people would stay more alert than in warmer CCT condition. Yet, some field studies found different effects of high CCT onto alertness level. In previous study done by Górnicka (2008), data of the two lighting conditions (2700K vs. 17000K) were compared. However, He has drawn a conclusion that there were no significant effects between light setting with 2700K and 17000K on non-visual processes, which was evening alertness level in his research.

Since there were inconsistence of finding in regard to the effects of such parameter, it will be beneficial to add more input in related field.

2.7 Visual Task Performance

The CCT of light had a direct impact on the visual operation of the human eye, moreover it was found to be the major factor to affect the daily and overall productivity of employees in offices (Stephenson, 2005; Hameed & Amjab, 2009).

In buildings, typical applications of lighting include writing, typing, reading, communicating and viewing slides and videos, or performing detailed tasks like sorting products. In order to provide people to better see what they are doing, make task easier, perform those visual tasks efficiently, safely and comfortably, proper lighting with suitable illuminance level and colour temperature should be installed (Sanaz, 2011; Halonen, Tetri, & Bhusal, 2010).

Visual performance does not have clear importance in all tasks, as some tasks do not need much light in order to be performed well visually (Sanaz, 2011). Thus, productivity was not a standalone factors, it is related and much influenced by visual discomfort experienced by an occupant. According to Hammed & Amjab (2009), working in bad lighting leads to eye strain and thus causing headaches and irritability. Due to this discomfort, productivity is very much affected causing overall decrease in employee's performance.

Presently, some researchers agreed that productivity increased when the CCT was high. The potential benefits resulted from optimum usage of right colour temperature in an indoor environment include higher attention span of worker, improvements in wellbeing, functioning and work performance (Mills, Tomkins & Schlangen, 2007; Juslen, 2006)

Handfuls of studies have been done among workers, while there was still a considerable gap to be filled in for effects of lighting among students. As quoted by Lin et al (2007), there were still inadequate numbers of studies on effects of colour temperature to performance of students or undergraduate.

2.8 Visual Contrast Threshold

Contrast is defined as the ratio of the difference in the luminance of these two adjacent areas to the lower or higher of these luminance values (Owsley, 2003). It is one of the important factors affecting visibility is, thus the quality of lighting has to take consideration of its influence on occupants' visual contrast, especially when there is variation of age and other physiological factors among the occupants. Contrast threshold is affected by several factors such as target size, background luminance, and viewing duration. Contrast threshold is the reciprocal of the contrast sensitivity, therefore the lower the contrast threshold the higher the contrast sensitivity and visual performance (Capo-Aponte, Temme, Task, Kalich, Pantle, & Rash, 2009).

However, many results drawn from past researches gave an idea that CCT was not the contributing factor to more sensitive visual contrast (lower threshold). Arranzal Matesanza, de la Rosaa, Mene´ndezb, Issolioc, Mara and Aparicioa (2011) found no statistically significant differences in contrast sensitivity for CCT of 2000K and CCT of 2800K. When measuring contrast sensitivity function under combination of different illuminance levels and colour temperature, again it had no systematic difference appeared across colour temperature. Also, Boyce et al (2003) have performed a study to assess the performance of a visual contrast task requiring the observer to identify the orientation of Landolt rings. They did not find influence of colour temperature (3000K and 6500K) on the visual contrast threshold among the occupants.

CHAPTER 3

METHODOLOGY

3.1 Study Background

The repeated-measures experimenter study was took part from 29th February 2012 until 18th April 2012. The study involved 47 young and healthy undergraduate students from FPSK, UPM, where they had normal or corrected visual acuity. The experiments were scheduled in such a way that each subject performed the test once a day.

3.2 Study Location and Setup

The experiment was conducted in a windowless room inside the Occupational Health and Safety Laboratory, FPSK, UPM. The dimension of the room is 6.2m x 3.1m x 2.8m.

There were three lighting scenarios to be tested. The default CCT of light sources in the room was WW light (3000K), which was illuminated by nine ceiling light tubes by Philips' MASTER PL-L 36W/830/4P. In the CW (4000K) lighting scenario, eight ceiling light tubes of Tian He's Tricolour (36W) were set up. Next, eight ceiling light tubes of Liyoda's PLL*36W/EX-D were installed to present DL (6500K) lighting scenario.

Figure 3.1 below shows the three lighting scenarios of different CCT of light sources.

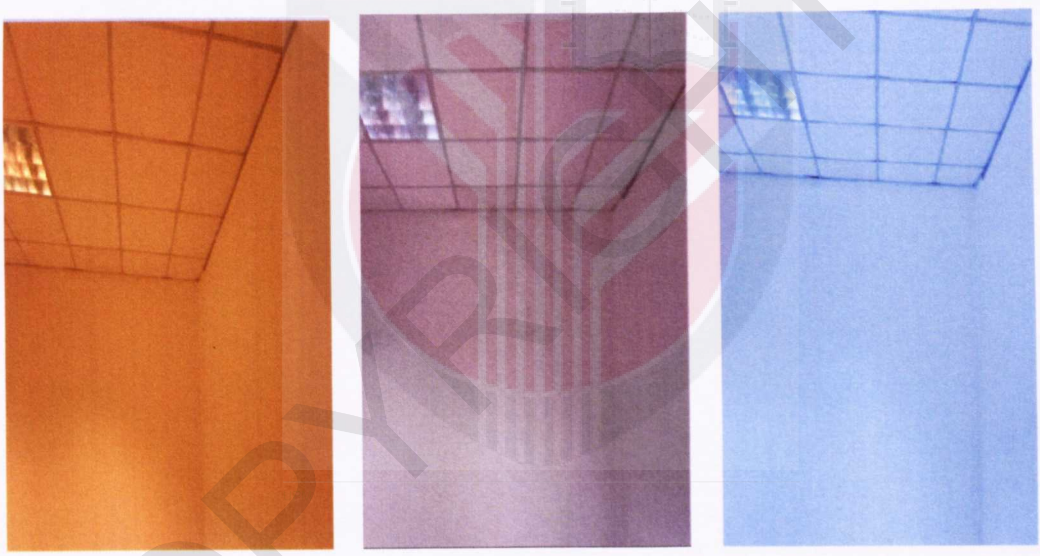

Figure 3.1 : Photographs of the three different lighting scenarios, taken with digital camera. From left to right: 3000K, 4000K, and 6500K light scenario.

3.3 Study Design

This experiment was a within-subject repeated experimental study. The independent variable was colour temperature of light (WW light, CW light and DL) and the dependent variables included task performances, visual comfort level and individual preferences, and subjective alertness of the subjects. The subjects were assigned to all experiment scenarios in a randomized order. Each subject was his/her own control (within-subjects design), thus between subjects variation in experimental variables was eliminated as a source of error.

Table 3.1 : Three experimental lighting conditions WW light, CW light, and DL in the experiment

Lighting scenarios	CCT	Vertical illuminance (average)
WW light	3000 K	385 lux
CW light	4000K	389 lux
DL	6500K	404 lux

The principle of constant illuminance level at the eye independent of viewing directions was maintained. As shown in Table 3.1, the CCT of light sources were varied between the experimental conditions, while lighting level (vertical illuminance on the eyes) was maintained at smallest range possible.

3.4 Sampling

3.4.1 Study Population

The study population of this study was the current undergraduate students of FPSK, UPM, Serdang, Selangor.

3.4.2 Study Sample

The study samples included all undergraduate students from the programme of Doctor of Medicine, Biomedical Sciences, Environmental and Occupational Health, Nutrition and Community Health, and Dietatics.

3.4.3 Sampling Frame

The sampling frame used was the name lists of the undergraduate students from every programme in the FPSK, which was obtained from academic department of faculty.

3.4.4 Sampling Unit

The sample unit for this study was an undergraduate student who fulfilled the inclusive criteria of the study.

3.4.4.1 Inclusive Criteria

1) Malaysian
2) Have normal or corrected visual acuity.
3) Undergraduate student of age of 19 to 25 years old.
4) Non-smoker

3.4.5 Sampling Method

Purposive sampling method was used to recruit respondents who fulfilled the inclusive criteria of the study in the study.

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Purposive sampling method was used to recruit respondents who fulfilled the inclusive criteria of the study in the study.

3.4.6 Sampling Size

The sample size of this study was calculated by using a sample calculation software named G-Power (Version 3.1.3), which is written by Franz Faul, from Universitat Kiel, Germany. The software was designed as a general stand-alone power analysis programme for statistical tests, which commonly used in a social and behavioral research (Erdfelder, Daul & Buchner, 1996). This research could be a behavioral study, as it studied about human responses to CCT of light sources.

Effects size, power of study, number of groups, and number of measurements were set to determine total sample size required. Below is the protocol of power analysis:

[1] -- *Monday, January 23, 2012 -- 22:36:58*
F tests - ANOVA: Repeated measures, within factors
Analysis: A priori: Compute required sample size
Input:

Effect size f	=	0.20
α err prob	=	0.05
Power (1-β err prob)	=	0.80
Number of groups	=	1
Number of measurements	=	3
Corr among rep measures	=	0.5
Nonsphericity correction ε	=	1

Output:

Noncentrality parameter λ	=	10.0800000
Critical F	=	3.1078913
Numerator df	=	2.0000000
Denominator df	=	82.0000000
Total sample size	=	42

The total sample size calculated was 42, with the actual power of 0.8027. In consideration of non-response rate, 10% of respondents were added. Thus, the sample size needed in this study design was total of 47 persons.

3.5 Data Collection

3.5.1 Visual Comfort and Subjective Preferences Assessment

Subjects were required to rate their satisfaction level at the end of every lighting scenario. To assess visual comfort and preferences of occupants, a slightly modified OLS was adapted and used as in previous related researches (Linhart & Scartezzini, 2011; Akashi & Boyce, 2006). There were 12 questions in total, where first six questions were asking about visual comfort level, while the following six were asking about preference of subjects. Below is the list of questions asked in the modified OLS:-

1) I like the lighting in this office.
2) In general, the lighting in this office is comfortable.
3) This colour 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.
6) The lighting in this office is too cold.
7) I feel eye strain.

8) My eye lids are heavy.

9) My eyes feel dry.

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.

The occupants have to rate each question subjectively based on a scale of 4 levels of satisfaction for each question asked, including "Yes", "Rather Yes", "Rather No" and "No" after the trial. Score would be given for every response made. For Question 1 to 4 (positive statements), +3 points were given for response of 'Yes', +2 for 'Rather yes', +1 for 'Rather no' and +0 for 'No'. For Question 5 to 12 (negative statements), +3 points were given for 'No', +2 for 'Rather No', +1 for 'Rather yes' and +0 for 'Yes'. At last, standard scores were generated for rating of preferences and visual comfort level, respectively.

3.5.2 Alertness Monitoring

Before and after the experiment, the respondent's subjective alertness levels were monitored using a translated Karalinska Sleepiness Scale (KSS). Each participant had to state their actual alertness level on a 9-stage scale based on the value and corresponding rating as shown in Table 3.2. The KSS was validated against electroencephalography (EEG) data by Askertedt and Gillberg in 1990 (as cited Linhart & Scartezzini, 2011).

Table 3.2 : The Karolinska Sleepiness Scale (KSS)

Value	Rating
1	Extremely alert
2	Very alert
3	Alert
4	Rather alert
5	Neither alert nor sleepy
6	Some signs of sleepiness
7	Sleepy, no effort to stay awake
8	Sleepy, some effort to stay awake
9	Very sleepy, great effort to keep awake, fighting sleep

3.5.3 Computer-Based Task Performance

To compare the influence of the three different CCT lighting scenarios "WW light", "CW light" and "DL" on the subjects' performance during a computer-based task, the "Freiburg Visual Acuity & Contrast Test" (FrACT) has been used. It was to determine a person's visual acuity and contrasting threshold through correct recognition of Landolt rings on a PC screen. The methods and procedures have been benchmarked and modified from Linhart and Scartezzini's study (2011).

The entire FrACT test is illustrated in Figure 3.1. In the figure, (a) visualizes the use of the four direction keys in the FrACT, (b) showing the "acuity"-task and (c) showing the "contrast"-task.

