A Noble Approach for Identifying Effect of Colour Temperature on Landolt's Ring-Based Task Performance

A THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENT FOR A DEGREE OF

MASTER OF ENGINEERING

IN

ILLUMINATION ENGINEERING

SUBMITTED BY

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AUGUST, 2022

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RECOMMENDATION CERTIFICATE

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I hereby declare that this thesis contains a literature survey and original research work by the undersigned candidate, as part of my Master of Engineering in Illumination Engineering studies.

All information in this document has been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that, as required by thesis rules and conduct, I have fully cited and referenced all material and results which are not original to this work.

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ACKNOWLEDGEMENT

I take this opportunity to express my deep sense of gratitude and indebtedness to **Dr. Suddhasatwa Chakraborty**, Assistant Professor, Department of Electrical Engineering, Jadavpur University, Kolkata, without his mission and vision, this project would not have been possible.

I would like to acknowledge my sincere thanks to **Dr. Biswanath Roy**, Professor of Illumination Engineering, Electrical Engineering Department, Jadavpur University, Kolkata and, **Sangita Sahana**, Assistant Professor of Illumination Engineering, Electrical Engineering Department, Jadavpur University for their constant guidance and supervision. I would also like to thank them for providing me with their valuable time and helpful suggestions.

Again, I would like to acknowledge my sincere gratitude to **Prof. (Dr.) Saswati Mazumdar**, Head of the Department (HOD) of Electrical Engineering Department, Jadavpur University, Kolkata for providing me with the opportunity to carry out my project work in Illumination Engineering Laboratory, Jadavpur University.

I am also thankful to **Mr. Pradip Pal** of the Illumination Engineering Laboratory for his co-operation during my project work.

A special thanks to **Saddam Hussain**, who has contributed immensely for the successful completion of the experiment. He has been a constant source of motivation and a strict criticizer of my work improving the quality of the work.

At last, I want to convey my thanks to **Joy Das**, and **Souran Sadhukhan** who helped me directly in completing my thesis successfully.

Last but not least, I wish to convey my gratitude to my parents, whose love, teachings and support have brought me this far…

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Abstract

Regarding both the psychological and physiological needs of the tenant, correlated colour temperatures (CCT) of the light source in an interior setting are crucial. CCTs are of particular relevance since they are one of the factors that determine illumination quality, which has an impact on the standard of work, learning in the classroom and any critical human work or performance.

The aim of this study is to determine the effects of CCT on performance, subjective alertness level, and visual comfort level of humans. A controlled laboratory experiment was carried out on a total of 15 participants who agreed to take part in a series of tests using five distinct CCTs, namely, 2500K, 3500K, 4500K, 5500K & 6500K of white light sources. Performance on the visual task was evaluated using Landolt's ring chart.

In comparison to the other CCT condition, a considerable improvement in the time response of detection was seen under the 6500K CCT condition. Respondents did much better in terms of fewer time taken under 6500K CCT than other CCTs for counting the Landolt's ring chart. Under 5500K CCT, followed by the he rest of the CCTs, errors were made at the lowest rates.

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Chapter1: Introduction

1.1 The nature of light

Light is electromagnetic energy that spans the entire electromagnetic spectrum and induces visual sense in humans. In particular, the visible spectrum only includes electromagnetic waves with wavelengths between 380 and 780 nm. The full electromagnetic spectrum is depicted in Figure 1.1. [1]

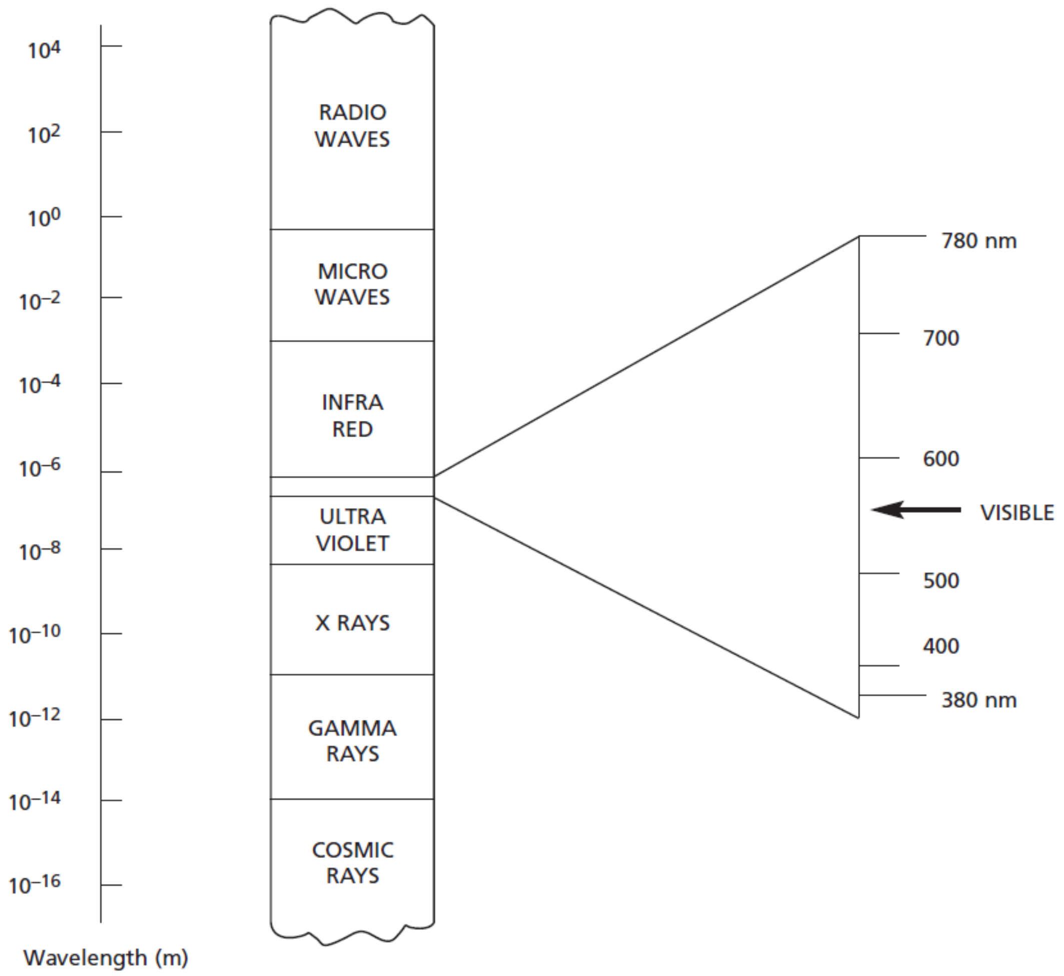


Figure 1.1 A schematic diagram of the electromagnetic spectrum showing the location of the visible spectrum. The divisions between the different types of electromagnetic radiation are indicative only.

The human visual system is not equally sensitive to all wavelengths between 380 and 780 nm. As a result, it is impossible to quantify light using the radiometric numbers that are often employed to measure the properties of the electromagnetic spectrum. Instead, by weighing the radiometric quantities according to the spectral sensitivity of the human visual system, a unique set of quantities must be derived. The photometry system is what came of it.

This change in sensitivity is brought on by how bright or dark something appears to be. An intermediate state between photopic vision and scotopic vision is known as mesopic vision. Photopic vision occurs when the human eye is adapted to a high level of brightness (luminance more than 3 cd/m2), whereas scotopic vision occurs when the light level is relatively lower (luminance less than 0.1 cd/m2). Cone cells and Rod cells, two different types of photoreceptors, are found in the retina and are in charge of colour perception. Cone cells, which are responsible for photopic vision, have a maximal sensitivity of 683 lm/W at 555 nm. In contrast, scotopic vision is produced by rod cells, which have a maximal sensitivity of 1700 lm/W at 507 nm. The Commission Internationale de l'Eclairage (CIE) has established a standard photopic observer, denoted by V(λ), and a standard scotopic observer, denoted by V′(λ), which represents the variation of sensitivity as a function of wavelengths, to model the sensitivity variation at various brightness levels. The absolute and relative sensitivities of the CIE standard scotopic observer and photopic observer are shown in Figure 1.2 .

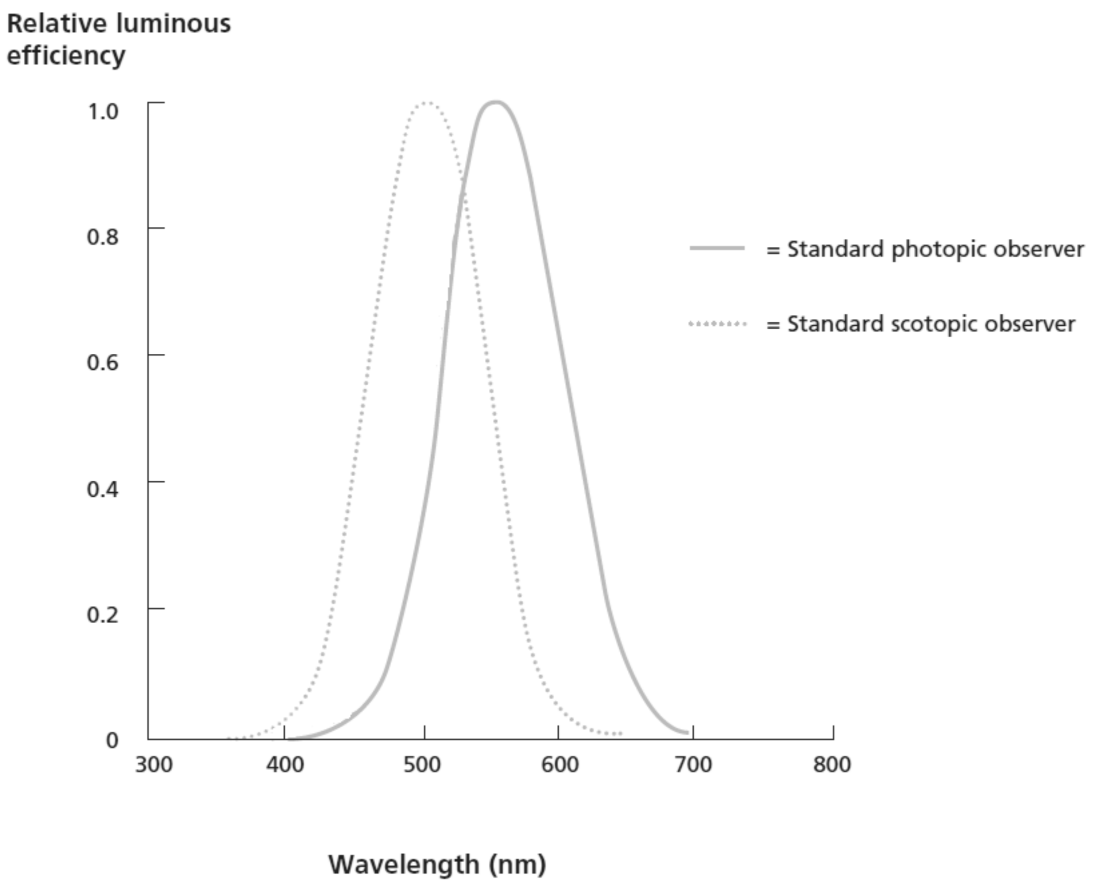


Figure 1.2 The relative luminous efficiency functions for the CIE Standard Photopic Observer, and the CIE Standard Scotopic Observer

1.2 The measurement of light

1.2.1 Photometry

Luminous flux- Radiant flux is the simplest basic metric for electromagnetic radiation emissions from a source. The amount of energy being released at any given time is measured in watts. Luminous flux is the most basic quantity used to gauge light. Radiant flux spanning the wavelength range of 380 nm to 780 nm is multiplied by the relative spectral sensitivity of the human visual system, wavelength by wavelength, to get the luminance flux. The equation represents this procedure.

$$\Phi = K_m \sum \Psi_\lambda V_\lambda \Delta\lambda$$

where: Φ = luminous flux (lumens)

Ψ_λ = radiant flux in a small wavelength interval Dl (watts)

V_λ = the relative luminous efficiency function for the conditions

K_m = constant (lumens/watt)

$\Delta\lambda$ = wavelength interval

Luminous intensity- The luminous flux emitted per unit solid angle in a given direction is what is referred to as Luminous intensity. Solid angle is measured in steradians and is calculated by dividing the area by the square of the distance. One steradian is equal to one square metre at a distance of one metre from the origin. The candela, which is equal to one lumen/steradian, is used to measure luminous intensity. The amount of light coming from a luminaire is measured in terms of its Luminous intensity.

Illuminance- Illuminance is the luminous flux falling on unit area of a surface. The unit of measurement of illuminance is the lumen/m2 or lux. The illuminance incident on a surface is the most widely used electric lighting design criterion. Figure 1.3 shows some typical illuminances on different surfaces under the noonday sun in temperate climates.

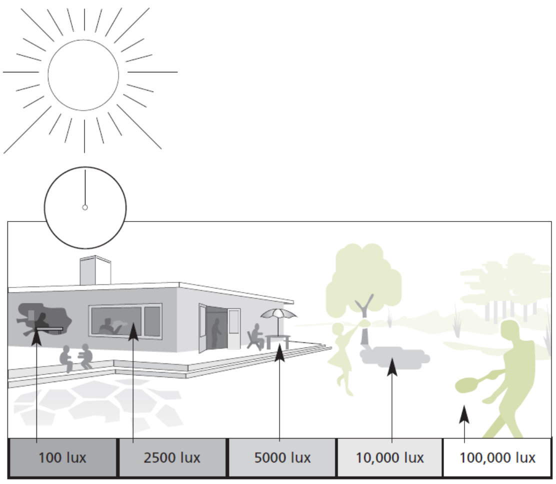


Figure 1.3 *Typical illuminances on different surfaces under the noonday sun in temperate climates*

Luminance- The luminance of a surface is the luminous intensity emitted per unit projected area of the surface in a given direction. The unit of measurement of luminance is the candela/m2. Luminance is widely used to define stimuli presented to the visual system.

1.2.2 Colourimetry

The wavelength combination of the light is not taken into account in photometry. As a result, two surfaces that reflect light may have the same luminance but have completely distinct wavelength combinations. The two surfaces in this scenario will appear to be different colours, if there is sufficient light for colour vision to function. A way to measure colour is offered by the CIE colourimetry system.

CIE chromaticity diagrams

Colour matching is the basis of the CIE colourimetry system. Another type of standard observer is represented by the CIE Colour Matching Functions, which are the relative spectral sensitivity curves of the human observer with normal colour vision. The CIE colour matching functions are mathematical constructions that represent the relative spectral sensitivity needed to guarantee that all wavelength combinations that are perceived as having the same colour occupy the same position in the CIE colourimetry system and that all wavelength combinations that are perceived as having a different colour occupy different positions. Two sets of colour matching functions are displayed in Figure 1.4. For colours

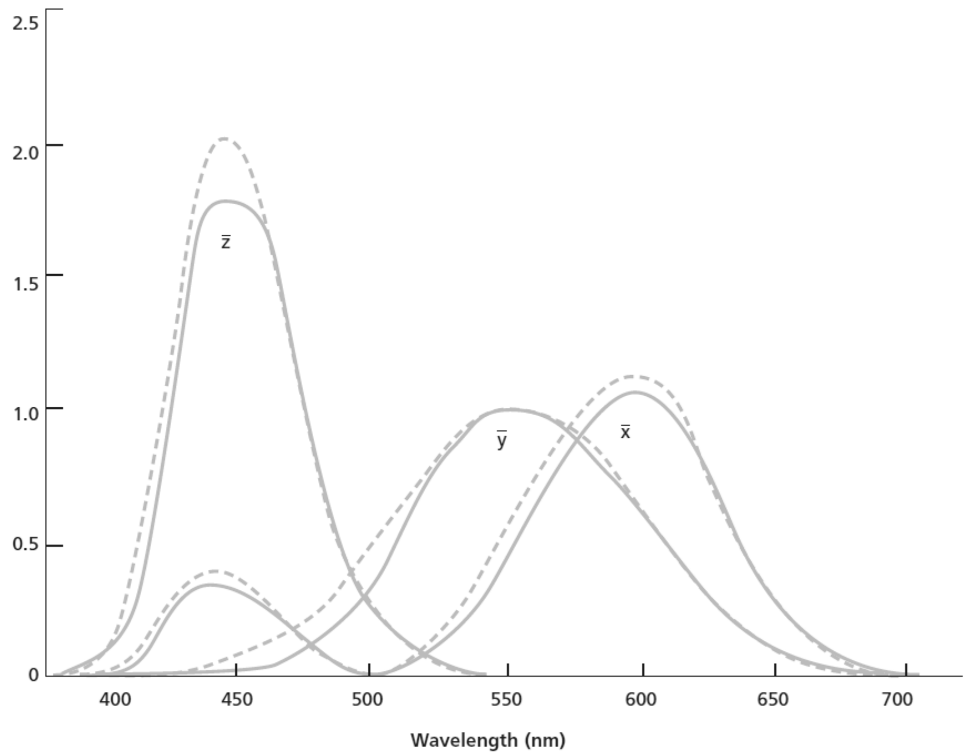


Figure 1.4 *Two sets of colour matching functions: The CIE 1931standard observer (2 degrees)(solid line) and the CIE 1964 standard observer (10 degrees) (dashed line).*

occupying visual fields up to 4° of angular subtense, the CIE 1931 [2] Standard Observer is considered. For colours encompassing visual fields greater than 4° in angular subtense, the CIE 1964 Standard Observer is recommended. The spectral tristimulus values are the colour matching function values at various wavelengths.

The three colour matching functions x(λ), y(λ), and z(λ) can be used to multiply the spectral power distribution of a light source, wavelength by wavelength, to produce the amounts of the three fictitious primary colours X, Y, and Z needed to match the colour of the light source [3] [4]. X, Y, and Z are represented by the following equations:

$$X = h \sum S(\lambda)\, x(\lambda)\, \lambda$$
$$Y = h \sum S(\lambda)\, y(\lambda)\, \lambda$$
$$Z = h \sum S(\lambda)\, z(\lambda)\, \lambda$$

where: S(λ) = spectral radiant flux of the light source (W/nm)
x(λ), y(λ), z(λ) = spectral tristimulus values from the appropriate colour matching function
λ = wavelength interval (nm)
h = arbitrary constant

If only relative values of the *X*, *Y* and *Z* are required, an appropriate value of *h* is one that makes *Y* = 100. If absolute values of the *X*, *Y*, and *Z* are required it is convenient to take *h* = 683 since then the value of *Y* is the luminous flux in lumens.

Having obtained the *X*, *Y*, and *Z* values, the next step is to express their individual values as proportions of their sum, i.e.

$$x = \frac{X}{(X+Y+Z)}\ ,\ y = \frac{Y}{(X+Y+Z)}\ ,\ z = \frac{Z}{(X+Y+Z)}$$

The CIE chromaticity coordinates are defined as the three values x, y, and z. Only two of the coordinates are necessary to describe the chromaticity of a colour because x + y + z = 1. The x and y coordinates are employed by convention. All colours can be represented on a two-dimensional surface since a colour may be described by two coordinates. The CIE 1931 chromaticity diagram is displayed in Figure 1.5. The spectrum locus is the outer, curving edge of the CIE 1931 chromaticity diagram. All pure colours—those made up of only one wavelength—lie on this curve. The purple boundary, which is a straight line connecting the ends of the spectrum, is where it is possible to find the most saturated purples.

The CIE 1931 chromaticity diagram can be considered as a map of the relative location of colours. As the chromaticity coordinates move away from the equal energy point and toward the spectrum locus, the saturation of a colour increases [5]. The direction in which the chromaticity coordinates move affects the color's hue. Indicating roughly how a colour will seem, the CIE 1931 chromaticity diagram is a valuable tool (CIE Publication 107:1994). It provides chromaticity coordinate boundaries for signal lights and surfaces such that they will be recognised as red, green, yellow, and blue.

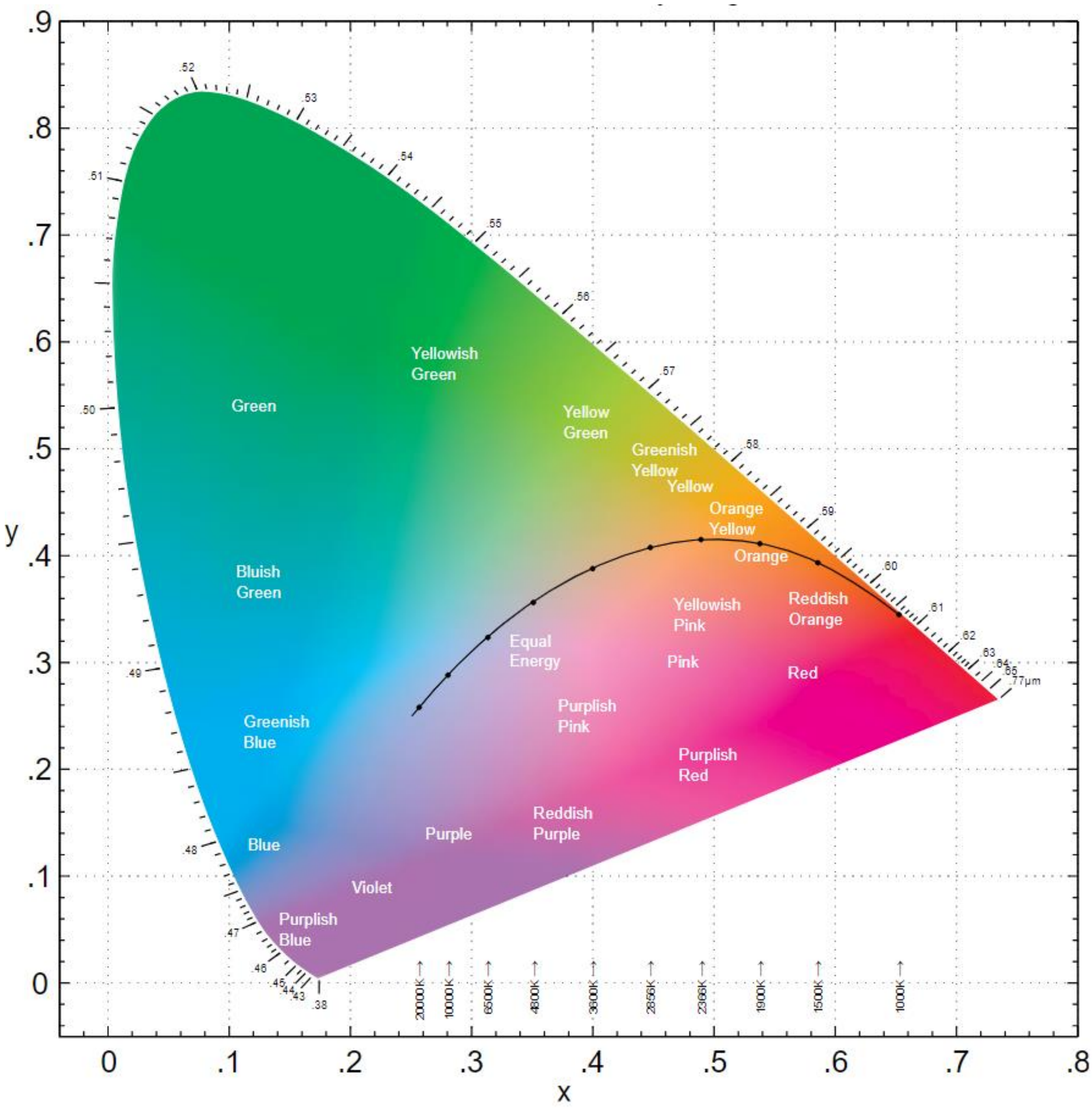


***Figure 1.5** The CIE 1931 Chromaticity Diagram showing the spectrum locus, the Planckian locus and the equal energy point)*

Perceptually, the CIE 1931 chromaticity diagram is not uniform. Red colours are condensed in the bottom right corner whereas green colours are spread out over a vast area. Any attempt to measure significant colour variances using the CIE 1931 chromaticity diagram is fruitless due to this perceptual non-uniformity. The CIE first introduced the CIE 1960 Uniform Chromaticity Scale (UCS) diagram and then, in 1976, recommended the adoption of the CIE 1976 UCS diagram in an effort to remedy this problem. The CIE 1931 chromaticity diagram is merely transformed linearly in both figures. The CIE 1976 UCS diagram's axes are

$$u' = \frac{4x}{(-2x + 12y + 3)}$$

$$v' = \frac{9y}{(-2x + 12y + 3)}$$

Where *x* and *y* are the CIE 1931 chromaticity coordinates. Figure 1.6 shows the CIE 1976 UCS diagram.

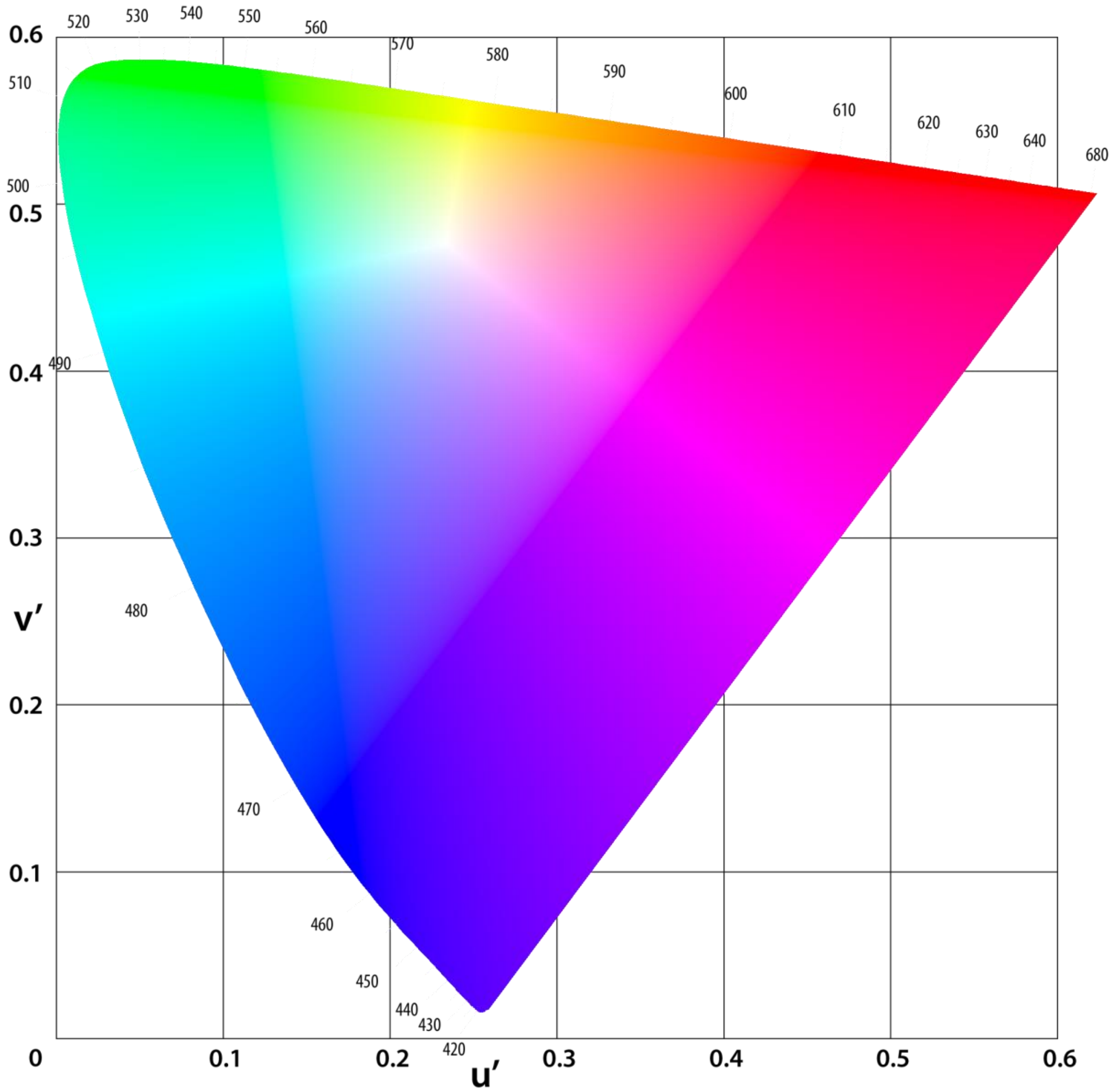


***Figure 1.6** The CIE 1976 Uniform Chromaticity Scale Diagram*

Correlated Colour Temperature

Although the CIE colorimetry system is the most accurate way to measure colour, it is complicated. The lighting industry has therefore developed two single-number metrics to describe the colour characteristics of light sources using the CIE colourimetry methodology. The associated colour temperature is a measure used to describe how a light source's light seems to be coloured. This measurement's basis is the fact that a black body's spectral power distribution is only dependent on temperature because it is determined by Planck's Radiation Law.

A portion of the CIE 1931 chromaticity diagram is given in Figure 1.7, along with the Planckian locus. The curving line connecting the chromaticity coordinates of black bodies at various temperatures is known as the locus. It is iso-temperature lines that intersect the Planckian locus. When a light source's CIE 1931 chromaticity coordinates fall exactly on the Planckian locus, the colour temperature—that is, the temperature of the black body with the same chromaticity coordinates—expresses the colour appearance of that light source. The associated colour temperature, or the temperature of the isotemperature line that is closest to the actual chromaticity coordinates, is used to quantify the colour appearance of light sources that have chromaticity coordinates close to the Planckian locus but not on it.