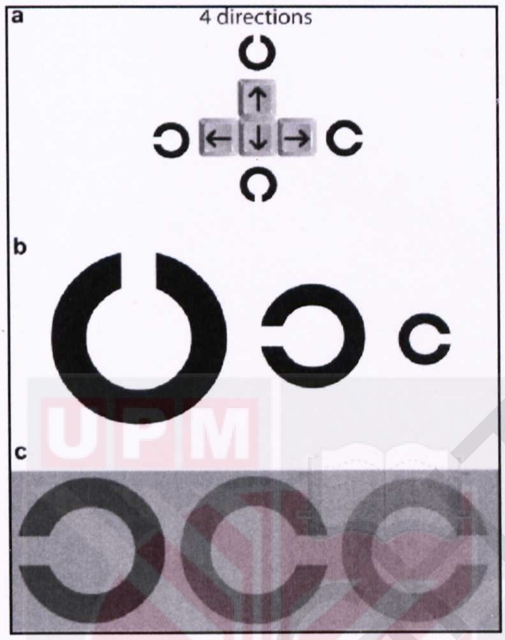

Figure 3.2 : Overview of the computer-based FrACT test

The "acuity"-task consists of showing the subject a sequence of 30 Landolt rings of different sizes and orientations on laptop, as shown in Figure 3.2 (b). The respondent had to determine the orientation of the ring and give corresponding answer by clicking on keyboard as quickly as possible. For a more accurate reading to be taken, each respondent repeated the 'acuity' task three times under each lighting condition. For each sequence, the performance was determined as follow calculation:

$$\text{Acuity Task Performance} = \frac{\text{Total number of correct response}}{\text{Total duration to complete a trial}}$$

3.5.4 Performance at Paper-Based Task

To test the influence of the light's CCT on the performance during a paper-based task, the test suggested by Courret (as cited in Linhart & Scartezzini, 2011) was adopted. As shown in Figure 3.3, the subjects received a piece of white paper which 96 Landolt rings were printed in weak contrast. Subjects were given 5 minutes to complete the task. They had to determine, without marking on the paper, the correct orientations of the 96 rings by writing down the number of counted rings for all four possible orientations, which were open on top, bottom, left, and right. Different version of the test papers were used in every lighting scenario to avoid bias from people who remembered the number of rings previously counted. Then, the numbers of mistakes are counted as the performance at paper-based task for each lighting scenario.

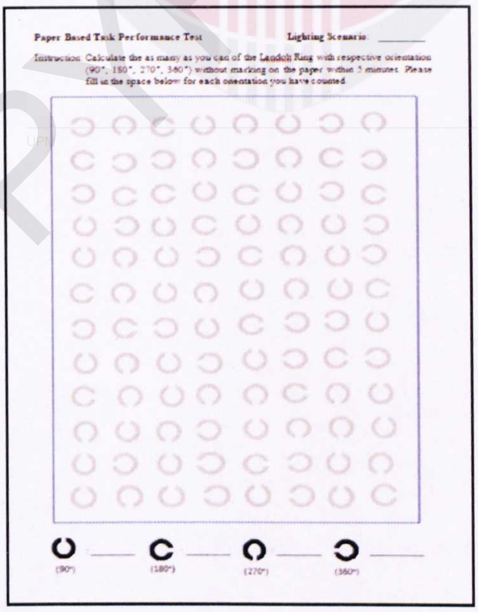

Figure 3.3 : Overview of the paper-based FrACT test

3.5.5 Visual Contrast Threshold

The effect of coloured lighting on human's visual contrast threshold was again determined by using FrACT software. As shown in Figure 3.2(c), the contrast test modified the contrast between the ring and the screen background instead of sizes of the rings. Similarly, each participant was asked to perform three sequences of this 'contrast' task of 30 Landolt rings for each of the lighting scenario. Then, contrast threshold was determined by the computerized program. Average of the contrast threshold for all three trials would be taken as indicator.

3.5.6 Typing Performance Test

To determine the optimum CCT of light source for typing performance, subjects were asked to type an article referring to printed article, with the length of approximately 400 words in 10 minutes. To avoid bias due to familiarization, different articles were used in different lighting scenario (Appendix 5). Microsoft Office Word 2007 was used for the trial, and automatic spelling and grammar checking were disabled for accurate indication of subjects' performance. Lastly, typing speed (total numbers of words typed) and typing accuracy (percentage of typing errors) of the subjects for every lighting scenario would be recorded.

3.6 Study Instrumentation

Instruments that were being used for this study were as follows: -

i) "Freiburg Visual Acuity & Contrast Test" (FrACT)

ii) Modified Office Lighting Survey (OLS)

iii) Karolinska Sleepiness Scale (KSS)

iv) Light meter

v) Notebook computer

3.6.1 "Freiburg Visual Acuity & Contrast Test" (FrACT)

The FrACT is a program that enables automatic and observer-independent determination of visual acuity at a defined optotype contrast or contrast sensitivity, and at a specific optotype size (Buhren, Terzi, Bach, Wesemann, & Kohnen, 2006). It functions though correct recognition of Landolt rings on a notebook computer screen. The results obtained were used as indicator of visual performance for computer-based task as the respond speed and accuracy were recorded automatically (Bach, 1996). The computerized test was downloaded free of charge on www.michaelbach.de/fract.

Similarly, the Landolt rings were also used to assess the subjects' performance in paper-based task. This test was suggested by Courret (as cited in Linhart & Scartezzini, 2011) in 1999. Under different lighting scenarios, respondents had to determine the correct orientations of the 96 grey-colour-rings printed on a white paper within 5 minutes. The number of mistakes would be recorded manually to evaluate the performance of subjects.

3.6.2 Office Lighting Survey (OLS)

OLS was modified and adopted to assess the subjective visual comfort level and preference of colour of light among the tested colour temperature. This survey form has been used in many studies since 1996 (Eklund & Boyce, 1996; Akashi & Boyce, 2006). In total, there were 12 questions to be answered in the questionnaire (Appendix 4), where each question follows by four statements: Yes / Rather Yes / Rather No / No.

3.6.3 Karolinska Sleepiness Scale (KSS)

As discussed in the earlier part, a translated KSS was used to assess the alertness level of the subjects under different lighting scenarios. There were 9 rates (1-9) in the scale, where the smaller the number, the more alert the subject was. The subjects were required to rate the sleepiness stage before and after the test subjectively.

3.6.4 Light Meter

Figure 3.4 : The SPER SCIENTIFIC Model 840020 Light Meter

The lux meter was used to measure the illumination level of the laboratory where the tests conducted. This model of lux meter is capable to measure from 200 to 20,000 lux, which was sufficient for the use in this experiment. The accuracy is +/- 7%, while the repeatability is +/- 2%.

3.6.5 Notebook Computer

Figure 3.5 : The Lenovo Y410 Notebook computer

The notebook computer was used for computer-based task test, typing performances test and record keeping purposes. The contrast, brightness and background ratio of the notebook computer was kept unchanged throughout the experiment to avoid bias.

3.7 Procedures of Data Collection

This study was designed in such a way that the subjects would perform the experiment once a day under every type of lighting condition. This was to avoid possible bias due to visual fatigue or intolerance follow the last trial. Thus, every subject was required to attend the trial for three different days. The laboratory was adjusted to desired scenarios, which were WW light (3000K), CW light (4000K) and DL (6500K), at different day of experiment. The procedure of experiment was benchmarked from Linhart & Scartezzini (2011) into this study.

The study procedures consisted of two parts: intake and the experimental phase. At the intake phase, the subjects were informed about the study and the experimental procedures. A written permission form was given to them who decided to participate in the experimental testing. They had to return it undersigned before the experimental proceeds. In experiment phase, the sequence of lighting scenarios had randomized. Detailed schedule of the study was shown in Figure 3.6.

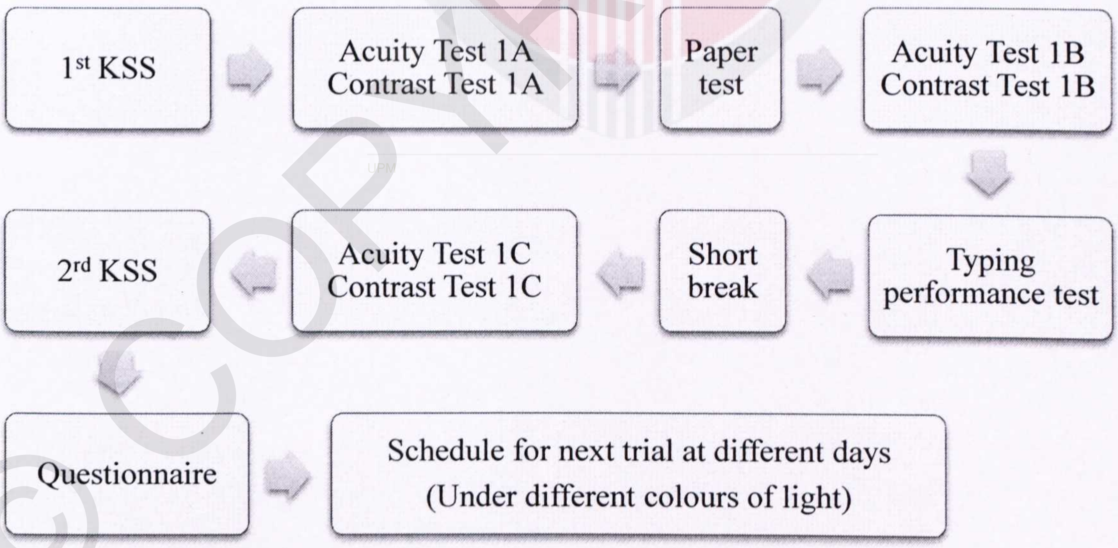

Figure 3.6 : Detailed schedule of the study for all lighting scenarios

3.7.1 Subject's Protocol

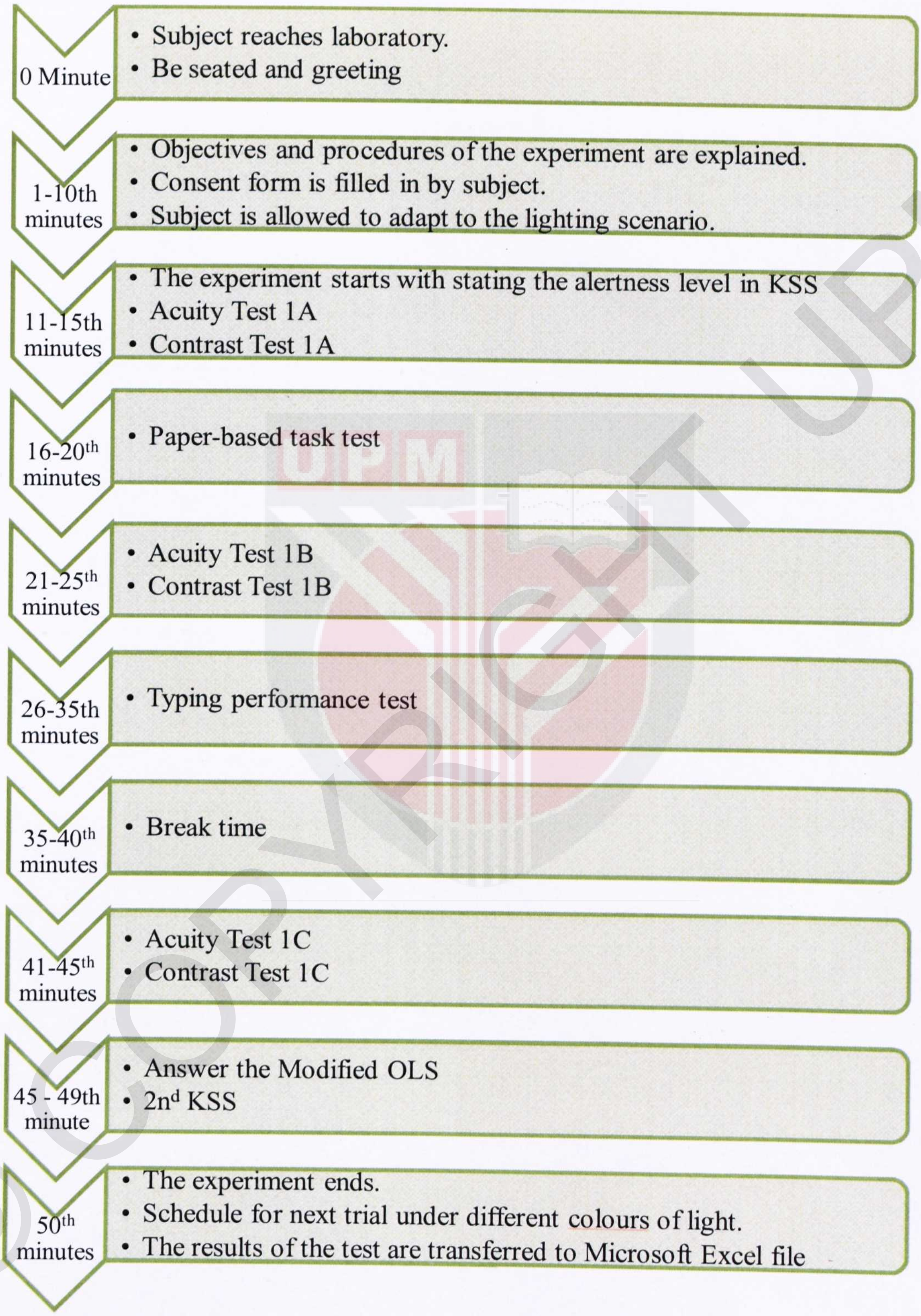

Figure 3.7 : Subject's protocol to be used in the experiment

Figure 3.7 shows the flow of protocol for every subject who participate in the study. Every trial was expected to complete in 50 minutes.

As subject arriving at the laboratory at the scheduled appointment time, each subject was given a quick introduction concerning the study and all the questions and doubts from subject were answered.