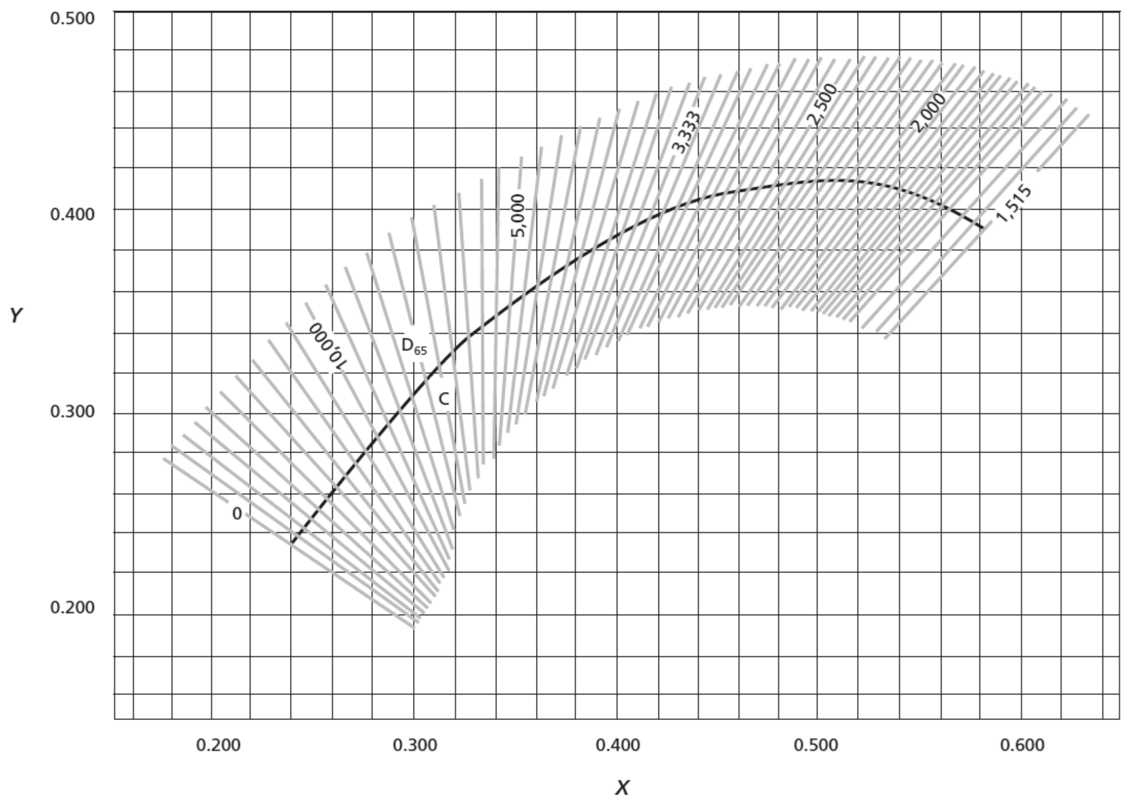


Figure 1.7 *The Planckian locus and lines of constant correlated colour temperature plotted on the CIE 1931 (x,y) chromaticity diagram. Also shown are the chromaticity coordinates of CIE Standard Illuminants, A, C, and D65 (from the IESNA Lighting Handbook).*

The corresponding colour temperatures of nominally white light sources range from 2,700 K to 7,500 K. A light source with a 2,700 K colour temperature, like an incandescent lamp, will seem yellowish and be referred to as "warm," whereas a light source with a 7,500 K colour temperature, like some types of fluorescent lamps, will appear blue and be referred to as "cold," It is crucial to understand that light sources shouldn't be assigned a correlated colour temperature if their chromaticity coordinates fall outside the boundaries of the iso-temperature lines depicted in Figure 1.7. When the chromaticity coordinates are above the

Planckian locus, the light from such light sources will appear green, and when they are below, it will appear purplish.

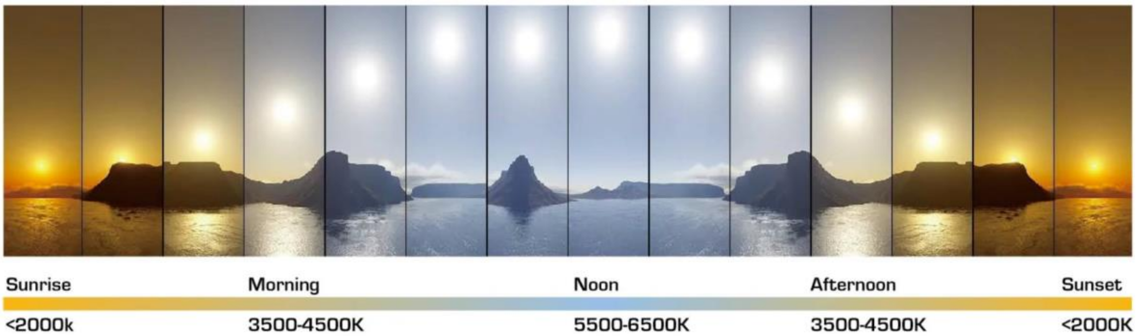


Fig 1.8 *Representation of CCT*

1.3 Human Centric Lighting

It is now simpler to alter photometric and colourimetric qualities including colour appearance, correlated colour temperature (CCT), etc. thanks to advancements in LED technology. In recent years, numerous research has been conducted to better understand how the human body reacts to various lighting situations. Current research focuses more on the non-visual impacts of lighting on task performance, suggesting that the response might not just be visual. Therefore, human centric lighting refers to a lighting situation that offers sufficient illumination and enhances overall task performance. The primary goal of human-centric lighting is to assist in providing users with the necessary set of optical, biological, and behavioural reactions [7] . A lighting design that satisfies the four fundamental criteria of spatial patterns, light spectrum, light level, and temporal patterns can accomplish this. In a three-dimensional light field, spatial patterns show how the light sources' luminances are distributed, whereas the light level shows how the workspace is illuminated horizontally. The colour rendering index (CRI), correlated colour temperature (CCT), chromaticity, etc. are all determined by the light spectrum. The timing and length of the light exposure make up the temporal pattern. Better lighting quality is produced by a lighting design that properly balances these four factors, which also improves non-visual reactions.

Figure 1.9 *Human Centric Lighting*

This entire thesis project has been summarised in an abstract study aimed at determining the impact of colour temperature on task performance. The goal of this research is to figure out how CCT affects task performance and human activity.

Chapter 2: Literature Review

To comprehend the link between lighting and work, it is necessary to first define the pathways via which lighting can influence human performance. There are three possible pathways through the visual system: the circadian timing system, and mood and motivation. Figure 2.1 depicts a conceptual framework for thinking about the factors that influence progress along each route, as well as their relationships [8].

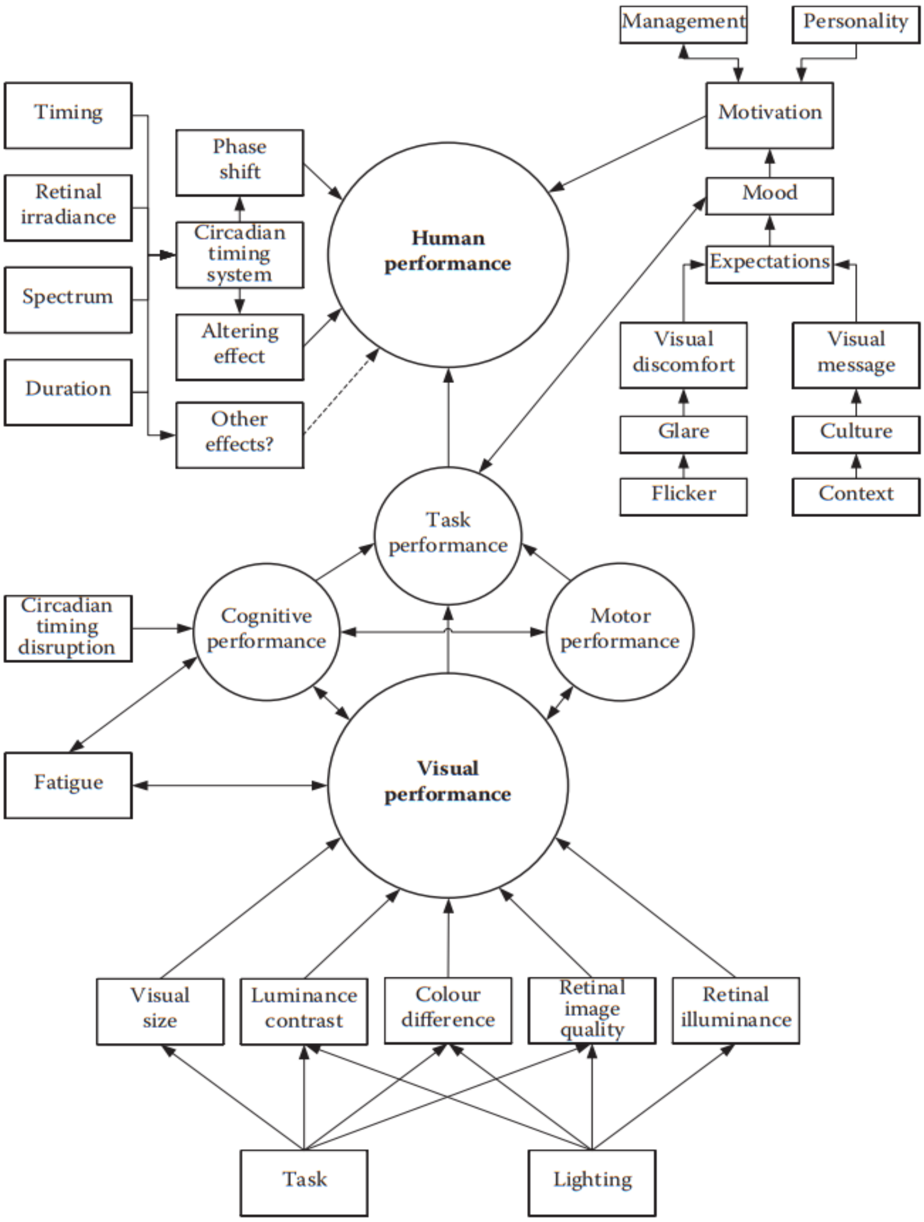


Fig.2.1 *Lighting conditions can influence human performance in three ways, according to this conceptual paradigm. The direction of effect is indicated by the arrows in the diagram.*

Visual size, luminance contrast, colour difference, retinal image quality, and retinal illuminance are five criteria that can be used to describe any stimulus to the visual system.

These characteristics are crucial in influencing the visual system's ability to recognise and identify the stimuli [9].

Visual size: The larger the visual size of detail in a stimulus, the easier it is to resolve that detail. The visual size for resolution is usually given as the angle the critical dimension of the stimulus subtends at the eye. For a Landolt ring, it is the side of the square forming the gap in the ring.

For complex stimuli, the measure used to express the dimensions is the spatial frequency distribution. Spatial frequency is the reciprocal of the angular subtense of critical detail. The match between the luminance contrast at each spatial frequency of the stimulus and the contrast sensitivity function of the visual system determines if the stimulus will be seen or not.

Luminance contrast: The luminance contrast of a stimulus expresses its luminance relative to its immediate background. The higher the contrast, the easier it is for the eye to detect the stimulus. There are several different kinds of luminance contrasts so it is important to know which definition you are using.

Colour difference: Luminance quantifies the amount of light emitted from a stimulus but ignores the combination of wavelengths making up that light. It is the wavelengths emitted from the stimulus that influences its colour appearance. Lighting can alter the colour difference between the object and its background.

Retinal image quality: The visual system works best when presented with a sharp image. A sharp image will have high spatial frequency components present; a blurred image will not. Lighting can do little to alter any of these factors, although it has been shown that light sources that are rich in short wavelengths produce smaller pupil sizes.

Retinal illuminance: The state of adaptation of the visual system is determined by the illuminance on the retina, which modifies the visual system's capabilities. The equation determines the retinal illuminance produced by a surface luminance.

$$E_r = e_t t \frac{cos\theta}{k^2}$$

Where,

Er is the retinal illuminance (lx)

t is the ocular transmittance

θ is the angular displacement of the surface from the line of sight (degrees)

k is a constant equal to 15

e_t is the amount of light entering the eye (trolands)

$$e_t = L \,.\, \rho$$

where

L is the surface luminance (cd/m2)

ρ is the pupil area (mm2)

The amount of light entering the eye is mainly determined by the luminance in the field of view. For exteriors, the relevant luminance are those of reflecting surfaces, such as the ground, and self-luminous sources, like the sky.

The interplay between the thing to be seen, the background against which it is seen, and the lighting of both the object and the background determines the stimulus the object presents to the visual system and the operating state of the visual system, according to these five criteria. The amount of visual performance achieved is determined by the stimulus and the visual system's operational condition, however, this is not the end of the narrative. Visual tasks appear to have three parts: visual, cognitive, and motor. The visual component refers to the process of using the sense of sight to extract information pertinent to task performance.

The cognitive component is the process of interpreting sensory data and determining the right action. The motor component is the process of manipulating stimuli in order to extract information and/or carry out the actions chosen. These three elements work together to create a complicated pattern of stimulus and reaction that leads to task completion. Furthermore, each task is distinct in terms of the balance of visual, cognitive, and motor components, as well as the impact lighting has on task performance. It is impossible to generalise from the influence of lighting on the execution of one task to the effect of lighting on the performance of another because of this uniqueness. The impact of lighting on task performance is determined by the task's structure, particularly the position of the visual component in relation to the cognitive and motor components. Generally speaking, tasks with a big visual component will be more sensitive to changes in lighting conditions than ones with a modest visual component. The notion that visual performance is not always the same as task performance is implicit. The completion of a task is known as task performance. The task's visual component is referred to as visual performance. Job performance is required to assess productivity and calculate cost-benefit ratios that compare the expenses of installing illumination to the advantages of better task performance. The only aspect of performance that may be directly affected by lighting conditions is visual performance.

The nonimage-forming system is another way that lighting conditions might effect operations. There are still many components of this system that need to be examined, but until they are, their implications on human performance remain a potential rather than a fact. The circadian timing system is the one part of the nonimage-forming system that has been proven to effect human performance. The sleep-wake cycle is the most evident external evidence for the presence of a circadian timing system in humans, yet it is simply the tip of the iceberg. The fluctuations in many different hormonal rhythms over a 24-hour period are hidden beneath the surface [10][11]. In humans, the SCNs are the organs that control these cycles. The retina is directly connected to the SCN. There is no attempt to retain the original location of signals transferred from the retina to the SCN. Rather, the retina's ipRGC network, which supplies the SCN, functions as a slow-response photocell [12]. This indicates that the amount and spectrum of radiation reaching the retina, as well as the timing and length of exposure, are all factors that alter the state of the SCN.

There are two distinct ways that light, acting through the circadian timing system, can be used to improve task performance: a phase-shifting effect, in which the phase of the circadian rhythm can be advanced or delayed by exposure to bright light at specific times (Dijk et al., 1995) [13], and an acute effect related to the suppression of the hormone melatonin at night that increases alertness (Dijk et al., 1995). (Campbell et al., 1995). There's also an interest in investigating if controlling the hormone cortisol can improve task performance by exposing people to light during the day. There is evidence that exposure to bright light soon after waking up raises cortisol levels (Scheer and Buijs, 1999) [14], but the consequences of what happens during the day are unclear. Ruger et al. (2006) found no influence on cortisol levels but a beneficial effect on alertness when subjects were exposed to 5000 lx between noon and 16.00 h. In a similar study, Kaida et al. (2007) discovered that early afternoon exposure to more than 2000 lx from daylight boosted alertness. These data suggest that physiological and psychological factors influence alertness. It's crucial to figure out which, if either, of these routes, is dominant and when, because if the physiology is dominant, a high light level is all that's needed, whereas if the psychology is dominant, it could make a difference whether the light exposure is provided by electric lighting or by daylight.