In the beginning, the subject's eyes would let to adapt to current scenario for 15 minutes. Subject had to fill out a KSS-test before performing a computer-based acuity-test and a computer-based contrast-test (to determine the orientation of Landolt rings in both cases). After that, the paper-based task was carried out. The latter was then followed by another sequence of acuity- and contrast-tests, and typing test for 10 minutes. After that, the subject was given time to rest. At this time, subject was offered to watch hilarious video or simply chatting. He or she then took a third sequence of acuity- and contrast-tests and second KSS-test. The trial was ended by filling out the modified OLS questionnaire. Lastly, appointment for next scenario was made and the subject was allowed to leave. After farewell, experimenter would save the results of the test (e.g. correct answers, response time per ring) in an Excel spreadsheet.

For the rest scenarios, the procedures were the same.

3.8 Data Analysis

To obtain the information about possible effects of lighting conditions (3000K vs. 4000K vs. 6500K) during the day on all parameters, data entry and analysis were done by using "Statistical Package for Social Science" (SPSS for Windows version 19.0) software. Also, Microsoft Excel was used in data analysis and presentation too.

3.8.1 Determination of Data Distribution

Since the sample size (n=47) were less than 50, Shapiro-Wilk normality test was used to test the distribution of each variable studied before performing statistical analysis performed on variables.

The result of normality test showed that the correct identification of ring orientation per second was normally distributed, which has significant difference at $p > 0.05$. For the variables such as socio-demographic data, KSS scores, visual comfort level and subjective preferences scores, the skewness distribution were at ±2. This is to say that these parameters showed normal distribution skewness in their respective variables, but were neither shift to right nor left side of the distribution curve. All parameters were normally distributed and could be analyzed by parametric test.

3.8.2 Univariate Analysis

Descriptive test, univariate analysis was used to produce the raw and basic statistical data of socio-demographic distribution, such as age, gender, programme of study, and numbers of words typed in typing performance test. The data was presented in the form of mean and standard deviation (S.D.) value.

3.8.3 Bivariate Analysis

Comparison of computer-based and paper-based task performances, visual comfort level, preferences, and typing performance under different lighting CCT were performed with Repeated-measures ANOVA test. For all tests, the *P*-value is determined at $p<0.05$.

On the other hand, alertness level before and after experiment were analyzed using Pair-sample T-Test. Similarly, the *P*-value is determined at $p<0.05$.

3.9 Quality Control

As mentioned in previous part, each subject had to separately perform three experiment trials with different CCT of light. To avoid possible biases resulting from the visual fatigue of the last trial, the trial was scheduled once a day for every lighting condition. The workplace factors (such as positions and types of table and chair) and environmental factors (such as room illumination, room temperature and glare) were the same for all the trials. The mean vertical illuminance levels on the eye in all lighting conditions were in the range of 500 ± 40 lux during the experiment. This was because subjects perform better under ambient illumination of 300 lux to 700 lux at workstation which involves the use of video terminal unit (DOSH, 2003; Wu, Lee & Lin, 2007).

All equipments including laptop and lux meter will be calibrated before use. For FrACT to be operated accurately, an extra check of visibility was done, with reading of classical Landol-C rings from the distance of 150 cm between subjects and laptop screen in all lighting conditions. The illumination of laptop was always set at brightest at its best.

Besides, the questionnaire was pre-tested to check if it was understandable. Then, same procedures were used on every respondent. Also, to prevent from visual fatigue, subject was asked not to perform any kind of VDT work at least 30 minutes prior to experiment. Before the experiment, subject was allowed to adapt to the lighting for 10 minutes. In between, each subject was given rest to avoid fatigue, which might lead to distortion of performance.

3.10 Ethical Concern

This study was approved by UPM Faculty of Medicine and Health Sciences Ethics committee, the approval letter with reference number UPM/FPSK/PADS/T7-MJKEtikaPer/F01(JKK(U)_Dis(11)33 was shown in Appendix 1.

Before the study was commenced, participation consent was given to each respondent who participated in this study. Consent was obtained before any experiment on them started. As agreement had made, respondent and experimenter had to sign on the consent form. Purposes and procedures of research, as well as the rights of respondent were explained. They had the right to withdraw from the study at anytime when they feel uncomfortable to continue the experiment. All the information, especially the identify and personal detail were remained confidential and be used for this study only. Also, the respondent was given option to be notified regarding the finding from this study. Lastly, souvenir was given as the token of the appreciation for every participated respondent.

3.11 Study Limitation

There were some limitations in this study that could not be avoided by the researcher. For instance, information involving self-reported perceptions was obtained, which might be problematic in terms of the reliability of measurements. Also, the study included respondents from one department building only, which makes generalizing the findings to other population somewhat difficult.

Besides that, as other experimental design on 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 influence of Hawthorne effect, where participants might perform outstandingly well (sometimes bad), as they know that they were being observed and cared.

In the study, alertness was measured as one of the main outcome. However, only subjective alertness was recorded, yet physiological alertness was not measured. Rüger et al. (2005) indicated that the subjective and physiological alertness effects of light were not strongly correlated. In the other words, subjective alertness was not able to reflect the physiological alertness of subjects.

Even though random fluctuations in a variety of initial conditions were expected, but since the subjects served as their own controls, the influence is tried to be minimized.

CHAPTER 4

RESULTS

4.1 Socio-Demographic Data for Respondents

The first objective of this study was to determine the socio-demographic status of responded undergraduate students of FPSK, UPM. The study showed the average age of subjects was 21.49 ± 1.3 (mean ± SD) years old. The average height was 161.94 ± 8.04 cm, while the average weight was 57.75 ± 11.02 kg. All of them were Malaysian, non-smoker, had normal or corrected visual acuity, and not colour blind. The ratio of female to male respondents was 3:2. Chinese students made up 55.3% of respondents in the test, followed by Malay students and students from other races.Table 4.1 shows the socio demographic data for respondents.

Table 4.1 : Socio-demographic data of respondents (N=47)

Variable	Undergraduate students	
	N = 47	Percentage (%)
Age		
19	3	6.4
20	10	21.3
21	11	23.4
22	10	21.3
23	10	21.3
24	3	6.4
Gender		
Male	19	40.4
Female	28	59.6
Ethnic/Races		
Malay	14	29.8
Chinese	26	55.3
Indian	2	4.3
Other	5	10.6
Program Undertaking		
Biomedical Science	13	27.7
Environmental and Occupational Health	12	25.5
Medical Doctor	5	10.6
Dietetics	7	14.9
Nutrition and Community Health	10	21.3
Year(s) of Study		
First year	16	34.0
Second year	7	14.9
Third year	10	21.3
Fourth year	14	29.8
Average Time Spend in Indoor with Light Switched On (in a day)		
Less than 4 hours	0	0
4 – 8 hours	14	29.8
8 – 12 hours	18	38.3
More than 12 hours	15	31.9

4.2 Visual Comfort Level and Preferences among the Subjects under Different CCT of Light

The second objective of the study was to compare the visual comfort level and subjective preferences among the students who worked under WW light, CW light and artificial DL. Figure 4.1 shows that CW light (14.638 points) was most preferred by students. Also, it is perceived to be the most comfortable light's CCT (14.702 points) compared to WW light (12.638 points) and DL (14.128 points).

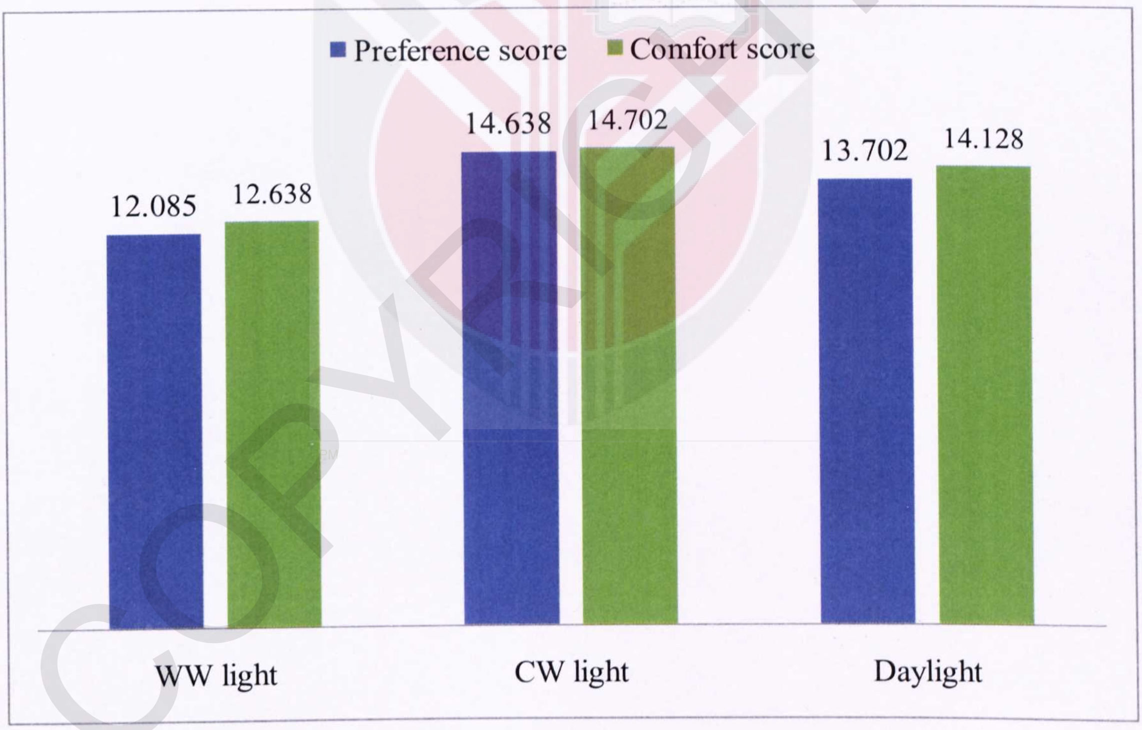

Figure 4.1 : Comparison of preference and comfort level between three different lighting scenarios

4.2.1 Visual Comfort Level

Repeated-measures ANOVA (r-ANOVA) were used to compare these parameters. Test of sphericity was used as an assumption that the different score of paired levels of repeated measures factors have equal population variance. Mauchly's Test of Sphericity indicated that the assumption of sphericity in visual comfort level had not been violated, as $\chi^2(2)=3.261$, $p>0.05$. The r-ANOVA yielded significant differences for the mean scores of visual comfort level ($F2,92=4.739$, $p<0.05$), while the effect size (partial eta squared) 0.093.

Table 4.2 : Pairwise Comparisons of CCT of Light on Visual Comfort Level

(I) CCT of Light	(J) CCT of Light	Mean Difference (I-J)	Std. Error	p value
Warm white	Cool White	-2.064*	0.598	0.004
	Daylight	-1.489	0.755	0.164
Cool White	Warm white	2.064*	0.598	0.004
	Daylight	0.574	0.713	1.000
Daylight	Warm white	1.489	0.755	0.164
	Cool White	-0.574	0.713	1.000

*Significant at p<0.05

As shown in Table 4.2, the visual comfort level of subjects working under CW light was statistically different from WW light ($p<0.05$). The mean difference of the comfort scores between these two light sources was 2.064, where significantly the subjects of the study felt more comfortable in visual aspect under CW light over WW light.

4.2.2 Subjective Preference

Similarly, r-ANOVA was used to compare these parameters. Mauchly's Test of Sphericity indicated that the assumption of sphericity in preference scores had not been violated, as $\chi^2(2)=4.899$, $p>0.05$. The r-ANOVA yielded significant differences for the mean scores for preferences score ($F2,92=7.303$, $p<0.05$), while the effect size was 0.137.

Table 4.3 : Pairwise Comparisons of CCT of Light on Preferences

(I) CCT of Light	(J) CCT of Light	Mean Difference (I-J)	Std. Error	p value
Warm white	Cool White	-2.553*	0.619	0.000
	Daylight	-1.617	0.777	0.129
Cool White	Warm white	2.553*	0.827	0.000
	Daylight	-0.909	0.657	0.414
Daylight	Warm white	1.617	0.644	0.129
	Cool White	0.909	0.657	0.414

*Significant at $p<0.05$

As shown in Table 4.3, the preference of subjects towards CW light was statistically different from WW light ($p<0.05$). The mean difference of preference scores between these two light sources was 2.553, where subjects of the study significantly preferred CW light over WW light.

4.3 Alertness Level among the Undergraduate Students of FPSK under Different CCT of Light

The third objective of the study was to determine the effects of different CCT of light on the students' alertness level. Paired Sample T-Test was used to compare the pre-experiment alertness level with the post-experiment alertness level under respective light source. Figure 4.2 showed different trends of effects on subjective alertness level for respective lighting scenario. There was decrease of KSS score (-0.45) (more alert) at the end of experiment under DL, increase of alertness level at the end of experiment under WW light (+0.13), as well as under CW light (+0.06) (less alert).