This takes us to the third way that lighting may influence work, namely through mood and motivation. The visual system creates a representation of the visual environment, which might elicit an emotional reaction. This emotional response, along with a variety of other circumstances, can have an impact on a person's mood and motivation at work. When lighting creates a sensation of visual pain, it has the simplest effect on mood and motivation. Illumination circumstances that make reaching a high degree of visual performance difficult, as well as lighting that causes distraction from the activity, such as when glare and flicker are present, will be regarded unpleasant. However, perception is far more complex than just establishing a sense of visual pain. Every lighting installation communicates a statement about the people who planned it, who bought it, who labour beneath it, who maintain it, and where it is positioned, whether or not it causes visual pain. The message is interpreted by observers based on the circumstances in which it happens as well as their own culture and expectations. As seen by the fact that lighting levels that would be deemed exceedingly uncomfortable in an office are favourably sought at a night club, the value of this message may occasionally outweigh conditions that could be expected to cause pain. The observer's attitude and motivation might be altered depending on the message. Every lighting designer recognises the importance of the message, but it is primarily in the retail and entertainment industries that the message a lighting system provides is accorded the weight it deserves in terms of its ability to impact behaviour (Custers et al., 2010).

While each of these paths has been explored in isolation, it is crucial to remember that they can interact. Someone who is required to work when sleep-deprived, for example, will be exhausted. Similarly, anyone attempting to work when their circadian timing system is interrupted is unlikely to succeed. Both of these situations will have an impact on task performance, both cognitively and visually and motorically. Another scenario is when the illumination makes it difficult to see the task at hand, resulting in poor visual performance and a bad mood among the workers. This form of connection can occur in a variety of ways. To further complicate the picture, it is important to recognise that, while lighting circumstances alone dictate visual performance for a specific activity, a worker's mood and motivation can be influenced by a variety of physical and social factors, lighting conditions being only one of many (CIBSE, 1999). The study of the link between illumination and work has taken so long and has been so difficult because of this intricate pattern of interacting effects.

Chapter 3: Experiment

3.1 Background Of The Experiment

Caveat emptor is the first thing to say about the link between light and labour. Many statements concerning the influence of lighting on worker productivity have been made that are nothing more than assertions, with none of the information needed to assess the claims. A few field studies, however, demand special attention. Studies of visual activities such as silk weaving (Elton, 1920), linen weaving (Weston, 1922), and typesetting by hand (Weston and Taylor, 1926), the last of which is now nearly extinct, were among the first. All of these activities need the detection of small, low-contrast features, so it's not unexpected that they tend to support common knowledge: lighting conditions can become insufficient for a task to be viewed clearly, and raising illuminance improves performance. The level of illumination at which this improvement stops will be determined by the work [1] [8].

Around the same time as these early research were being conducted, the Hawthorne experiments — a set of trials that have become folklore - began (Snow, 1927; Roethlisberger and Dickson, 1939). These studies were initially concerned with the impacts of illumination on productivity, but they gradually became more focused on the effects of payment systems, kind of supervision, rest times, and total hours of labour, for reasons that will become clear. The Western Electric Company, situated in Chicago's Hawthorne neighbourhood, made electromechanical telephone equipment. The business performed three trials to see how illumination affected the productivity of a group of women who examined components, constructed relays, or coiled coils at the start of the research. The task illuminations were adjusted in a series of steps up and down in the first experiment. The output in each of the three departments was altered, but there was no apparent link between the illuminance and the output. The first and second experiments involved both electric lighting and daylight. As the illuminance of the test group was changed, the work output of both groups increased to a similar extent. The workers were split into two groups of the same level of experience - one for coil-winding and the other for electric lighting. In the third experiment, daylight was eliminated. The control group worked under a constant illuminance of 110 lx, while the test group experienced illuminances starting at 110 and decreasing in steps of 11 lx. Both groups showed a slow but steady improvement in output.

There is a continuum of performance associated with lighting conditions ranging from no light to plenty of light. In the absence of light, we can see nothing, no matter how large or high a luminance contrast the task has. It is only when there is sufficient light to see the necessary detail that performance becomes possible. As the amount of light on the task increases, performance should increase until it becomes limited by some factor other than the visibility of the necessary details. What lighting can do is to make details easier to see and colours easier to discriminate without producing discomfort or distraction.The worker can then use this increased visibility to produce output if he/she is so motivated or is not limited by some other nonvisual factor. The Hawthorne experiment suggests that it was not until the illuminance fell to 33 lx that the visibility of the task began to limit the performance of the workers.

Stenzel (1962) measured the output from a leather factory over a 4-year period, in the middle of which he introduced a change in lighting installation. The work involved punching out fault-free outer leathers from skins for handbags, purses, etc., using iron shapes and mallets. There is a statistically significant improvement in performance with the higher illuminance giving the better performance. The average monthly performance for the 12 people who were present throughout the 4 years is shown in Figure 3.1.

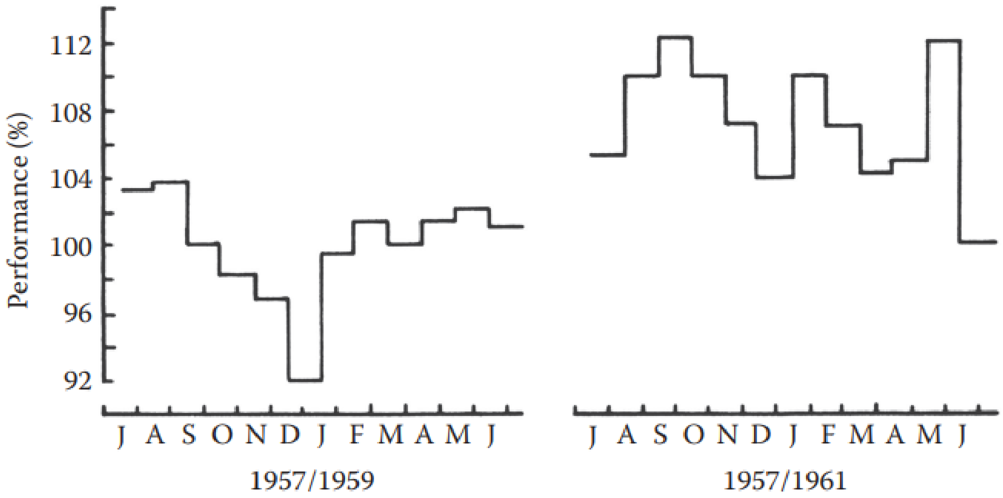


***Fig 3.1** For the years 1957–1959 and 1959–1961, the average monthly performance for cutting leather shapes. The average performance from 1957 to 1959 is used to standardise the results.* [15]

This study was well controlled but illustrates two problems common in field studies:. First, only two lighting conditions were used and those were widely different. Second, there is considerable uncertainty about the most important aspect of lighting for the change in performance because the new lighting installation changed several different aspects of the lighting simultaneously. In these circumstances, to ascribe the changes in output to the difference in illuminance alone may be misleading.

Stenzel and Sommer (1969) looked at sorting screws of various sizes and crocheting stoles; Smith (1976) looked at threading a needle; Bennett et al. (1977) looked at needle probing as well as micrometre reading, map reading, pencil note reading, drafting, vernier calliper measurement, cutting, and thread counting over a range of illuminances from 10 to 5000 lx; and McGuiness and Boyce (1984) looked at kitcs. This is not surprising given that these studies are primarily focused on task performance rather than visual performance, therefore the tasks differ not just in terms of the stimuli they show to the visual system, but also in terms of their cognitive and motor components. This is especially clear in two Smith and Rea experiments (1978, 1982). A small number of individuals proofread manuscripts for misspelt words in Smith and Rea's (1978) [16] study. At four different illuminances ranging from 10 to 4885 lx, measurements of the time it took to proofread a passage and the percentage of errors identified were taken. The consequence of raising illuminance, as shown in Figure 3.2 a, is to reduce the time spent and raise the percentage of errors identified (hits). The same apparatus, as well as the same range of illuminances, were used in the Smith and Rea (1982) study, but this time the subjects were instructed to read a text and then answer questions on their comprehension of the material. With increased illuminance, neither the speed nor the level of comprehension changed much (Figure 3.2 b). The cognitive component of reading for comprehension is substantially larger than that of proofreading.

Simulated work studies are carried out when it is necessary to investigate the impact of illumination on a certain task. They do allow for more exact experimental control than is generally achievable in the field, but the results are unavoidably limited in that they are only applicable to the specific activity at hand and cannot be applied to other tasks. Simulated work assignments, to take an analogy, are a dead end on the way to a general understanding of the link between light and work. Unless you have business there, there is no incentive to travel there.

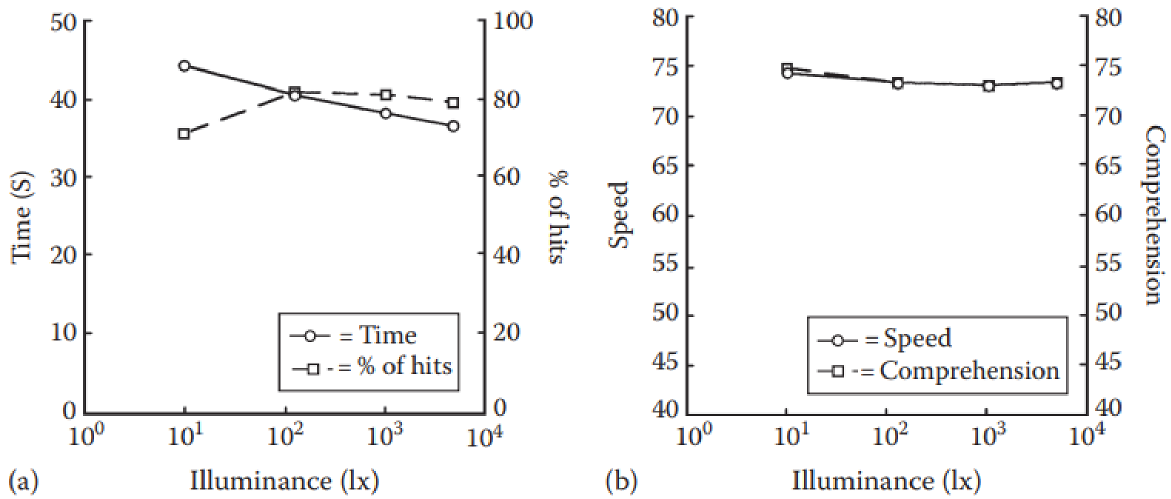


Fig 3.2 *Two types of reading tasks were used to assess performance. The printing on white paper for both tasks was of good quality: (a) time spent to proofread a section and percentage of hits, or errors identified, plotted against illuminance; (b) speed and level of comprehension plotted against illuminance. (After S.W. Smith and M.S. Rea, J. Illum. Eng. Soc., 8, 47, 1978; S.W. Smith and M.S. Rea, J. Illum. Eng. Soc., 12, 29, 1982.)*

Beutell produced one of the first attempts to create a broad model of the impact of lighting conditions on work (1934). His method began with the definition of a standard task. After that, the impact of lighting on this typical task could be thoroughly explored, and the illuminance for any desired level of performance could be determined. Then, by applying a series of multiplying factors that allowed for discrepancies between the task of interest and the standard task, the illuminance for any other task could be derived. The multiplying factors would be connected to the task's important detail's visual size and brightness contrast, any relative movement between the observer and the task, and the task's degree of emphasis in its context.

Weston (1935, 1945) took Beutell's proposal and turned it into a commonly used way of researching the impact of lighting on work. Weston devised a simple assignment in which the crucial feature could be easily identified and measured. This job is sometimes referred to as the Landolt ring chart since it is based on the Landolt ring used in visual acuity testing [17]. A Landolt ring chart is depicted in Figure 3.3. It's made up of a succession of Landolt rings, each with a gap oriented in one of the compass's four cardinal directions. The gap is a crucial feature of the Landolt ring. The critical contrast is the brightness contrast of the ring against its background, while the critical detail size is the angular dimension of the gap. The Landolt ring chart as a standard task has the advantage of being able to be replicated in huge numbers, on a variety of media, and the crucial size and contrast may be simply altered.

The Landolt ring chart task requires subjects to read through the chart and indicate all of the rings that have a gap oriented in a specific direction in some fashion. The time it takes to complete this task, as well as the number of errors made, are recorded under various lighting conditions. These measurements are then combined to create work speed and accuracy measurements. The total time taken is decreased by subtracting the time taken to mark the same number of rings with a gap in the specified direction when they were marked with red ink, and the total time taken is then divided by the number of rings successfully marked. The time spent marking the Landolt rings with red ink is subtracted from the total time spent on the task in order to reduce the contribution of the cognitive and motor components of the task and thus produce a measure of visual performance rather than task performance. The reasoning behind this is because by using red ink to designate the rings that need to be identified, the visual component of the job is reduced, allowing the cognitive and motor components of the work to take precedence. The number of rings accurately marked divided by the total number of rings that could have been marked gives the accuracy. The performance score is then calculated by multiplying speed and accuracy.

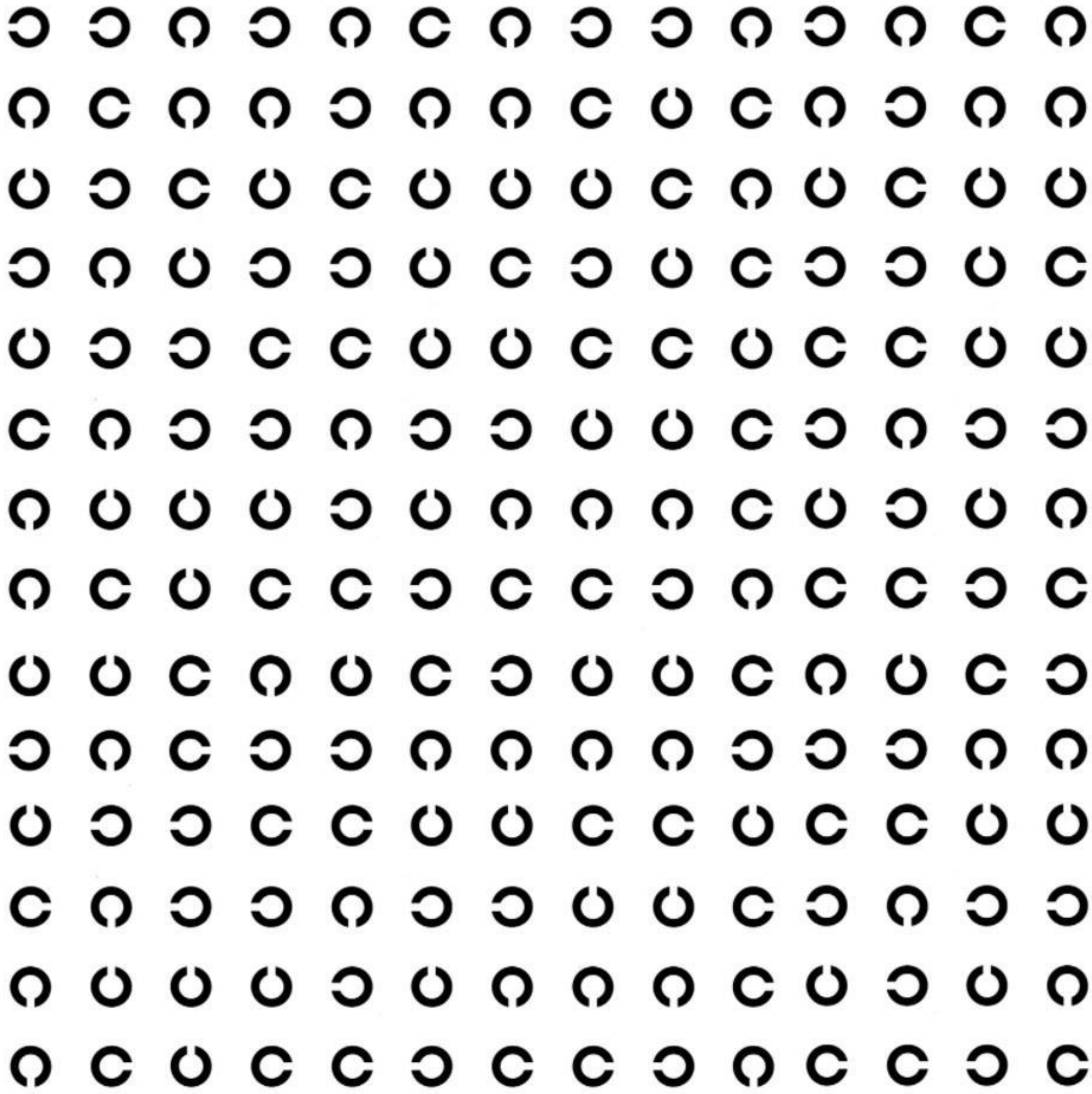


Fig 3.3 *A Landolt ring chart*

3.2 Experimental Design

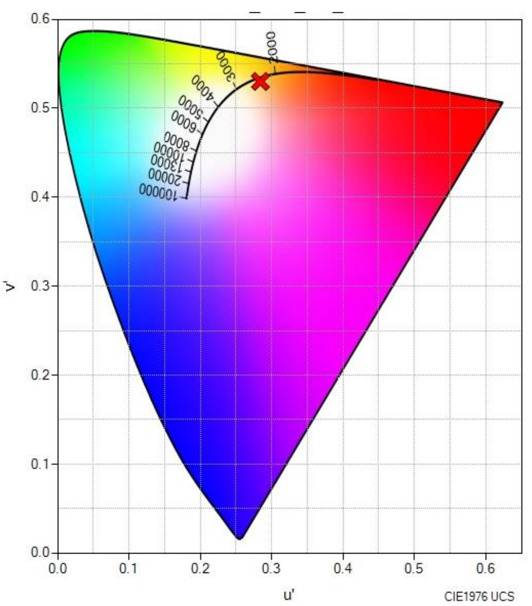
3.2.1 Experimental setup

A dark room was built for the experiment fifth floor of the Electrical Engineering Department, Jadavpur University. It's dimension was 5m*5m*2.5m. It was made of an iron structure and thick black cloth. The material of the cloth is chosen accurately so that it can absorb most of the lights from outside. almost no stray lights can enter in the dark room and affect the lighting conditions, made inside the dark room. The reflectance of the cloth is 2.75% which also reduced indirect lighting and helped to focus the light on the task plane.

Fig 3.4 *Darkroom setup*

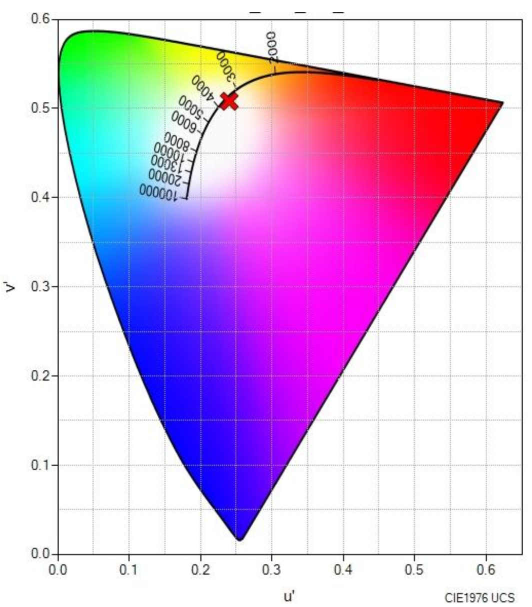
3.2.2 Lighting

The main light source was a Philips Wiz Wi-Fi Enabled B22 9-Watt LED Smart Bulb. The bulb is hung above the subjects. This is a wifi-enabled colour tunable smart bulb. This bulb gives millions of colours and shades of white light. It is dimmable too. The lighting is controlled by a smartphone application named Wiz. There is a sliding bar to change colour temperature too. In this application 2500K, 3500K, 4500K, 5500K, and 6500K CCTs are used in the experiment but these values are not accurately calibrated to the application. By KONICA MINOLTA CL-70F CRI Illuminance Meter their correct colourimetry is recorded and shown below



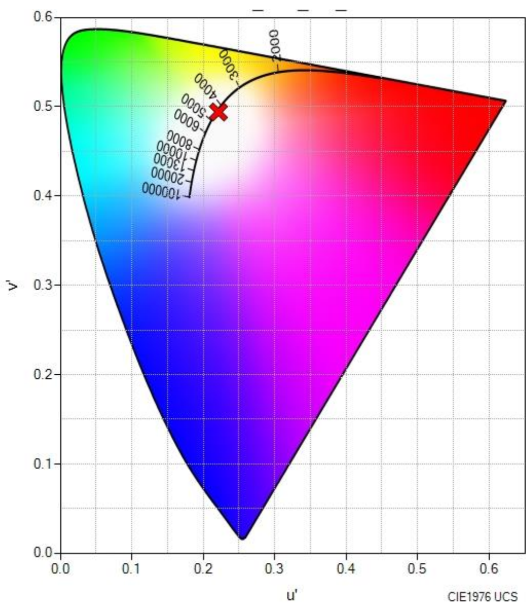
Measuring Mode = Ambient	Tcp = 2300K
u' = 0.2841	v' = 0.5303

(a) Test record of 2500K CCT



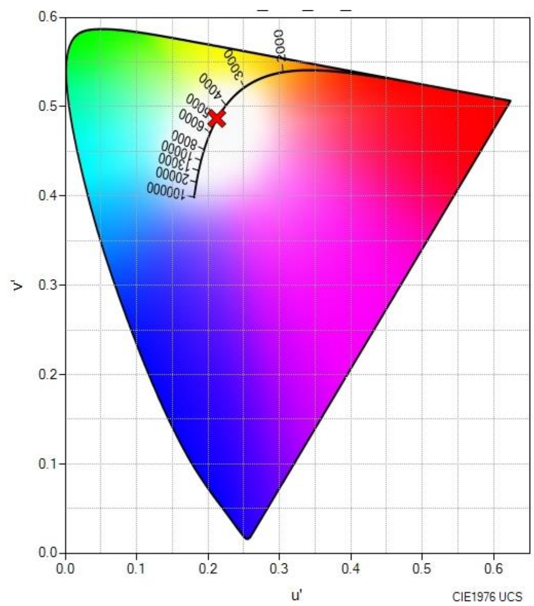
Measuring Mode = Ambient	Tcp = 3395K
u' = 0.2401	v' = 0.5083

(b) Test record of 3500K CCT



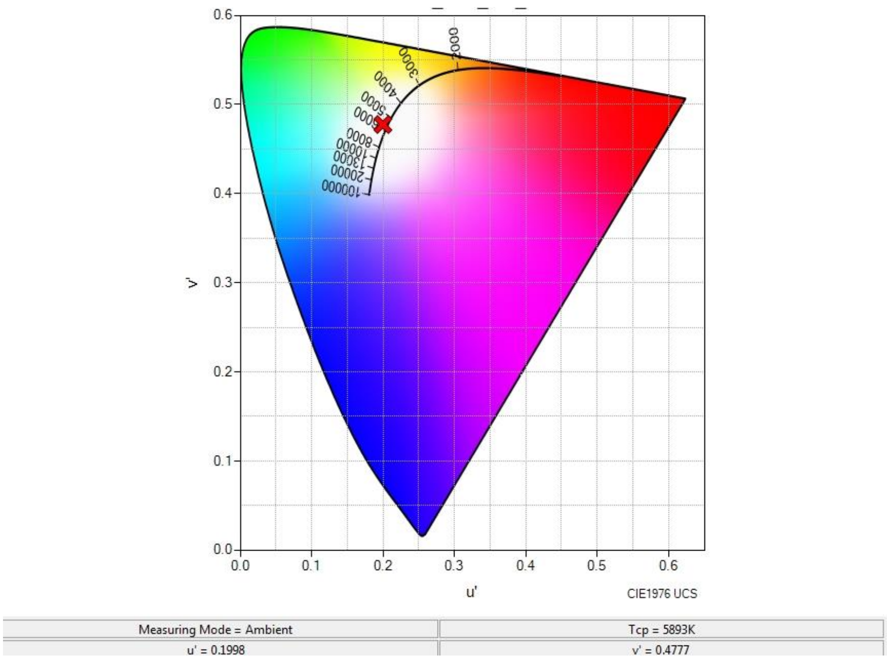
Measuring Mode = Ambient	Tcp = 4296K
u' = 0.2213	v' = 0.4942

(c) Test record of 4500K CCT



Measuring Mode = Ambient	Tcp = 4895K
u' = 0.2121	v' = 0.4870

(d) Test record of 5500K CCT

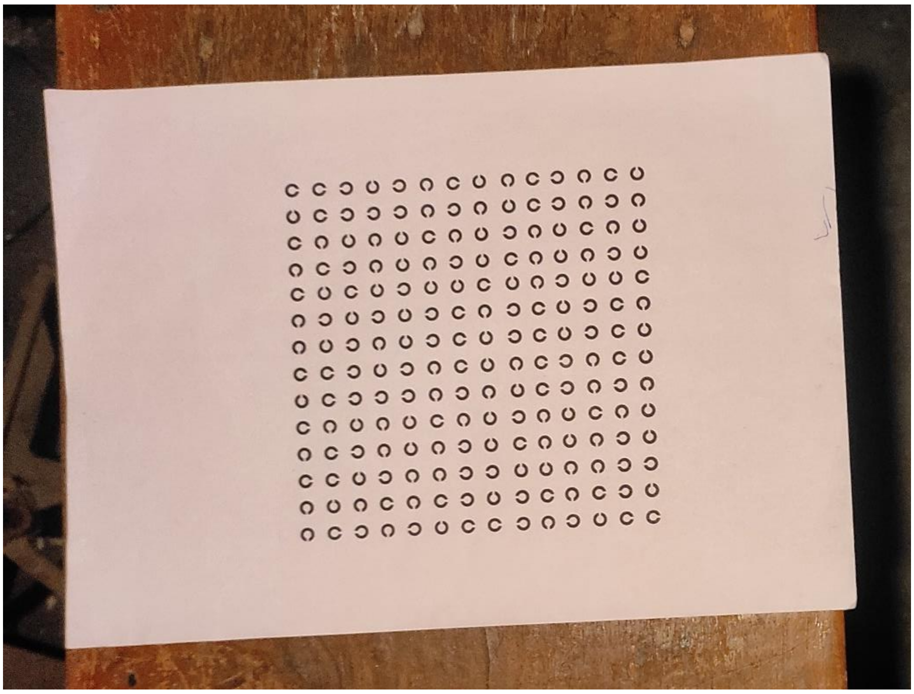


(e) Test record of 6500K CCT

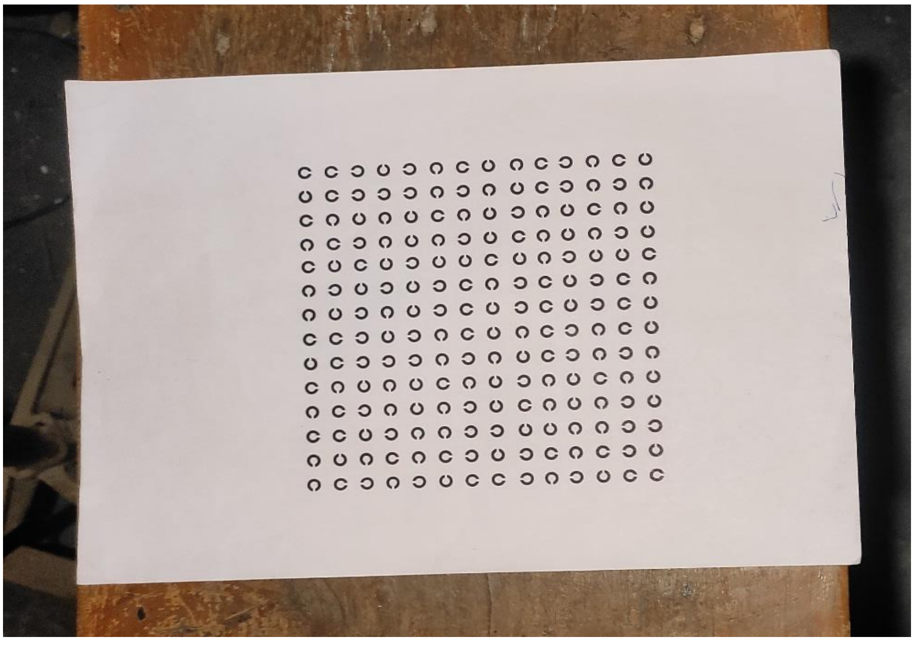
Fig 3.5 *Konica Minolta CL-70F Test record of (a) 2500K , (b) 3500K , (c) 4500K , (d) 5500K , (d) 6500K CCT*

3.2.3 Object

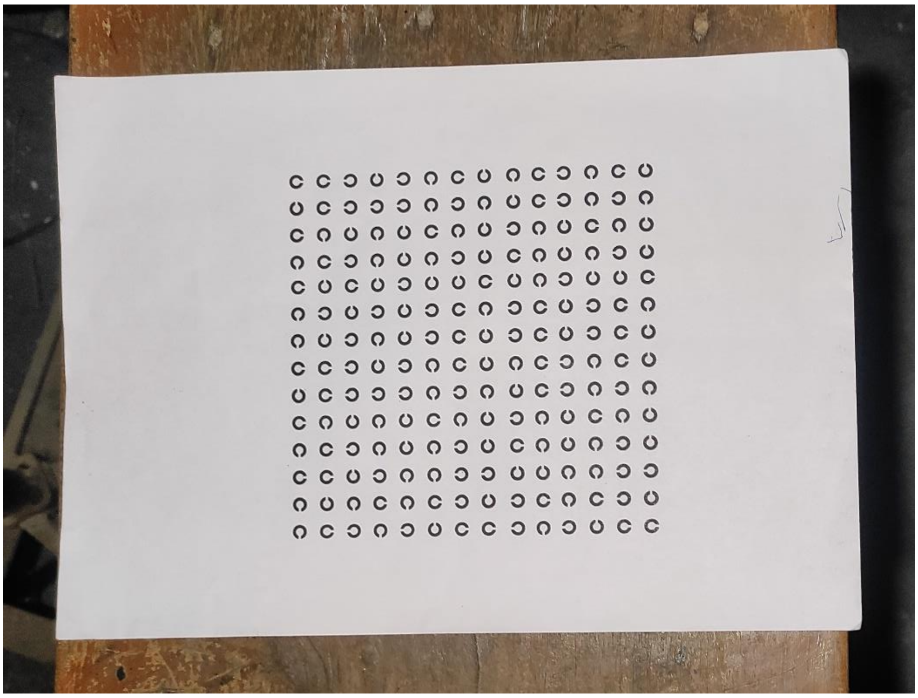
The Landolt's ring was used as a standard object in the study to determine task performance under various illumination conditions. The Landolt's ring chart is printed on white A4 paper. This was used as the object, and the subjects were asked to count the Landolt Ring's specific side openings. 5 types of the chart are prepared with a maximum shuffle of Landolt's Rings as the mind is very critical for Human subjects. Visualisations of charts under different CCTs are shown in Fig 3.6.