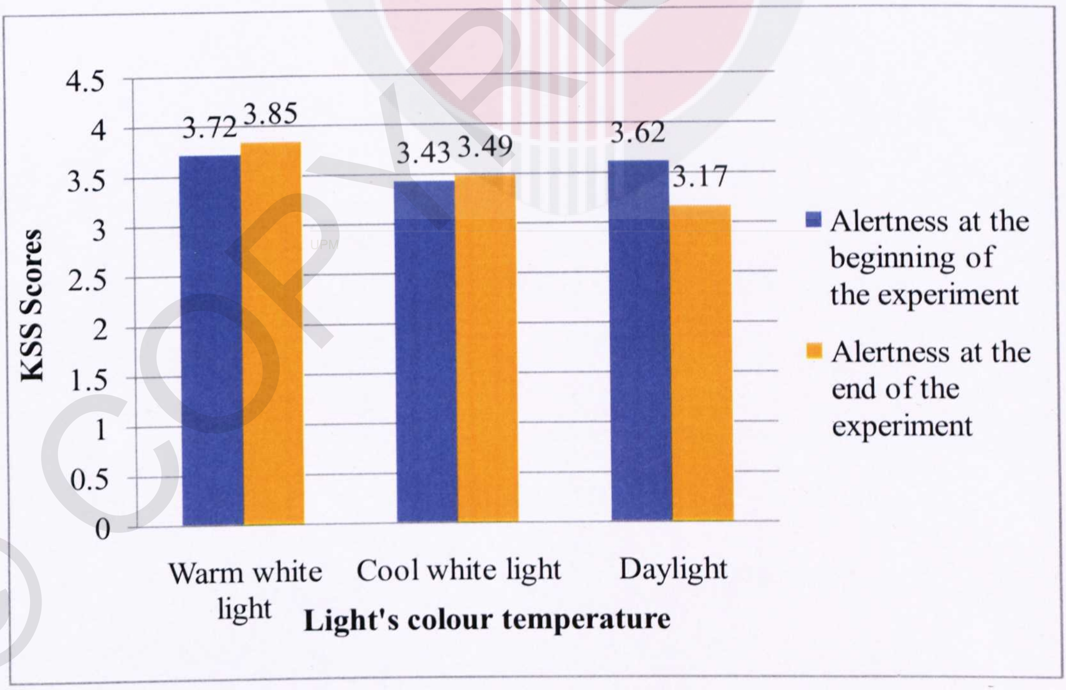

Figure 4.2 : Comparison of alertness level before and after the trial

Table 4.4 : Paired Sample T-Test of Alertness Level under Different CCT of Light

Scenario	KSS score before the experiment (mean)	KSS score after the experiment (mean)	t value	p value
WW light	3.72	3.85	-0.675	0.503
CW light	3.43	3.49	-0.322	0.749
Daylight	3.62	3.17	2.130	0.041*

*Significant at $p<0.05$

As shown in Table 4.4, the Paired Sample T-Test yielded significant differences for the mean of KSS score at the beginning of experiment with the KSS scores at the end of experiment under DL scenario ($p<0.05$). This is to say that subjects became significantly more alert after approximately 50 minutes of staying under such lighting. For WW light and CW light, there were no significant changes of subjective alertness level among the subjects.

On the other hand, r-ANOVA was used to compare the KSS score changes between three lighting scenarios. Mauchly's Test of Sphericity indicated that the assumption of sphericity in both variables (alertness level before and after the experiment) had not been violated, as $\chi^2(2)=0.951$, $p>0.05$, and $\chi^2(2)=0.089$, $p>0.05$, respectively. There was no significant difference of alertness level at the beginning of the experiment under all lighting scenario. In contrast, the r-ANOVA yielded significant differences for the mean scores for KSS score at the end of experiment ($F2,92=4.121$, $p<0.05$), while the effect size was 0.082.

Table 4.5 : Pairwise Comparisons of CCT of Light on Alertness Level at the End of Experiment

(I) CCT of Light	(J) CCT of Light	Mean Difference (I-J)	Std. Error	p value
Warm white	Cool White	0.362	0.232	0.380
	Daylight	0.681*	0.238	0.019
Cool White	Warm white	-0.362	0.232	0.380
	Daylight	0.319	0.242	0.579
Daylight	Warm white	-0.681*	0.238	0.019
	Cool White	-0.319	0.242	0.579

*Significant at p<0.05

As shown in Table 4.5, the subjective alertness at the end of experiment of subjects working under DL scenario was statistically different from WW light ($p<0.05$). The mean difference of KSS scores between these two light sources was 0.681, where significantly the subjects of the study felt more alert under DL over WW light after the experiment was performed.

4.4 Visual Task Performance among the Undergraduate Students of FPSK under Different CCT of Light

The fourth objective of the study was to compare the effects of light's CCT on visual task performance, in both computer-based and paper-based task performance, among the undergraduate students.

4.4.1 Computer-based task performance

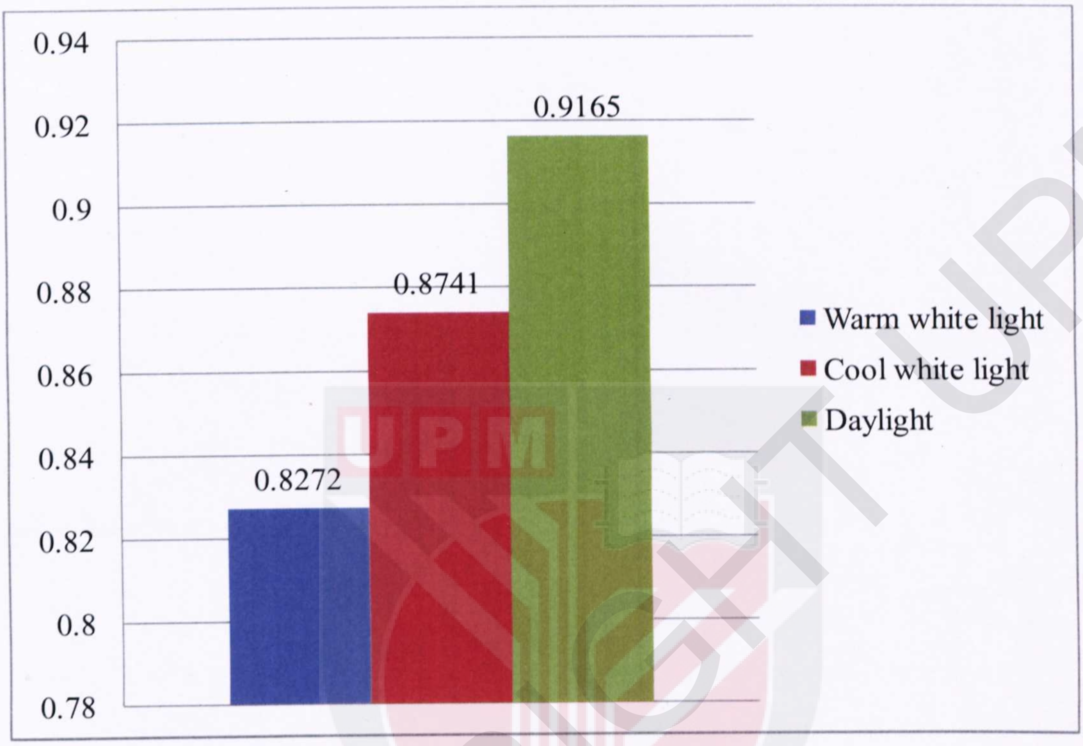

Figure 4.3 : Comparison of mean score of correct responses made per second under different lighting scenarios

Figure 4.3 shows the mean results of acuity tests under three different light's CCT settings. Subjects performed best under DL (0.9165 correct responses per second) rather than WW light (0.8741 correct responses per second) and CW light (0.8272 correct responses per second). This indicated that DL allows subjects to respond in better speed and accuracy when performing computer tasks, followed by CW light and WW light.

To compare computer-based task performance, r-ANOVA was performed on the mean score for acuity task for all lighting scenarios. Mauchly's Test of Sphericity indicated that the assumption of sphericity in preference scores had not been violated, as $\chi^2(2)=1.082$, $p>0.05$. The r-ANOVA yielded significant differences for the mean scores for acuity tasks ($F_{2,92}=7.284$, $p<0.05$).

Table 4.6 : Pairwise Comparisons of CCT of Light on Computer-based Task Performance

(I) CCT of Light	(J) CCT of Light	Mean Difference (I-J)	Std. Error	p value
Warm white	Cool White	-0.037	0.021	0.249
	Daylight	-0.079*	0.019	0.000
Cool White	Warm white	0.037	0.021	0.249
	Daylight	-0.042	0.022	0.184
Daylight	Warm white	0.079*	0.019	0.000
	Cool White	0.042	0.022	0.184

*Significant at p<0.05

As shown in Table 4.6, the acuity task performance of subjects working under DL was statistically different from WW light ($p<0.05$). The mean difference of acuity task performance between of these two light sources was 0.079, where subjects performed significantly better in computer-based task under DL compared to WW light.

4.4.2 Paper-based Task Performance

Paper-based task performance was tested by calculating number of incorrectly identified ring's orientation under each lighting scenario. The lower was the number of errors, means the better was the paper-based task performance.

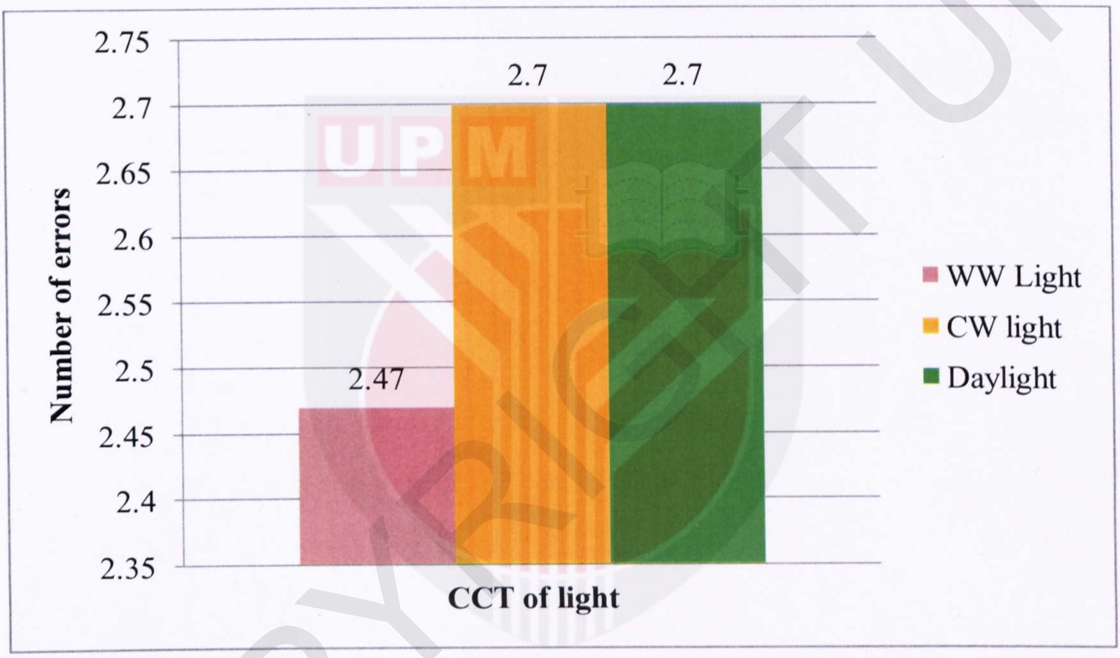

Figure 4.4 : Comparison of mean number of errors made in paper-based task performance test

Figure 4.4 shows that the subjects scored the best (mean of 2.47 errors) under WW light, followed by CW light and DL (mean of 2.70 errors).

Similarly, r-ANOVA was performed on the number of errors made in paper-based task for all lighting scenarios. Mauchly's Test of Sphericity indicated that the assumption of sphericity in preference scores had not been violated, as $\chi^2(2)= 4.551$, $p>0.05$. The r-ANOVA yielded no significant differences for the mean scores for acuity tasks ($F2,92=0.142$, $p>0.05$). Thus, there was no significant increment of performance under one lighting scenario than the rest.

4.5 Visual Contrast Threshold among the Undergraduate Students of FPSK under Different Light's CCT

The fifth objective of the study was to compare the effects of light's CCT on contrast threshold of subjects. If a subject had low contrast threshold, he had the more sensitive vision to detect an object from its background.