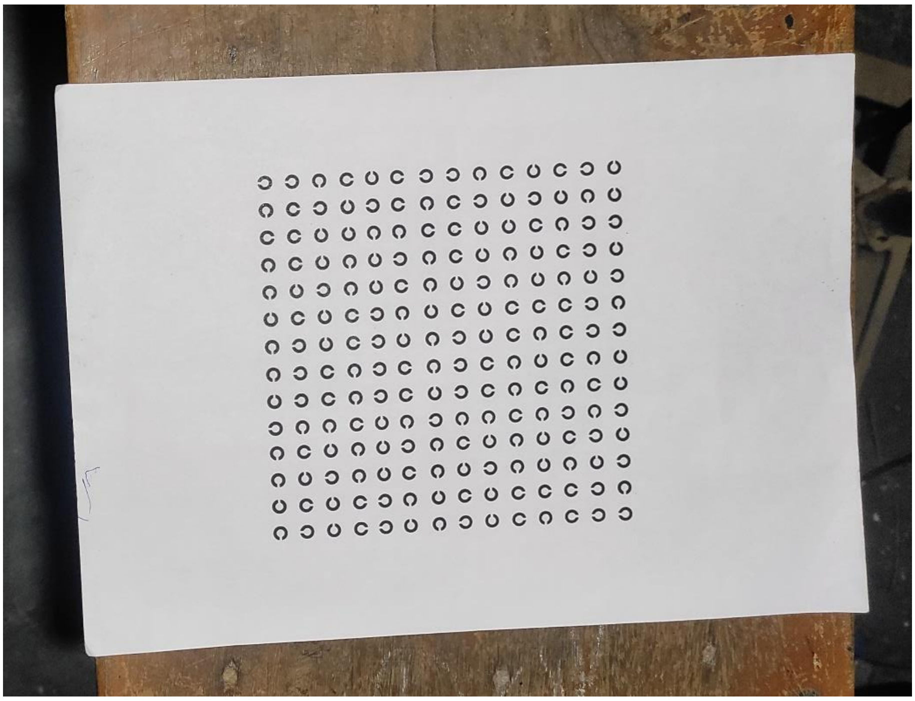
(a) Landolt's Ring chart under 2500K CCT



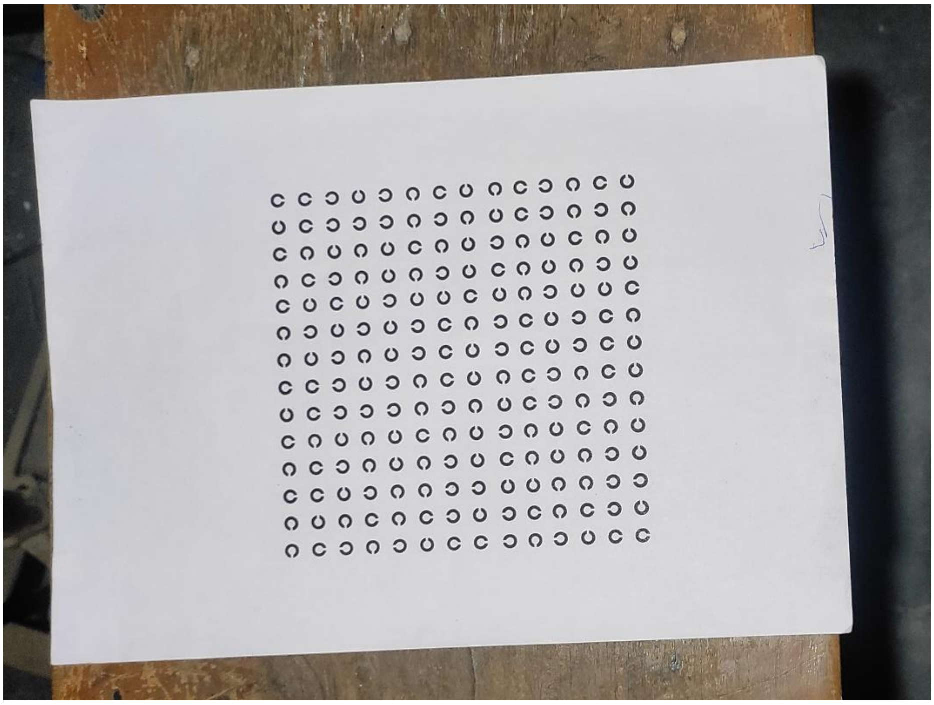
(b) Landolt's Ring chart under 3500K CCT



(c) Landolt's Ring chart under 4500K CCT



(d) Landolt's Ring chart under 5500K CCT



(e) Landolt's Ring chart under 6500K CCT

Fig 3.6 *Landolt's Ring charts under Different CCT*

3.2.4 Participants

The experiment was carried out on fifteen neurologically healthy students (ten male and five female) ranging in age from 18 to 25 years old. All of the individuals stated that their colour vision and visual acuity were normal. They were given instructions about the experiment and asked to sign a consent form before beginning the experiment.

Sl No	Name	Age	Gender
1	Subject 1	25	Male
2	Subject 2	24	Male
3	Subject 3	22	Male
4	Subject 4	24	Male
5	Subject 5	18	Female
6	Subject 6	20	Female
7	Subject 7	25	Female

8	Subject 8	21	Male
9	Subject 9	23	Male
10	Subject 10	23	Male
11	Subject 11	23	Male
12	Subject 12	25	Male
13	Subject 13	24	Female
14	Subject 14	25	Male
15	Subject 15	24	Female

Table 3.1 *Details of the participants in the experiment*

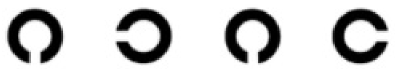
3.3 Experimental Procedure & Data Recording

At first, the electrical connection of the Philips Wiz Wi-Fi Enabled B22 9-Watt LED Smart Bulb was done and then the smart bulb, as well as a smartphone, was connected with the WIFI so that it can be controlled by an application named "Wiz". Five distinct CCTs were chosen to carry out the experiment, and the appropriate CCT values were calibrated using a Konica Minolta CL-70F Chromameter. 2500K, 3500K, 4500K, 5500K, and 6500K were the CCTs. The lamp was positioned over the participants so that the average illuminance on the working plane on the task surface remained nearly constant during the experiment. The illuminance values were determined using a calibrated Konica Minolta CL-70F Chromameter.

Under the lamp, a chair and table (height 0.8m) is placed. Participants are called to enter the darkroom one by one and said to take a seat on the chair. At first, they were given about 3minutes to adapt to the particular CCT. Then they were given an instruction sheet (Table 3.3) to read and were told what to do.

RULES

1. A chart will be given to you, where some rings are shown. Some are right opening rings, some are left openings, and some are upside and downside opening rings.



2. You have to count the rings with openings in the same direction as you are told.

3. You have to count that rings as fast as you can.

Table 3.2 *Instruction sheet given to participants*

After that 3min they were given a Landolt's ring chart and instructed to go through the chart and mark rings of a specific side opening with a pen in the minimum time. During this whole test, I took a position on the back side of the participants so that they could not see me and did their tasks without being disturbed. The time required to do this under the different lighting conditions was measured using a stopwatch and was noted down. Each time when they completed their task, no of the marked rings are also noted with that particular direction of opening. After that test, he or she was told to rest outside the darkroom and another participant was called to do the same. They are instructed not to discuss the test with any other participants.

Fig 3.7 *Experimental procedure*

After taking data of a particular CCT, the next CCT was set to the smart bulb by the Wiz application and then the participants were called again to do the same. To adapt the CCT for the experiment, the time difference between two consecutive CCT's trial was 15 minutes, as 15 minutes is sufficient for human relaxation. 5types of Landolt's ring charts are used where the patterns of rings were different. These are used randomly for different CCTs as the mind is critical for human subjects.

Chapter 4: Experimental Results

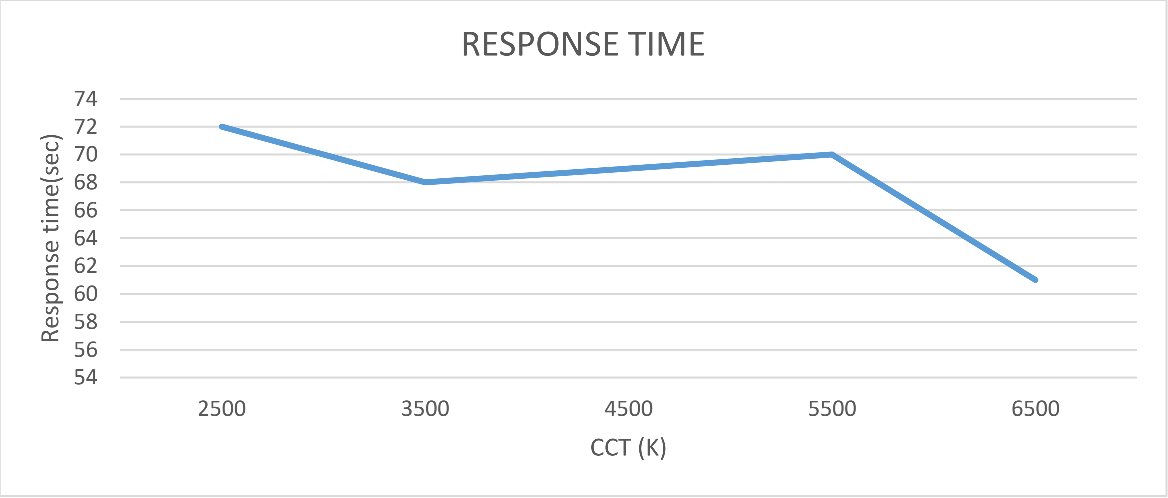
The experiment has 2 objectives. The first one is about Response Time and the second one is about Errors & False Positives. The experiment was conducted with 15 subjects under 5 different CCTs (2500K, 3500K, 4500K, 5500K & 6500K). Response time for each task for each subject is measured by stopwatch and every time the number of rings they counted is also noted. The actual count for each direction of the opening in the rings for every Landolt's Ring chart is counted earlier and also mentioned below tables according to their tasks. Subjectwise tabular and graphical representations of data are given below.

When a subject missed a ring (which he/she was asked to count) to count, then this was taken as an Error. In other words, Error is the number of misses. When a subject counted rings of other direction of opening mistakenly in order to count a specific direction of opening of Landolt's Rings, then this was taken as False Positives. Errors as well as False Positives are counted from each subject's marked Landolt's Ring charts and mentioned below.

Subject 1

CCT	DIRECTION of Opening of Landolt's Rings	RESPONSE TIME	ACTUAL COUNTS	ERROR	FALSE-POSITIVE
2500	RIGHT	72	36	15	0
3500	DOWN	68	42	7	0
4500	LEFT	69	40	11	0
5500	UP	70	35	5	0
6500	UP	61	41	4	0

Table 4.1 *Datasheet of subject 1*



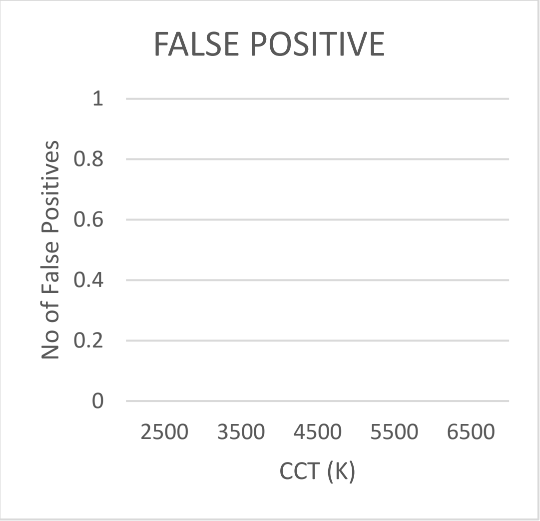
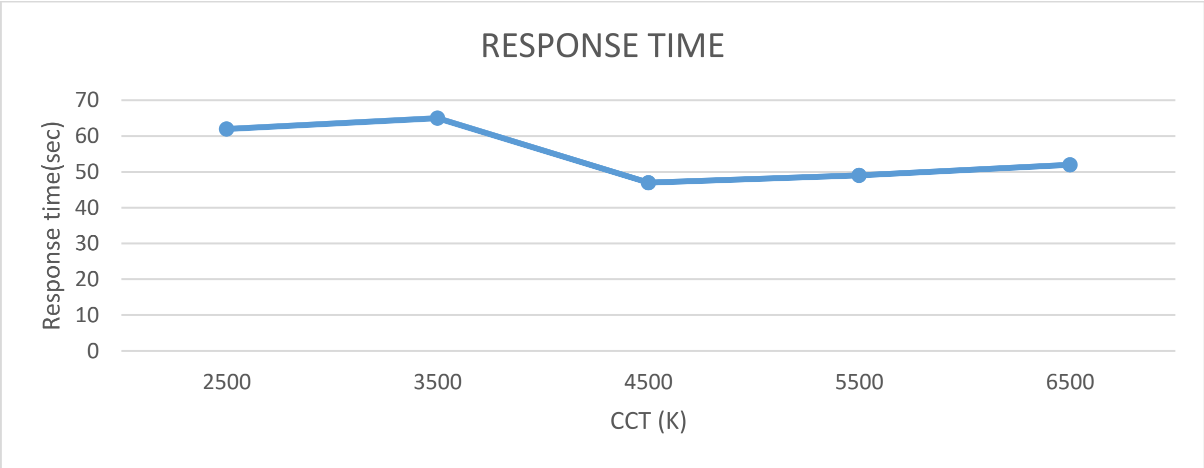


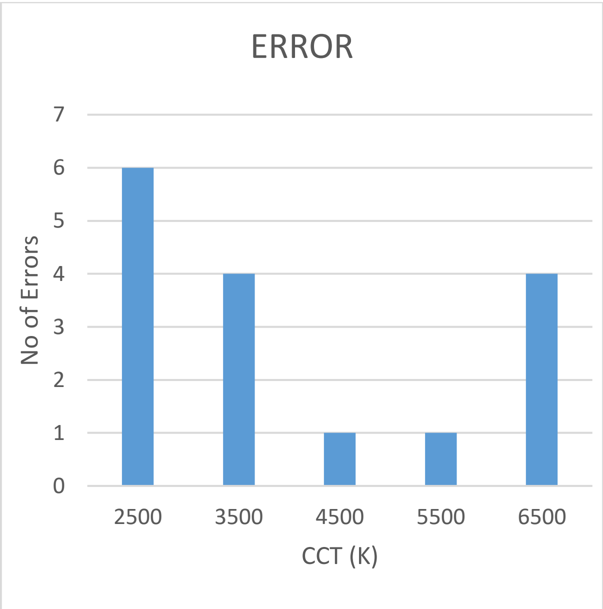
Fig 4.1 *Graphical representation of results of subject 1*