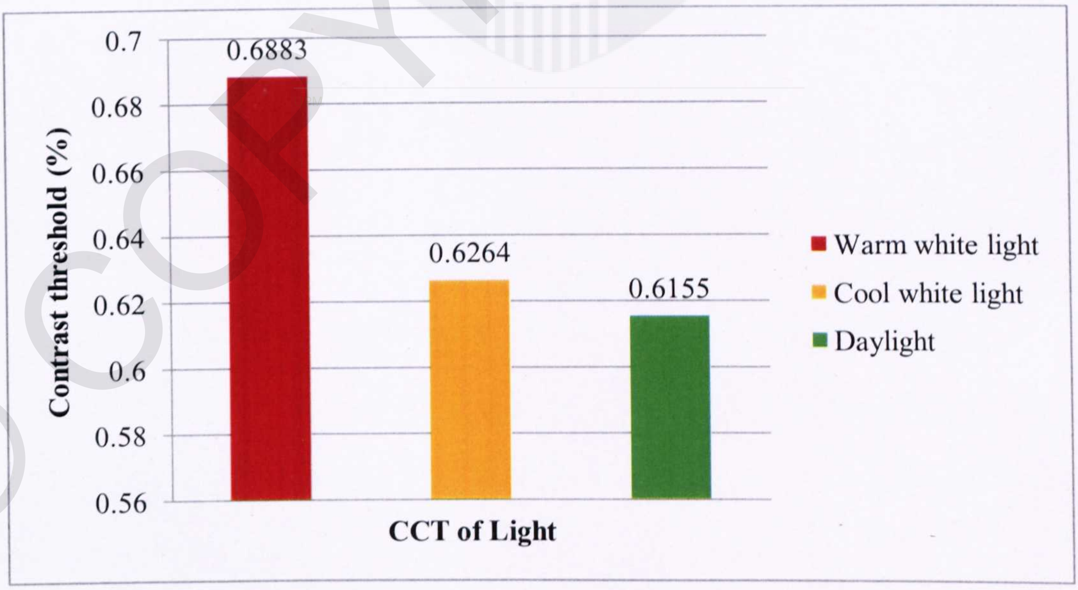

Figure 4.5 : Comparison of contrast threshold under different light's CCT

Figure 4.5 shows that the contrast threshold of subjects were the lowest when working under DL (0.6155%), compared to WW light (0.6883%) and CW light (0.6264%). This indicated that DL was better for subjects to perform activities related to distinguishing objects, especially when the contrast between objects and background is low.

To compare contrast threshold of subjects, r-ANOVA was performed on the mean score of contrast threshold under all lighting scenarios. Mauchly's Test of Sphericity indicated that the assumption of sphericity in had not been violated, as $\chi^2(2)= 6.170$, $p<0.05$. The r-ANOVA yielded no significant differences for the mean scores for acuity tasks ($F1.773, 81.551=0.696$, $p>0.05$). This means that there was no significant influence of different CCT of light on contrast threshold among the subjects.

4.6 Typing Performances among the Undergraduate Students under Different Light's CCT

The sixth objective of the study was to compare typing performances, in term of typing speed and typing accuracy, among the undergraduate students under different light's CCT. In the experiment, subjects were given 10 minutes for typing performance test.

4.6.1 Typing Speed

Table 4.7 : Comparison of typing speed of subjects

No. of words typed under lighting scenarios	Min.	Max.	Mean ± SD.
WW Light	174	447	263.36 ± 71.93
CW light	165	465	282.89 ± 71.68
Daylight	172	430	275.06 ± 66.93

Table 4.7 shows the statistics for numbers of words typed by subjects under all lighting scenarios. The minimum words typed (165 words) was recorded under CW light, maximum words typed (447 words) was recorded under WW light. By comparing the average of total words typed by subjects, CW light allowed subjects to type most words (282.89 ± 71.68 words) in given time, in relative to WW light (263.36 ± 71.925 words) and DL (275.06 ± 66.93 words).

To compare the typing speed, r-ANOVA was performed on the mean of number of words typed under all lighting scenarios. Mauchly's Test of Sphericity indicated that the assumption of sphericity in preference scores had not been violated, as $\chi^2(2)=1.773$, $p>0.05$. The r-ANOVA yielded significant differences for the mean scores for typing speed ($F2,92=10.829$, $p<0.05$), while the effect size was 0.191.

Table 4.8 : Pairwise Comparisons of CCT of Light on Typing Speed

(I) CCT of Light	(J) CCT of Light	Mean Difference (I-J)	Std. Error	p value
Warm white	Cool White	-19.532*	4.362	0.000
	Daylight	-11.702*	3.794	0.010
Cool White	Warm white	19.532*	4.362	0.000
	Daylight	7.830	4.485	0.263
Daylight	Warm white	11.702*	3.794	0.010
	Cool White	-7.830	4.485	0.263

*Significant at $p<0.05$

Pairwise comparison in Table 4.8 indicates that subjects could type in significantly better speed under DL ($p<0.05$) and CW light ($p<0.05$) compared to WW light, and the mean difference was 11.702 words and 19.532 words respectively. Yet, there was no significant difference between typing speed under DL and CW light ($p>0.05$). This is to say that WW light was the worst in facilitating subjects' typing speed.

4.6.2 Typing Accuracy

At the end of each trial, percentage of words that have wrongly typed was calculated. Again, r-ANOVA was used in analyzing this parameter too.

Table 4.9 : Comparison of typing accuracy of subjects

Percentage of wrong words typed under lighting scenario	Min.	Max.	Mean ± SD.
WW light	0.439	11.765	3.361 ± 2.453
CW light	0.000	8.385	2.470 ± 2.043
Daylight	0.000	8.232	2.248 ± 1.868

Table 4.9 describes the statistics typing accuracy by subjects under respective light's CCT. The DL allowed subjects to make least mistakes (2.248 ± 1.868%), in relative to WW light (3.361 ± 2.453%) and CW light (2.470 ± 2.043%).

To compare the typing accuracy, r-ANOVA was performed on the percentage of wrong words typed under all lighting scenarios. Mauchly's Test of Sphericity indicated that the assumption of sphericity in preference scores had been violated, as $\chi^2(2) = 11.212$, $p<0.05$. Thus, Greenhouse-Geisser correction was made. The r-ANOVA yielded significant differences for the mean scores for typing speed ($F1.639, 75.376=10.829$, $p<0.05$), while the effect size was 0.136.

Table 4.10 : Pairwise Comparisons of Ligh's CCT of on Typing Accuracy

(I) CCT of Light	(J) CCT of Light	Mean Difference (I-J)	Std. Error	p value
Warm white	Cool White	0.891	0.372	0.062
	Daylight	1.113*	0.248	0.000
Cool White	Warm white	-0.891	0.372	0.062
	Daylight	0.222	0.297	1.000
Daylight	Warm white	-1.113*	0.248	0.000
	Cool White	-0.222	0.297	1.000

*Significant at p<0.05

Pairwise comparison in Table 4.10 indicates that subjects could type in significantly better accuracy under DL (p<0.05) compared to WW light, and the mean difference was 1.113% of error. Yet, there was no significant difference between typing accuracy under DL and CW light (p>0.05), and WW light and CW light (p>0.05).

4.7 Selection of the Optimum Light's Colour Temperatures

To identify the most suitable CCT of lighting for undergraduate students, table of comparison below was used. For each variables tested, the light's CCT that gave best result was indicated as " / ".

Table 4.11 : Comparison of light's CCT on all variables tested

Paramenters	WW Light	CW Light	DL
Visual comfort level (*)		/	
Subjective preference (*)		/	
Alertness (*)			/
Computer-based task performance (*)			/
Paper-based task performance	/		
Contrast threshold test			/
Typing speed (*)		/	
Typing accuracy (*)			/
Duration of working comfortably perceived by subjects (mode hours)	2 – 4 hours	> 6 hours	4 – 6 hours

(*) Significant differences

Table 4.11 summarizes the optimum CCT for all interested variable. Among the listed, all results were significantly different from one another, except for the results for paper-based task performance and contrast threshold. DL was best in alerting effect, computer-based task performance, contrast threshold test and typing accuracy. Meanwhile, CW light was the best in visual comfort level, preferences, and typing speed. Also, subjects agreed that they could work comfortably under CW light most (>6 hours). Lastly, WW light aided in paper-based task performance

The selection of optimum colour temperature of lighting system for students would be further discussed in following chapter.

CHAPTER 5

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Study Background

The purpose of this research was to answer a research question: how CCT of light influences alertness, performance and visual comfort of people in an indoor environment. Also, it was expected to meet the objective of this research which is to find out, whether the students can benefit from the different light's CCT in a learning atmosphere. The study hopes to contribute with the results to the discussion about lighting norms for the office-like environment. The study was meant as a bridge between fundamental research of the non-visual effects of light and applied research in an indoor environment.

5.2 Socio-demography Background

This study involved 47 respondents (40.4% of male respondents and 59.6% female respondents) from five programmes of study in FPSK, UPM. The range weight of the respondents was 57.75 ± 11.02 kg, while the range height was 161.94 ± 8.04 cm. There were 14 respondents (29.8%) were Malay, 26 respondents (55.3%) were Chinese, 2 respondents (4.3%) were Indian, and 5 respondents (10.6%) were consisted from other races. In this study, the mean age of the respondents was 21.49 ± 1.38.

The factor of age in this study was controlled, and those who were in the age of 19 years old to 24 years old would be selected. Age is an important criterion to affect performance on visual tasks, since lighting requirements increase with age (Joseph, 2006). This factor was controlled because age affects the deterioration of the transmittance of the aging eyes' lenses, where the lenses gradually turn yellowish. Thus, the aging eyes see a less-blue world (van Bommel & van den Beld, 2004; Edwards & Torcellini, 2002). Also, Górnicka (2008) mentioned that the probability of making an error increases also with age, because of changes in retina and lens. By controlling enrollment of undergraduate students within desired age range, confounder factors such as aging factor and differences in literacy level were minimized.

In the aspects of average time spent in indoor, there were 70.1%, or total of 33 respondents revealed that they spent more than 8 hours with light switched on under environment in a day. This was not surprising, as Altomonte (n.d.) mentioned, most people nowadays spend more than 90% of their time indoors, including in school and workplace.

5.3 Subjective Preferences and Visual Comfort Level

In the study, visual comfort level and preference were both subjectively rated by respondents using modified OLS. There are large individual differences in what is considered comfortable lighting, as well as cultural differences between different regions would affect one's perception (Halonen, Tetri, & Bhusal, 2010). Visual comfort of human is highly dependent on the application, for example lighting that is considered comfortable in an entertainment setting may be disliked and regarded as uncomfortable in a working space (Boyce et al., 2003). Also, the preferences of light's characteristic vary among people and for the same person at various times during the day (Miller, 2007).

5.3.1 Subjective Preferences

Table 4.3 showed that in comparison of preferences between WW light (3000K), CW light (4000K) and DL (6500K), CW light was the most preferred colour temperature among the three. It was significantly different from WW light. Most subjects agreed that working under lighting in higher CCT was more comfortable, allowed occupants to have better colour rendering, and helpful in carrying out different tasks.

The lighting should permit the "real" colours to be seen. Proper colour rendering of the human skin is especially important, since lighting that makes the skin look pale and unhealthy often leads to complaints (van Bommel & van den Beld, 2004). This was particularly true when 31.9% of subjects in the study thought that their skin look unnatural under WW light, while only 12.8% of subjects thought so under DL.

However, the finding of preferences of colour temperature of lighting was contradictory to some studies. For example, at daylight levels (500 lux), the average preferred CCT was around 3300K to 3500K (Miller, 2007; Park, Chang, Kim, Jeong & Choi, 2010). Also, Sanaz (2011) cited that Flynn (1997) has indicated that people prefer more "warm" colour temperature and dim (lower illuminance) than "cool" and bright (higher illuminance) white lighting.

The differences of finding might be due to personal preference of human (Miller, 2007; Górnicka, 2008) and also results from distinct duration of exposure between previous experiments with the current one. To be specific, unlike previous trial involved couples of hours, subjects in current experiment were exposed to certain light's CCT for less than an hour before making assessment on their preferences. This might lead to inconsistence of results.

5.3.2. Visual Comfort Level

Similar to subjective preference as discussed in Chapter 5.2.1, CW light was perceived as the best in term of visual comfort level. In opposite, WW light was the worst in term of occupant's perception in this parameter. Causes of visual discomfort could be too little light and too much light, too much variation in luminous distribution, too uniform lighting, annoying glare.

In this study, subjects were significantly felt more comfortable under CW light compared to WW light. By assessing through modified OLS, the reasons of visual discomfort under WW light were revealed: 31.9% of subjects had mild eyes strain, 29.8% had heavy eyes lid, 21.3% had dry eyes, 19.1% had burning eyes, and 17.0% had headache after experiment under WW light. All of these illnesses or symptoms could be referred to poor lighting in the offices (Halonen, Tetri, &

Bhusal, 2010; Sanaz, 2011), light's CCT in specific. This finding was in line with Lin (2008), where human subjectively preferred blue and white colour of light.

Yet, Górnicka (2008) again pointed out that most of the people gave a high score of reading comfort to warm light condition; while the opinions were more diverse if in the cool light. Nevertheless, the difference was not significant. He also reported that some people experienced also kind of dizziness in the cool light condition possibly due to chromatic aberration.

The inconsistent finding was again probably due to personal perception and shorter duration of experiment. Also, not to forget to mention the possibility of "Hawthorne effect", where subjects purposely rated low scores for default (WW light in this study), and rated relatively better scores for 'new' settings (CW light and DL). Quality assurance was taken in place, yet it seems almost impossible to implement a double-blinded design in study dealing with the effects of different lighting.

5.4 Subjective Alertness Level

Among three lighting scenarios, only DL allowed respondents to subjectively feel more alert, while WW light and CW light made subjects felt sleepier at the end of experiment. Besides that, the differences between alertness before and after the experiment under DL were significant using paired T-Test. It proved that subjects became significantly more alert after approximately 50 minutes of exposure to light with high CCT.

The finding was in line with many studies. Recently, it has been suggested that high CCT of light could be used in increasing human alertness (Halonen, Tetri, & Bhusal, 2010). The suggestion supports the finding of effects of higher CCT (6500K) could increase alertness of occupants in the indoor environment. Also, van Bommel & van den Beld (2004) mentioned that the bluish morning light has biologically an activating (alerting) effect, while the red sky in the early evening has a relaxing effect. When comparing the mental activity level and autonomic nervous system, Hoffmanna et al (2008), found that higher CCT have been shown to improve both variables, and at the same time emphasized its potential in ameliorating the degree of drowsiness, fatigue, or daytime sleepiness.

Few researches have been worked on effects of lighting on students' alertness level in classroom or lecture hall. For instance, the CCT of light did prove to be associated with the alertness of the subject in the end so that he higher the CCT of light was during the lecture, the better the alertness was in the end. More interestingly, blue light seemed to help the students to maintain their alertness in the afternoon (Rautkylä, Halonen & Lehtovaara, 2008). According to Mills, Tomkins & Schlangen (2007), their point of view was proved by the finding of current studies, where they said that studies have demonstrated that higher CCT (7500K versus 3000K in previous study) are more activating from the viewpoint of mental activity level. Also, drowsiness has been observed to be higher under lower CCT lighting when comparing 3000K with 5000K.

5.5 Visual Task Performance

Hameed & Amjab (2009) stated that the prime factor affects the productivity of occupants in the office (or similar environment) is lighting. The most obvious effect of light on humans is in enabling vision and performance of visual tasks. Colour of light is important in visual task performance, as it had direct impact on the visual operation of the human eye (Stephenson, 2005). Also, Juslen (2006) cited that productivity increased when the CCT was increased for 5.7%, and thus higher CCT increases the attention span of the worker .

5.5.1 Computer-based Task Performance

Light quality can be judged according to the visual aspect, for instances, level of visual comfort and performance required for our activities (Halonen, Tetri, & Bhusal, 2010). Yet, visual performance does not have clear deification and importance in all tasks. In generally, it was believed that with the right type of lighting in environment, it helps people to better see what they are doing and make task easier to do (Sanaz, 2011).

In this study, FrACT software was used to assess subjects' computer-based task performance, where correct responses made per second under respective lighting scenario were generated. By doing such test, visual acuity of subjects were tested. All targets are presented at the same contrast, but their sizes vary during the test.

It involved concentration on laptop screen and quick reply using external keyboard attached to. DL was found to be the best light's CCT, the possible reason behind the significant result was due to the bluish spectrum it has. According to Lehrl et al. as cited by Hoffmanna et al (2008), with respect to alertness and speed of information processing, illumination with blue light (455 nm) proved to be more effective as compared to yellow light (580 nm) or white light, independent of its level of intensity.

Similar to current study, it was found that whiter light (CCT >6000K) produced better acuity scores over a series of visual tests (Stephenson, 2005). To support the statement, Berman et al. (1994) discovered that the whiter light induced a smaller pupil size for the same intensity of light. Physiologically, the smaller pupil was easier for the eye muscles to focus. This created better visual performance. Additionally, it was found that the contracted pupil in white light reduced the visual influence of defects that develop mainly around the periphery of the eye.

Thus, the whiter light (higher CCT and greater blue content), the higher visual acuity and greater apparent brightness it produced in computer-based task performance.

5.5.2 Paper-based Task Performance

The task performance on paper-related activity was assessed by using printed version of 96- rings (as in Appendix 6). The time given was 5 minutes for every test, and the number of incorrectly identified rings' orientation was taken as indication of performance under respective lighting scenario.

In Figure 4.4, it was interesting to find that WW light allowed subjects to score the least mistakes on paper-based task performance, unlike what had been observed during computer-based task performance. Averages of 2.47 errors were made under WW light, while 2.70 errors were made under CW light and DL. Even though the differences were not significant to the colour temperature of light statistically, yet it was motivating to find the new trend in the field. The better performance in paper-based task under WW light might be related to the relaxing emotion and cozy atmosphere created compared to the two, which created more business-like feeling (van Bommel & van den Beld, 2004).

However, the results were subjects to reliability and comprehensibility of the current test used. In the experiment, only one paper-based test was done, which was identifying the openings of rings printed on a paper in low contrast from background. In real life, there are more tasks relate to the use of paper, such as writing notes, reading and drawing.

5.6 Visual Contrast Threshold

In present study, contrast thresholds were measured by visual decision making task that involved simple detection (is something there) through FrACT software on laptop. In this case, contrast of target from its background was not kept constant during the test but is varied so that the minimum level of contrast for seeing a target can be determined (Owsley, 2003).

Figure 4.5 showed that the average of subjects' contrast threshold was highest under WW light (0.6883%), which means that this colour temperature has resulted in the lowest visual sensitivity among the three. In opposite, DL led to lowest contrast threshold (0.6155%), which has highest visual sensitivity in the other words.

The differences of contrast threshold were not significant, thus there was a considerable probability that the variations observed in had occurred by chance.

Yet, it gave an idea of possibility of cooler CCT is more beneficial for occupants to perform low contrast tasks, such as identifying targets on computer screen or differentiating objects of similar colours.

5.7 Typing Performances

Typing in an indoor environment is one of the most common activities performed by students, thus it was important to understand which CCT of light lead to best results. This test involved looking at a given article (approximately 400 words), reading and typing in Microsoft Words document in 10 minutes. Different articles with similar difficulties and structure were prepared for the means of trials under different lighting scenarios.

5.7.1 Typing Speed

In 10 minutes given, subjects were significantly fastest in typing under CW light, while they typed least words under the WW light, which was the default lighting setting.

The reason that led to such performance under yellowish light was probably due to unclear colour rendering effects when subjects looking at article printed on A4 paper, as well as on laptop screen. In contrast, whiter colour (with higher degree of blue content) has advantage in presenting the words in both paper and electronic devices effectively.

Between typing speed under CW light and DL, it should be related to visual comfort level as discussed in previous section. This was in line with finding that subjects found it was most comfortable working under CW light. Logically, an occupant would perform better in the test when feels comfortable when typing,

5.7.2 Typing Accuracy

In current study, typing accuracy was indicated by the percentage of wrong words typed under respective lighting scenario. DL setting was the setting that allowed least typing errors among the three, followed by CW light and WW light. In addition, there were significant differences in typing accuracy between WW light with DL. The mean difference of 1.113% showed that WW light did not allow subjects to type in high accuracy.

This result was parallel to finding of typing speed, where WW light was the least optimum for both typing performance's indicators. It was again proving that in term of information processing (looking at paper and reading) and implementation in processing, yellow light was less effective independent of its level of intensity (Lehrl, Gerstmeyer, Jacob, Frieling, Henkel, Meyrer, Wiltfang, Kornhuber, & Bleich, 2007).

Also, it should be noted that typing accuracy in current study took into consideration of total words typed (formula was listed in section 1.7.6). Therefore, with statistically less word typed and many errors made, it leads to lower typing accuracy.

5.8 Selection of the Optimum Light's Colour Temperature

The final objective in this study is to recommend appropriate CCT of light that is optimum for the visual comfort, alertness maintenance and performance (both computer- and paper-based, and also in typing wise), as well as preferred by majority of undergraduate students in FPSK, UPM.

Table 4.11 was tabulated after considering all finding of interested variables obtained from experiment as discussed before. The table showed that DL was the light's CCT that allowed subjects to be more alert, scored better in computer-based task performance, visual contrast level and typing accuracy. On the other hand, CW light was determined to be the most comfortable lighting, where subjects preferred the most. Also, it allows subjects to type in better speed and work comfortably for more than 6 hours compared to the others. Lastly, WW light is the least favorable among the three settings; while subjects thought that they can only work comfortably under this light's CCT for 2 to 4 hours.

To summarize, CW light is suitable for long term use (> 6hours) and activity that requires occupants to spend longer time and attention. For example, CW light should be used for typing, revising, working on assignment or even doing information processing. On the other hand, artificial daylight is ideal for an activity that requires students to be alert, and involve differentiation of tiny or unclear objects. For instance, artificial daylight can be installed at places for students to attend lecture, performing laboratory work, or even conducting meticulous research.

On the other hand, the usage of WW light, which has installed in most area of faculty, should be revised for the sake of better students' performance.

5.9 Conclusion

Total of 47 healthy undergraduate students participated in the study. In overall, the study subjects significantly preferred the CW light most, and they agreed that CW light was the most comfortable light sources. The subjects revealed that they could work comfortably under CW light for more than 6 hours. Also, CW light was the best light that led to highest typing speed, which had significant differences with the other light's CCT. For subjective alertness level, DL significantly increased subjects' alertness level at the end of the experiment. In addition, the computer-based task performance was the best under DL. Lastly, DL was significantly better for typing accuracy too. Yet, no significant differences in the contrast threshold test and paper-based task were found. It is concluded that there is no absolute 'perfect light's colour temperature', but CW light and DL were more beneficial to students than the WW light, which is the default lighting in used in FPSK, UPM.

5.10 Recommendations

This study was conducted in a controlled laboratory setting, which involved short-term tests. It is recommended that to further study at a longer period to access the long term effects of such light' CCT for occupants. This is because short duration of exposure for each lighting scenario might not be adequate for complete understanding of its effect in both visual and non-visual parameters.

Based on the results obtained in the study, recommendations can be given to Universiti Putra Malaysia (UPM), undergraduate students, and lighting designers.

At the moment, WW light is used in laboratory, lecture hall, tutorial room and library of FPSK, UPM. It was not favoring the requirements of students in term of performances, alertness, visual comfort and preferences. By comparing to CW light and DL, it was clear that students could have performed better or feel more comfortable. Therefore, technical management of FPSK, UPM, can consider reinstalling new lighting system that fits different needs of students in the near future.

For undergraduate students, where there is possibility to control the CCT of light, they can opt for higher CCT (6500K) when performing academic activities that require high attention or have to be meticulous.. On the other hand, moderate CCT (4000K) is suitable for them to perform activities that need longer duration, such as typing using laptop.

Lastly, the results can be proposed to lighting designers or engineers as a reference to achieve better indoor environment quality. For example, natures of activities in the new building should be considered before installing lighting system. This is because the CCT of light source lead to different effects on perception and performances of human in the building.

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APPENDIX 1

ETHIC APPROVAL LETTER

APPENDIX 2

ETHIC CONSENT FORM

UPM
UNIVERSITI PUTRA MALAYSIA
BERILMU BERBAKTI

FAKULTI PERUBATAN DAN SAINS KESIHATAN
FACULTY OF MEDICINE AND HEALTH SCIENCES
UNIVERSITI PUTRA MALAYSIA, 43400 UPM SERDANG, SELANGOR, MALAYSIA

CONSENT FORM (RESPONDENT)

RESEARCH TITLE : EFFECTS OF LIGHT'S COLOUR TEMPERATURE ON TASK PERFORMANCE, INDIVIDUAL VISUAL COMFORT LEVEL, AND ALERTNESS AMONG STUDENTS OF FPSK, UPM.

RESEARCHER : SIA CHEE CHAI

I ……………………………………… Identity Card No. ……………………………… address……… ………………………………………………………….hereby voluntarily agree to take part in the clinical research *(clinical study, questionnaire study/ drug trial) specified above.

I have been informed about the nature of the clinical research in terms of methodology, possible adverse effects and complications (refer to Information Sheet). I understand that I have the right to withdraw from this clinical research at any time without assigning any reason whatsoever. I also understand that this study is confidential and all information provided with regards to my identity will remain private and confidential.

I wish to *know/don't wish to know the results of the tests performed on my sample.

* delete where necessary

Signature …………………………………… (*Respondent*)

Date :…………………………………………

Signature …………………………………… (*Witness*)

Name :…………………………………………

I/C No. :…………………………………………

I confirm that I have explained to the respondent the nature and purpose of the above –mentioned clinical research.

Date …………………………………

Signature …………………………………… (Researcher)

UPM/FPSK/PADS/T7-MJKEtikaPer/F01

APPENDIX 3

RESPONDENT INFORMATION SHEET

FAKULTI PERUBATAN DAN SAINS KESIHATAN
FACULTY OF MEDICINE AND HEALTH SCIENCES
UNIVERSITI PUTRA MALAYSIA, 43400 UPM SERDANG,
SELANGOR, MALAYSIA

RESPONDENT'S INFORMATION SHEET

Please read the following information carefully, do not hesitate to discuss any questions you may have with your researcher.

STUDY TITLE :

Effects of Light's Colour Temperatures on Visual Comfort Level, Task Performances, and Alertness among UPM's Students.