Subject 2

CCT	DIRECTION of Opening of Landolt's Rings	RESPONSE TIME	ACTUAL COUNTS	ERROR	FALSE-POSITIVE
2500	LEFT	62	45	6	0
3500	RIGHT	65	47	4	0
4500	DOWN	47	44	1	0
5500	UP	49	44	1	0
6500	RIGHT	52	47	4	0

Table 4.2 *Datasheet of subject 2*





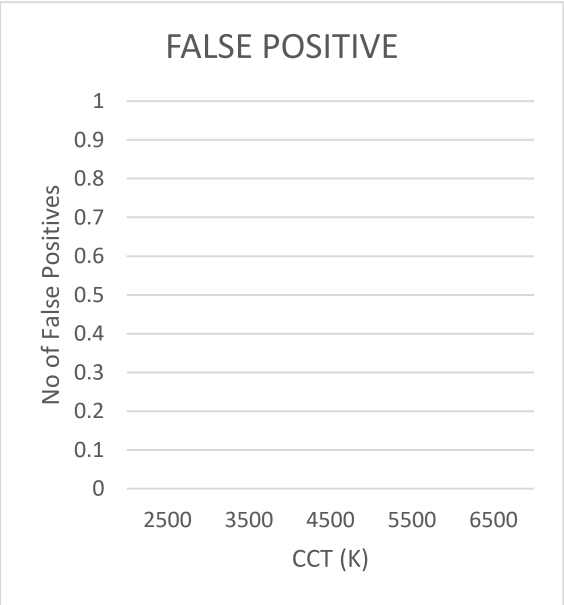
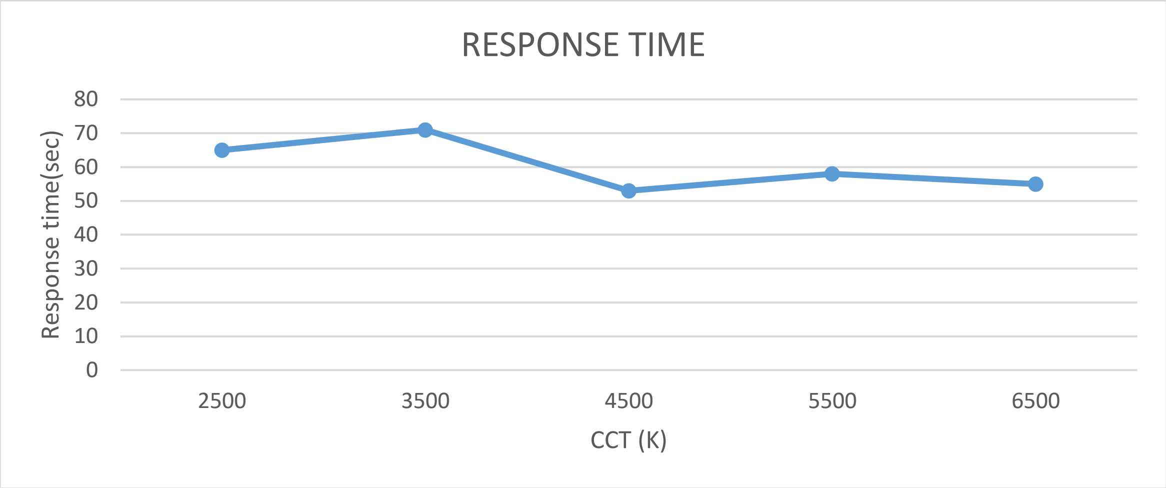


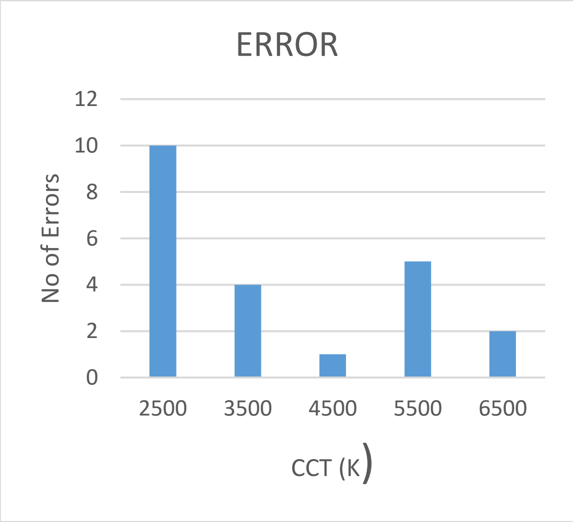
Fig 4.2 *Graphical representation of results of subject 2*

Subject 3

CCT	DIRECTION of Opening of Landolt's Rings	RESPONSE TIME	ACTUAL COUNTS	ERROR	FALSE-POSITIVE
2500	RIGHT	65	41	10	0
3500	DOWN	71	45	4	0
4500	UP	53	48	1	0
5500	LEFT	58	39	5	0
6500	RIGHT	55	49	2	0

Table 4.3 *Datasheet of subject 3*





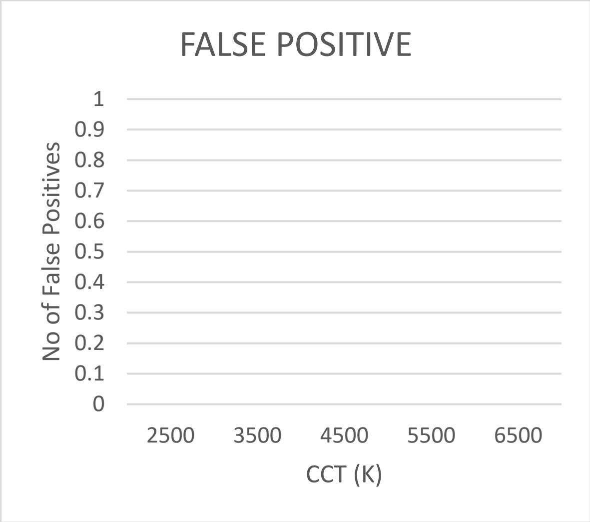
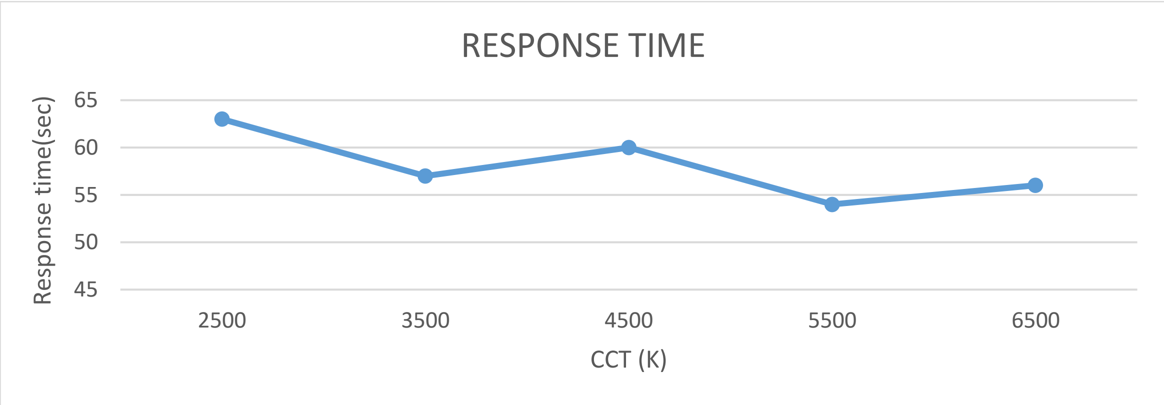


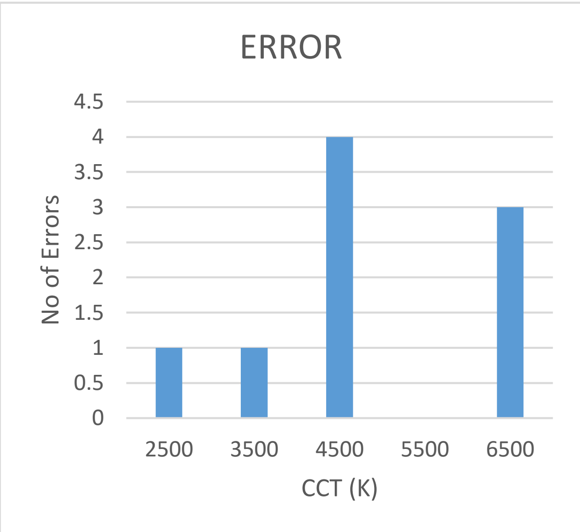
Fig 4.3 *Graphical representation of results of subject 3*

Subject 4

CCT	DIRECTION of Opening of Landolt's Rings	RESPONSE TIME	ACTUAL COUNTS	ERROR	FALSE-POSITIVE
2500	RIGHT	63	50	1	0
3500	DOWN	57	44	1	0
4500	LEFT	60	47	4	0
5500	UP	54	48	0	3
6500	RIGHT	56	48	3	0

Table 4.4 *Datasheet of subject 4*





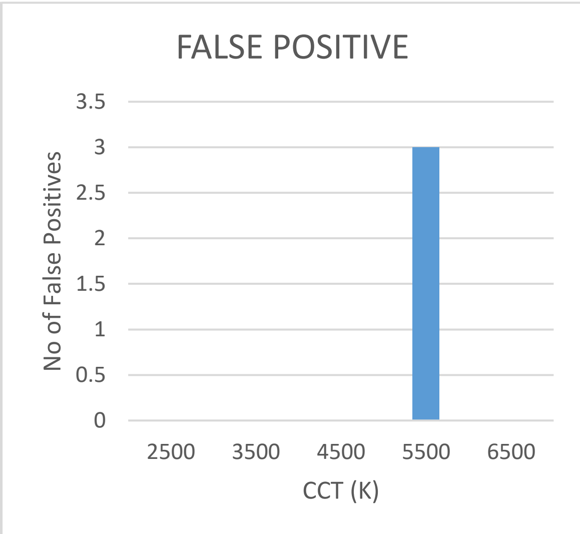


Fig 4.4 *Graphical representation of results of subject 4*

Subject 5

CCT	DIRECTION of Opening of Landolt's Rings	RESPONSE TIME	ACTUAL COUNTS	ERROR	FALSE-POSITIVE
2500	RIGHT	108	46	5	0
3500	DOWN	78	41	4	0
4500	UP	75	45	4	0
5500	LEFT	87	46	5	0
6500	RIGHT	76	49	2	0

Table 4.5 *Datasheet of subject 5*

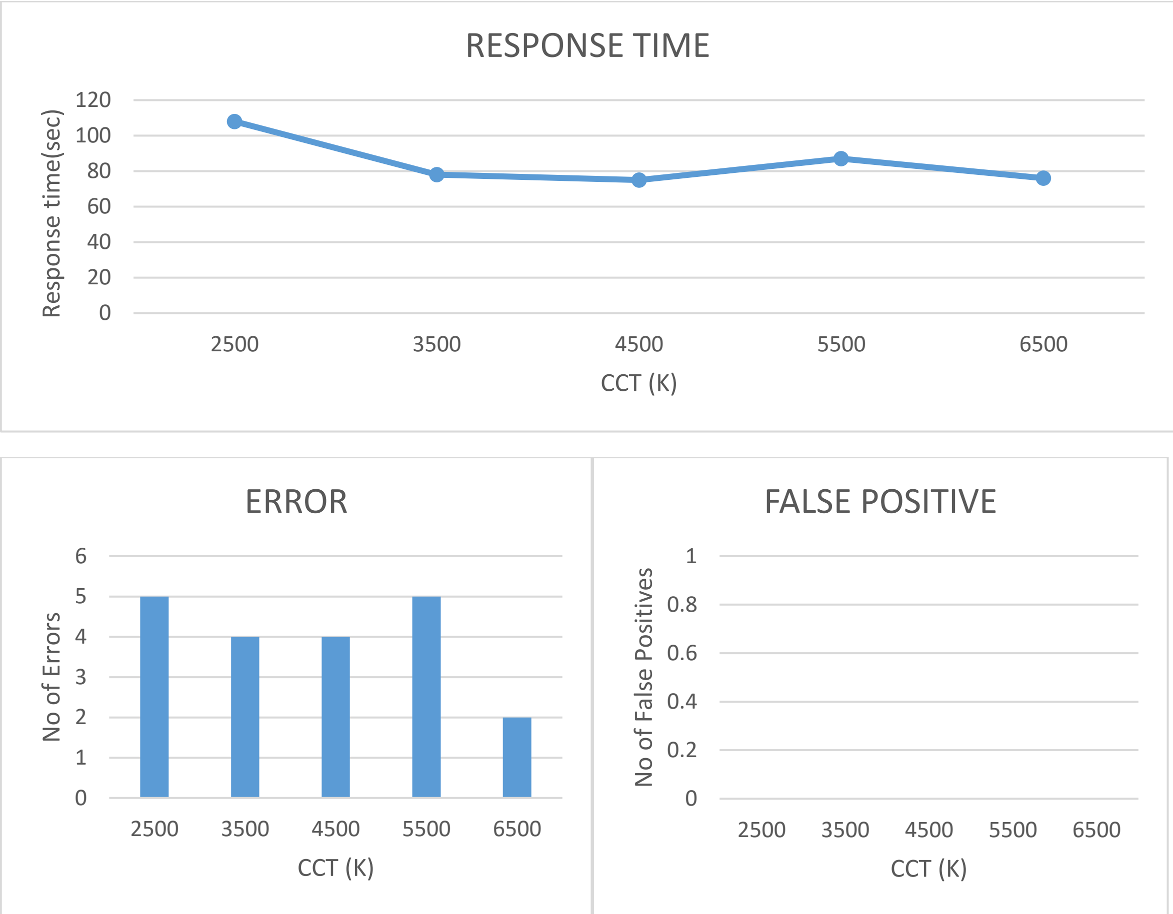


Fig 4.5 *Graphical representation of results of subject 5*

Subject 6

CCT	DIRECTION of Opening of Landolt's Rings	RESPONSE TIME	ACTUAL COUNTS	ERROR	FALSE-POSITIVE
2500	UP	87	48	1	0
3500	LEFT	79	51	0	0
4500	DOWN	75	45	0	0
5500	DOWN	75	50	0	1
6500	RIGHT	70	50	1	0

Table 4.6 *Datasheet of subject 6*

Fig 4.6 *Graphical representation of results of subject 6*

Subject 7

CCT	DIRECTION of Opening of Landolt's Rings	RESPONSE TIME	ACTUAL COUNTS	ERROR	FALSE-POSITIVE
2500	RIGHT	73	47	4	0
3500	LEFT	74	50	1	0
4500	DOWN	61	43	6	0
5500	RIGHT	69	50	1	0
6500	UP	56	50	0	1