INTRODUCTION

Light is defined as electromagnetic radiation that is visible to human eyes, and is responsible for the sense of sight. Since light is very critical for human to see things and perform activities, its quality is always one of the main consideration for indoor environment. Numbers of studies have found that different spectrums provided by the various types of lighting are important in affecting human beings psychologically and physiologically, such as productivity, sense of well being and impact on morale and motivation.. In the other words, good and suitable lighting quality is determined as one of the important factors of healthy indoor quality.

In regards of human perception, two of the most important characteristics of light are illuminance and colour temperature. However, the effects of different colour temperature of the lighting setting to performance and comfort level among those occupants are yet to be completely determined.

This study is performed to determine the effects of different light's colour temperature (full spectrum light, yellow light, white light and blue light) on human task performance, individual visual comfort level and alertness. Also, it is expected to increase evidence database on this field locally as well as to raise awareness in the issue of healthy lighting.

WHAT WILL YOU HAVE TO DO?

You should sign the consent letter to show that you are interested in participating this study, where you already been explained about the aims and process of the study. The consent letter have to be returned to the researcher before the interview and testing process. If you have any questions or doubts about this research, please be not hestitate to voice out or ask the researcher.

WHO SHOULD NOT ENTER THE STUDY?

Those who are smokers, pregnant, colour blind, uncorrected vision acuity and person who is ill should not be participating in this study. This is due to results might be differed if experiment is performed under these circumstances.

WHAT WILL BE BENEFITS OF THE STUDY:

(a) TO YOU AS THE SUBJECT?

The findings from the study can identify the optimum light's colour temperatures for better visual comfort level, visual task performances and alertness. Through this findings, optimum light's colour temperatures can be recommeded in the study environment, as well as in office workplace, in order to optimize both computer- and paper-based task performance.

(b) TO THE INVESTIGATOR?

From the findings from this study, the researcher can determine the relationship and compare how the diffreent light's colour temperature affect human's visual comfort level, alertness and visual task performance. These finidings can be further investigate at different settings and come out with a guideline of optimum light's colour temperature for Malaysian in their indoor working settings. Also, the finding is important for defining new reference for lighting installation, serving both visual and non-visual needs.

ARE THERE ANY RISKS?

There is no risk will be imposed on the respondents, as there are no explosive materials and blood sampling used in this study.

WHAT ARE THE POSSIBLE DRAWBACKS?

The respondent will not be required to pay any expenses for this study, as the researcher will covers all the expenses of the study. Also, this study will not affecting the health conditions of respondents.

WILL THE INFORMATION AND MY IDENTITY REMAIN CONFIDENTIAL?

The data obtained from each respondent will remain private and confidential, since the results obtained will be reported in a collective manner. Therefore, there will be no reference to a specific individual and names of each respondent will not be revealed out in any publications or report in the end of the study.

WHO SHOULD I CONTACT IF I HAVE ADDITIONAL QUESTIONS DURING THE COURSE OF THE RESEARCH?

If there is any doubts and questions about the study, please contact with the researcher (Sia Chee Chai) at 017-2133494 or his supervisor, Dr. Shamsul Bahri Hj Mohd Tamrin at 017-3134792.

APPENDIX 4

MODIFIED OFFICE LIGHTING SURVEY (OLS)

Respondent ID: ________

TITLE OF RESEARCH:

The effects of light's colour temperatures on task performance, individual visual comfort level, and alertness among students of FMHS, UPM.

PART A: SOSIO-DEMOGRAPHY QUESTIONNAIRE

INSTRUCTION: Please answer all the questions in the given space. Thank you.

No.	Items	Answer
1.	Age: _______ years old	
2.	Gender: 1. Male 2. Female	
3.	Height: _______ cm Weight: _______ kg	
4.	Ethnicity: 1. Malay 3. Indian 2. Chinese 4. Others	
5.	Program undertaking: 1. Biomedical Science 2. Environmental & Occupational Health 3. Medical Doctor 4. Dietetics 5. Nutrition and Community Health 6. Nursing	
6.	Year of study: 1. First year 4. Fourth year 2. Second year 5. Fifth year 3. Third year	
7.	In a day, how much time (hours) you spend in indoor environment with light switched on?	

PART B:

THE KAROLINSKA SLEEPINESS SCALE (KSS) (a)

INSTRUCTION:

Please rate your current alertness/sleepiness state for respective lighting scenario based on the value and rating given in the table.

Value	Rating
1	Extremely alert
2	Very alert
3	Alert
4	Rather alert
5	Neither alert nor sleepy
6	Some signs of sleepiness
7	Sleepy, no effort to stay awake
8	Sleepy, some effort to stay awake
9	Very sleepy, great effort to keep awake, fighting sleep

Current alertness/sleepiness state (in the beginning of the trial):

Lighting Scenario A: _____ Lighting Scenario C: _____

Lighting Scenario B: _____

THE KAROLINSKA SLEEPINESS SCALE (KSS) (b)

INSTRUCTION:

As refer to above table of rating, please rate your current alertness/sleepiness state for respective lighting scenario based on the value and rating given in the table.

Current alertness/sleepiness state (in the end of the trial):

Lighting Scenario A: _____ Lighting Scenario C: _____

Lighting Scenario B: _____

PART C: MODIFIED QUESTIONNAIRE - OFFICE LIGHTING SURVEY

INSTRUCTION:

Please answer all the questions by choosing the best answer that suits your current perception. Thank you.

Lighting Scenario: **A**

No.	Items	Subjective Perception			
		Yes	Rather Yes	Rather No	No
1.	I like the lighting in this office.				
2.	In general, the lighting in this office is comfortable.				
3.	This colour of light allows me to carry out the different tasks.				
4.	My skin looks unnatural under the light.				
5.	The lighting in this office is too warm (yellowish).				
6.	The lighting in this office is too cold (bluish).				
7.	The coloured illumination do not influences working.				
8.	I feel eye strain.				
9.	My eye lids are heavy.				
10.	My eyes feel dry.				
11.	I have burning eyes.				
12.	I have a headache working under this lighting scenario.				
13.	I have difficulties in seeing objects on the screen.				
14.	Please state the maximum amount of time per day which you could imagine yourself working comfortably under this lighting scenario. (< 2 hours, 2 – 4 hours, 4 – 6 hours, or > 6 hours)				

INSTRUCTION:

Please answer all the questions by choosing the best answer that suits your current perception. Thank you.

Lighting Scenario: ______**B**________

No.	Items	Subjective Perception			
		Yes	Rather Yes	Rather No	No
1.	I like the lighting in this office.				
2.	In general, the lighting in this office is comfortable.				
3.	This colour of light allows me to carry out the different tasks.				
4.	My skin looks unnatural under the light.				
5.	The lighting in this office is too warm (yellowish).				
6.	The lighting in this office is too cold (bluish).				
7.	The coloured illumination do not influences working.				
8.	I feel eye strain.				
9.	My eye lids are heavy.				
10.	My eyes feel dry.				
11.	I have burning eyes.				
12.	I have a headache working under this lighting scenario.				
13.	I have difficulties in seeing objects on the screen.				
14.	Please state the maximum amount of time per day which you could imagine yourself working comfortably under this lighting scenario. (< 2 hours, 2 – 4 hours, 4 – 6 hours, or > 6 hours)				

INSTRUCTION:

Please answer all the questions by choosing the best answer that suits your current perception. Thank you.

Lighting Scenario : **C**

No.	Items	Subjective Perception			
		Yes	Rather Yes	Rather No	No
1.	I like the lighting in this office.				
2.	In general, the lighting in this office is comfortable.				
3.	This colour of light allows me to carry out the different tasks.				
4.	My skin looks unnatural under the light.				
5.	The lighting in this office is too warm (yellowish).				
6.	The lighting in this office is too cold (bluish).				
7.	The coloured illumination do not influences working.				
8.	I feel eye strain.				
9.	My eye lids are heavy.				
10.	My eyes feel dry.				
11.	I have burning eyes.				
12.	I have a headache working under this lighting scenario.				
13.	I have difficulties in seeing objects on the screen.				
14.	Please state the maximum amount of time per day which you could imagine yourself working comfortably under this lighting scenario. (< 2 hours, 2 – 4 hours, 4 – 6 hours, or > 6 hours)				

- END OF SECTION -

APPENDIX 5

ARTICLES USED IN TYPING PERFORMANCE TEST

1) Shark fin soup alters an ecosystem

There is no animal on earth more vilified than the shark. Pop culture references and annual, over-hyped reports of attacks on swimmers or surfers have put sharks on the top of the list of the world's most feared living things. There is however, a creature far more predacious than the shark: Humans.

Sharks existed before there were dinosaurs and they pre-date humans by millions of years. Yet, in a relatively short period of time, humans and their technological arsenal have driven most shark populations to the verge of extinction. This is bad news for the world's oceans. Sharks are the top predator in the ocean and are vital to its ecosystem. The rapid reduction of sharks is disrupting the ocean's equilibrium, according to Peter Knights, director of WildAid International.

"These are ecosystems that have evolved over millions and millions of years," said Knights. "As soon as you start to take out an important part of it, it's like a brick wall, you take out bricks and eventually it's going to collapse."

When sharks attack humans, it inevitably makes news - it is a sexy story. What is rarely reported is that worldwide, sharks kill an average of 10 people every year. It's usually when people venture into a shark's habitat and not the other way around. By contrast, humans kill around 100 million sharks every year - a number that has ballooned in recent years because of the enormous demand for shark fins to make shark fin soup.

Shark fin soup is a delicacy reserved for the wealthy on special occasions and it has been part of Chinese culture for centuries. Over the last decade, the exploding middle class in China has changed the fate of the shark. With an unprecedented number of people making more money than ever, the demand for all things that signal an improvement in status is gargantuan. The ability to serve and consume shark fin soup is among the most revered of activities, because it signifies that one has made it.

Shark fin soup can be expensive. A bowl of imperial shark fin soup can cost upwards of $100. These days, shark fin soup is so fashionable that it's becoming commonplace. Buffets serve versions of it for as low as $10 a bowl. The irony is that shark fin is flavorless -- its cartilage has a chewy consistency. Tens of thousands of sharks are being killed for a gelatinous thing in a soup.

2) Reduce your daily sugar intake

There's no denying that sugar and obesity are intrinsically linked. Think of it this way, the more sugar you eat, the more effective your body is in absorbing it; and the more you absorb, the fatter you will get. Without a low daily sugar intake, complications like diabetes can also result and cause long-term complications. To extend your life, reduce your sugar intake.

All things should be in moderation. The recommended daily intake of sugar isn't zero grams, however. That's just not realistic. Nutrition experts recommend that the average person get about 12 teaspoons of sugar per day, or no more than 40 grams. And their recommendations focus on natural sugars, mostly the sugars found in fruit.

A health tip that you may not be aware of is when you ingest sugar, you should also ingest fiber. This reduces the damage on the body from sugar. Nature is smart. While there are high concentrations of sugar in fruit, for every gram of sugar, there is usually 2 grams of fiber.

The real killer is fructose and that includes high fructose corn syrup as it has been noted to be severely harmful to your health, as well as many other processed substances. You need to avoid fructose at all costs. It is a literal poison to your body. If you can find products that use raw sugars this is the most preferred. Natural sweeteners can help sweeten your food without the high restrictions on daily amounts and the negative side effects of refined sugars.

How to cut down on your daily sugar intake? Most people are consuming far more sugar than they realize. The recommended daily sugar intake is a mere 40 grams. And while 40 grams may sound like a high daily allowance, it's quite small in comparison to the amount of refined sugars contained sodas, chocolate, desserts, and other sweets.

To cut down, you must first know what your daily limit is, which you should talk to your doctor about. Then, prioritize your favourite sugary foods within your new constraints. Place special emphasis on more healthy sources of sugar, like fruits. Everything that doesn't fit in your new plan must be eliminated in order to preserve your good health. Research shows if you are being mindful of your sugar intake and knowing what to look for is key to reducing your weight and reduce your chances of major health risks.

3) A Short Article on Technology

The world has undergone enormous changes over the past decade. We now live in a world where communication is paramount. It seems that everyone and everything is connected in some way.

For school students this has made things much more efficient. Research papers that used to involve hours of laborious effort, can now be researched and documented without ever touching a card catalog or a periodical index. Worlds of information are now available at the click of a mouse.

Questions that people pondered without any answer previously can now simply be typed into any convenient search engine and answered almost immediately. There are countless sites filled with informative short articles all over the Internet. Videos and music can now be seen on demand and news from across the world can be delivered in an instant.

There are some people who worry that the technological revolution and evolution we are experiencing today is moving too fast. There seems to be a loss of privacy in some respects and the specter of a Big Brother society looms larger than it has since 1984. Whether their fears are well founded or not will remain to be seen, but it is unlikely that people will ever willingly give up the almost instant connections to our wired world.

Individuals are learning to take advantage of blogger's website by using their well placed blogs to sell products and services. The internet has allowed individuals an opportunity to step on to the same playing field as the big boys of business. With the right information and the ability to get it seen, anyone can now reach the masses and share their thoughts, feelings and even sales pitches.

Businesses as well as individuals have come to rely on the Internet as a source of advertising and actual sales. Entire business models have been constructed and thriving based solely on using Internet websites. Any business that does not adapt and grow to keep up with the newest technology seriously risks being left behind in the wake of their competitors who choose to ride technology's leading edge.

Time will tell where this all will lead. We should make the most of the positive possibilities technology promises, but we should also keep a careful watch on where we are going.

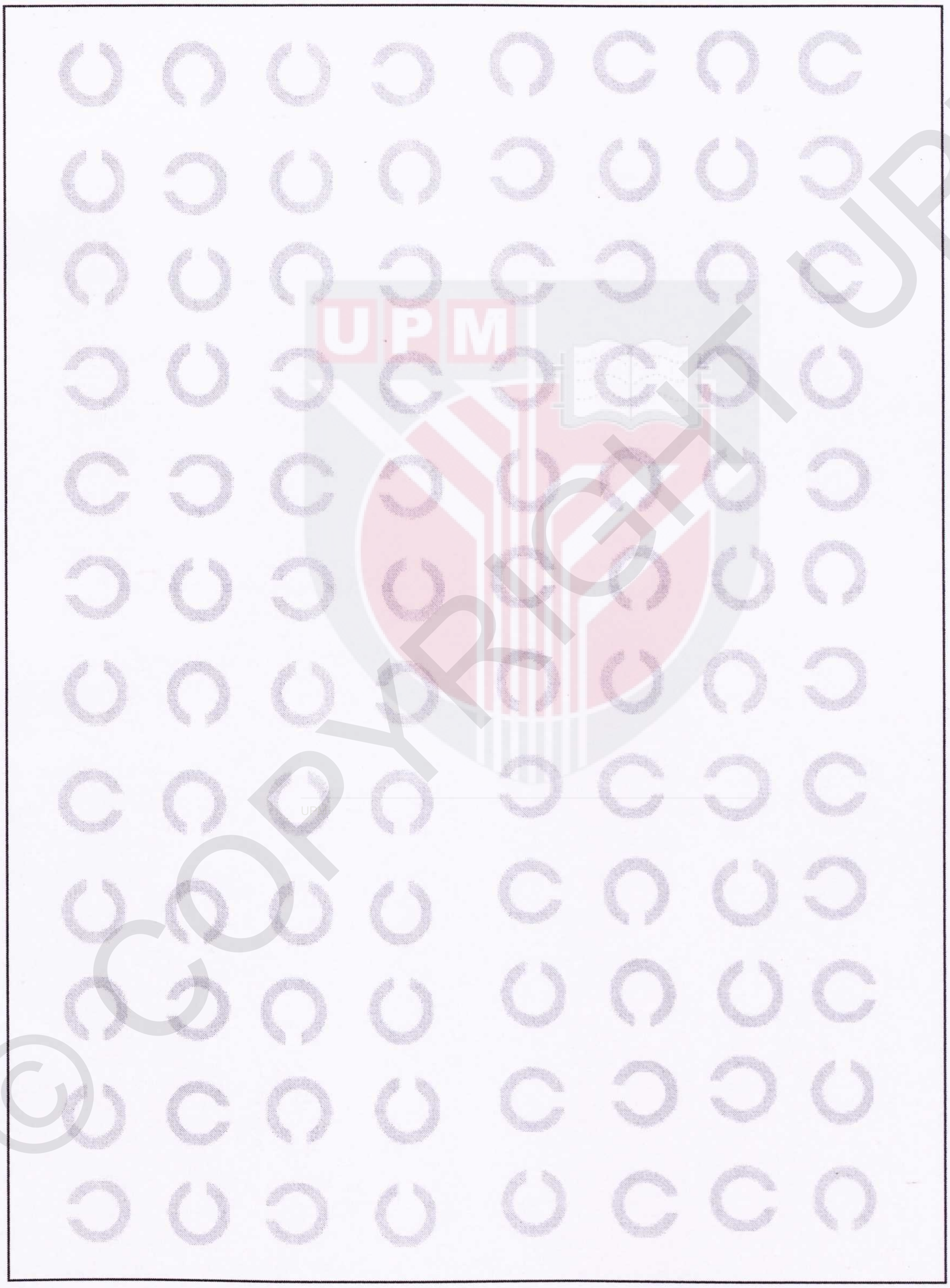
APPENDIX 6

PAPER-BASED TASK

PERFORMANCE TEST

Paper Based Task Performance Test **Lighting Scenario: ____A____**

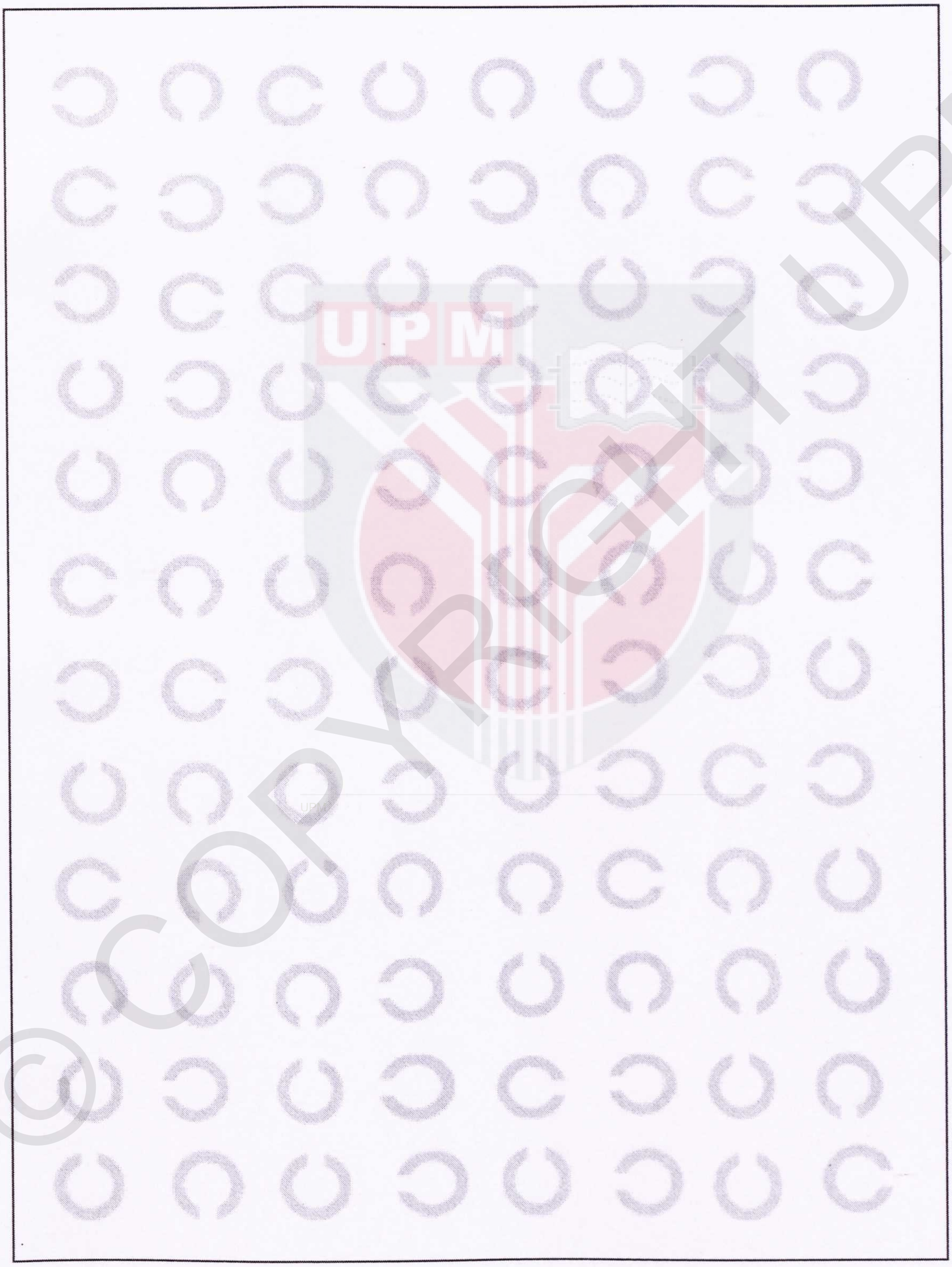
Instruction: Calculate the as many as you can of the Landolt Ring with respective orientation (90°, 180°, 270°, 360°) without marking on the paper within 5 minutes. Please fill in the space below for each orientation you have counted.



1 (90°) : ________ (180°) : ________ (270°) : ________ (360°) ________

Paper Based Task Performance Test **Lighting Scenario:** ____B____

Instruction: Calculate the as many as you can of the Landolt Ring with respective orientation (90 °, 180 °, 270 °, 360 °) without marking on the paper within 5 minutes. Please fill in the space below for each orientation you have counted.



 : ________ (90°)

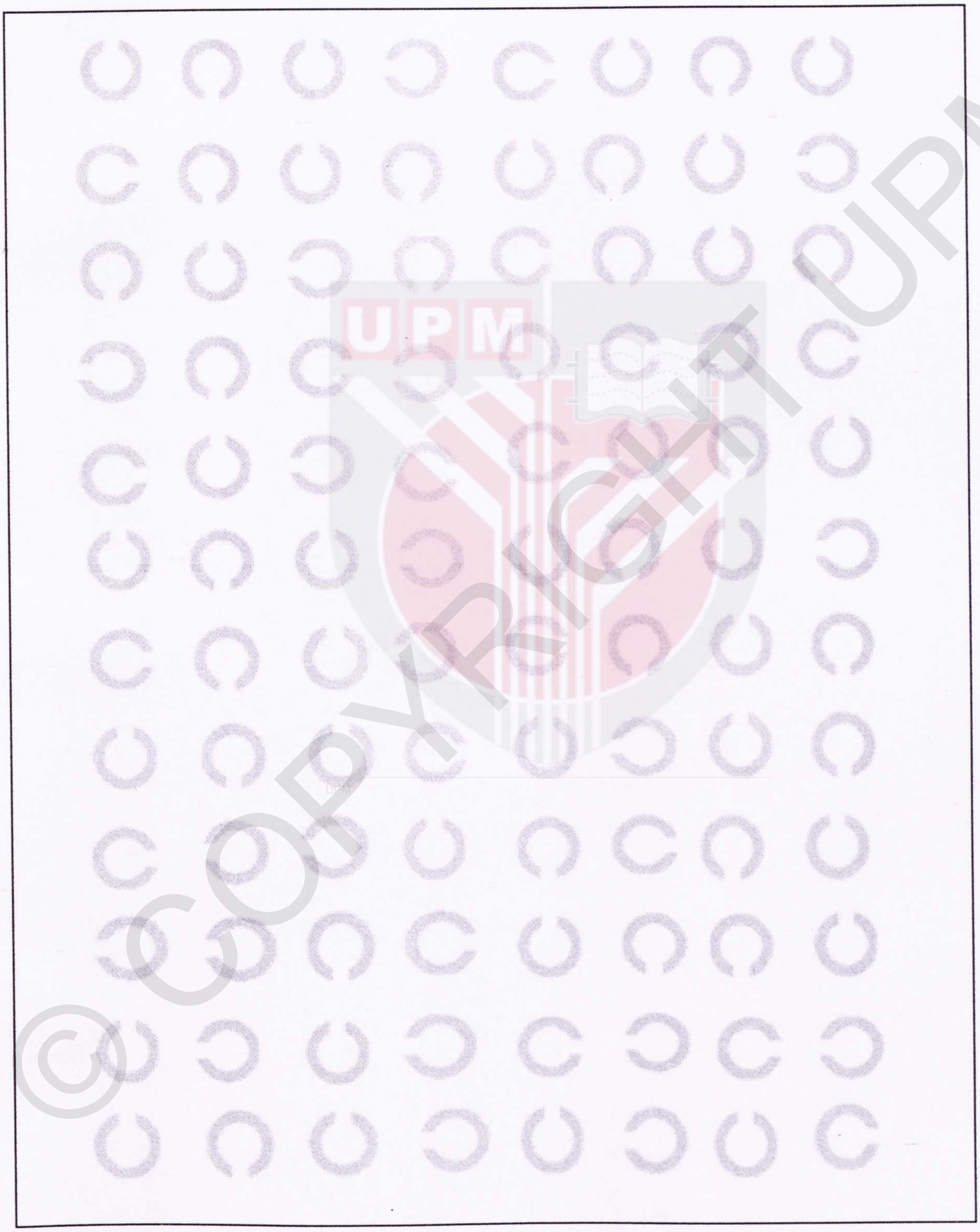
 : ________ (180°)

 : ________ (270°)

 : ________ (360°)

Paper Based Task Performance Test **Lighting Scenario:** ____C____

Instruction: Calculate the as many as you can of the Landolt Ring with respective orientation (90 °, 180 °, 270 °, 360 °) without marking on the paper within 5 minutes. Please fill in the space below for each orientation you have counted.



(90°) : ________ (180°) : ________ (270°) : ________ (360°) : ________