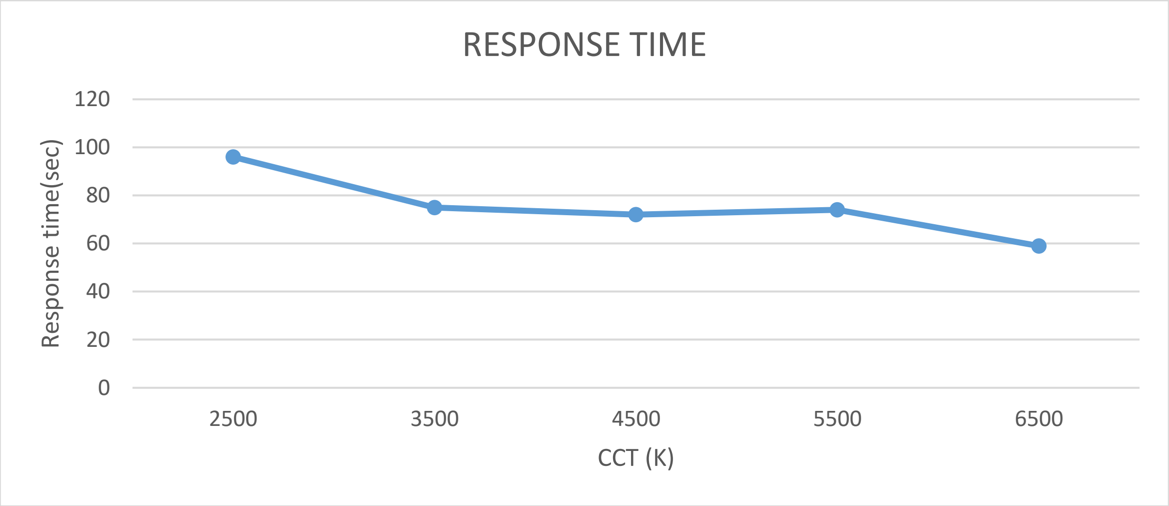
Table 4.7 *Datasheet of subject 7*

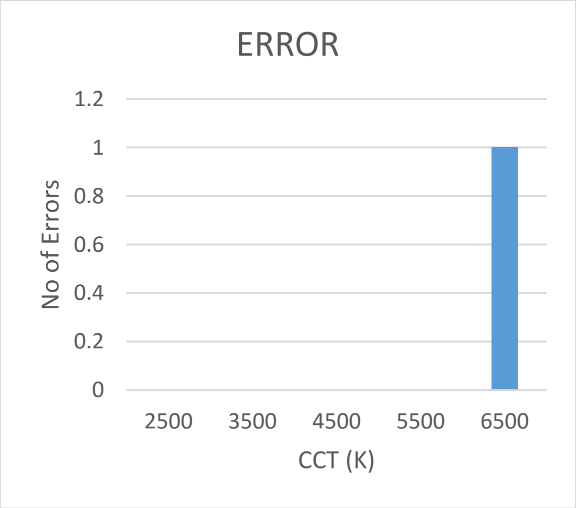
Fig 4.7 *Graphical representation of results of subject 7*

Subject 8

CCT	DIRECTION of Opening of Landolt's Rings	RESPONSE TIME	ACTUAL COUNTS	ERROR	FALSE-POSITIVE
2500	RIGHT	96	41	0	0
3500	DOWN	75	45	0	0
4500	UP	72	48	0	0
5500	LEFT	74	39	0	0
6500	RIGHT	59	49	1	0

Table 4.8 *Datasheet of subject 8*





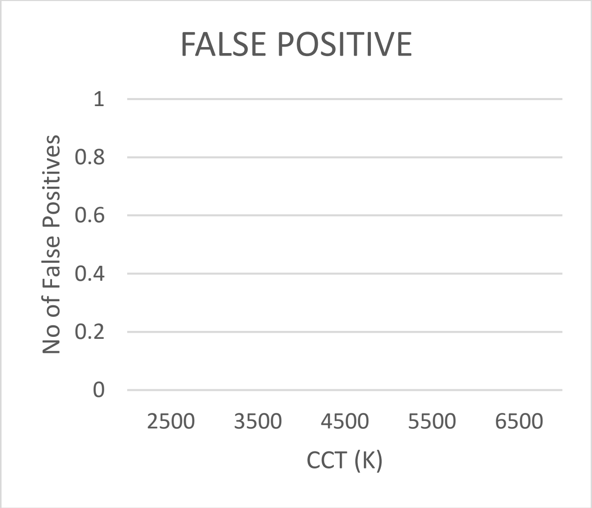
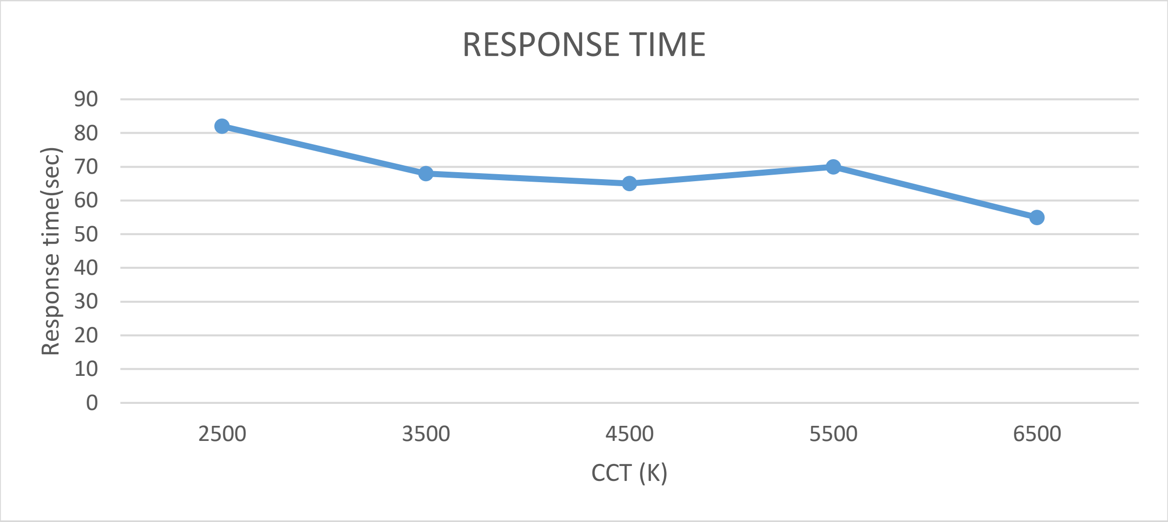


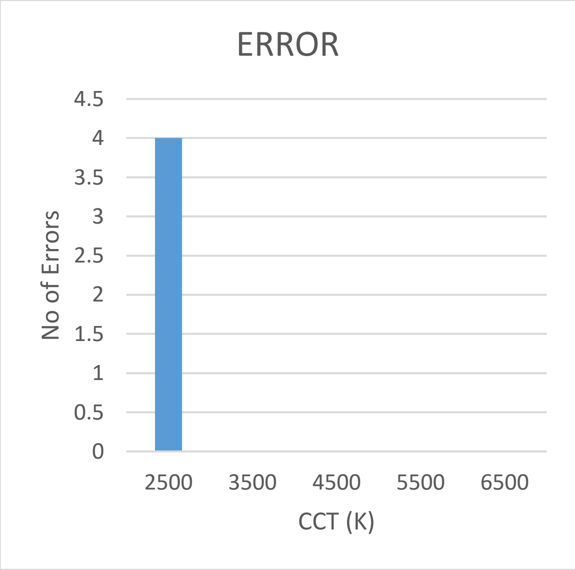
Fig 4.8 *Graphical representation of results of subject 8*

Subject 9

CCT	DIRECTION of Opening of Landolt's Rings	RESPONSE TIME	ACTUAL COUNTS	ERROR	FALSE-POSITIVE
2500	LEFT	82	47	4	0
3500	RIGHT	68	51	0	0
4500	UP	65	45	0	0
5500	DOWN	70	45	0	0
6500	RIGHT	55	51	0	0

Table 4.9 *Datasheet of subject 9*





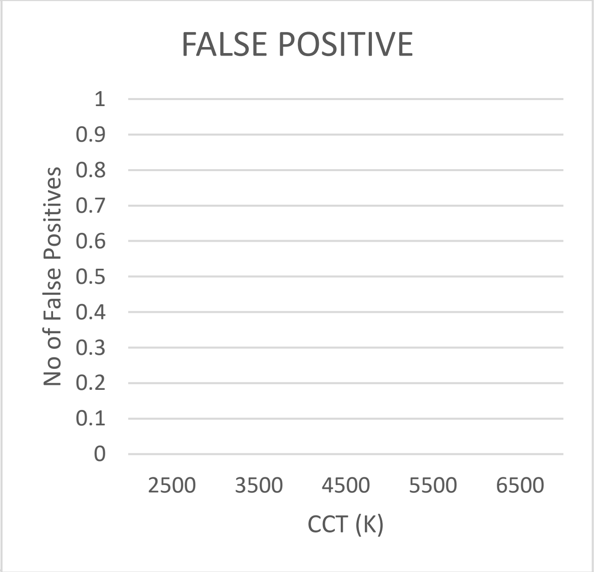


Fig 4.9 *Graphical representation of results of subject 9*

Subject 10

CCT	DIRECTION of Opening of Landolt's Rings	RESPONSE TIME	ACTUAL COUNTS	ERROR	FALSE-POSITIVE
2500	LEFT	116	48	3	0
3500	UP	114	48	1	0
4500	RIGHT	114	49	2	0
5500	DOWN	100	46	0	1
6500	LEFT	99	52	0	1

Table 4.10 *Datasheet of subject 10*

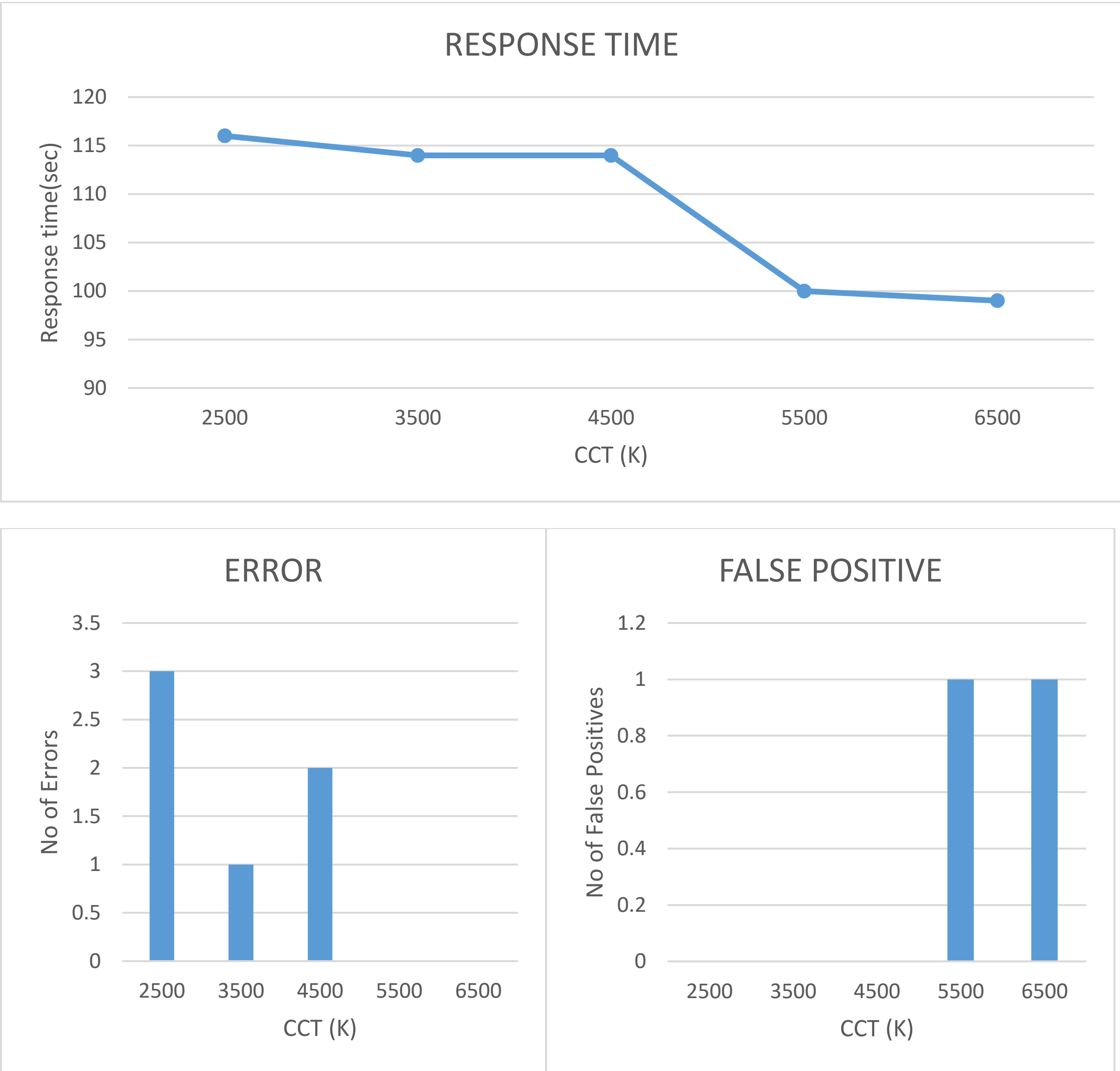
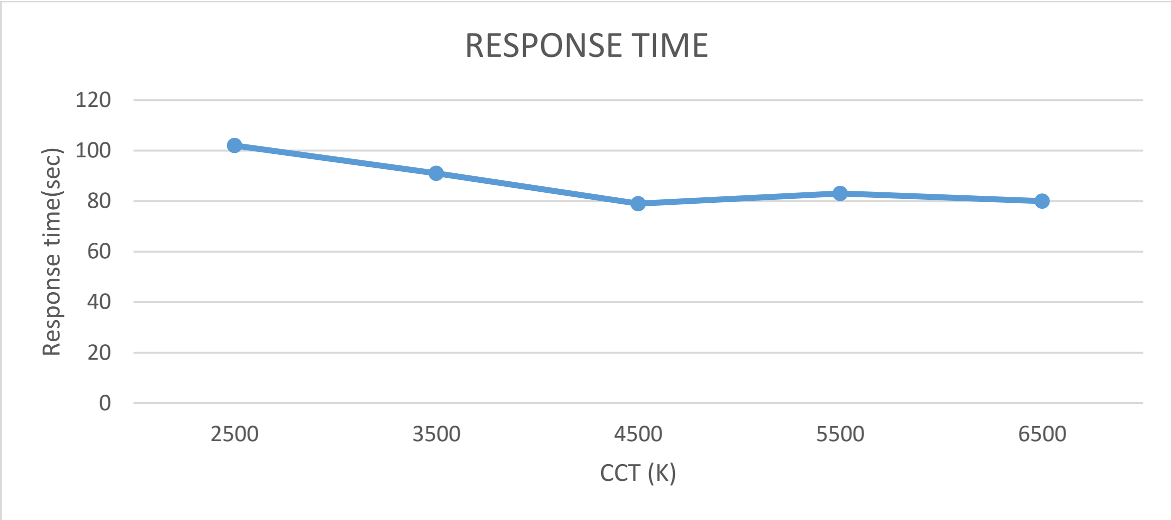


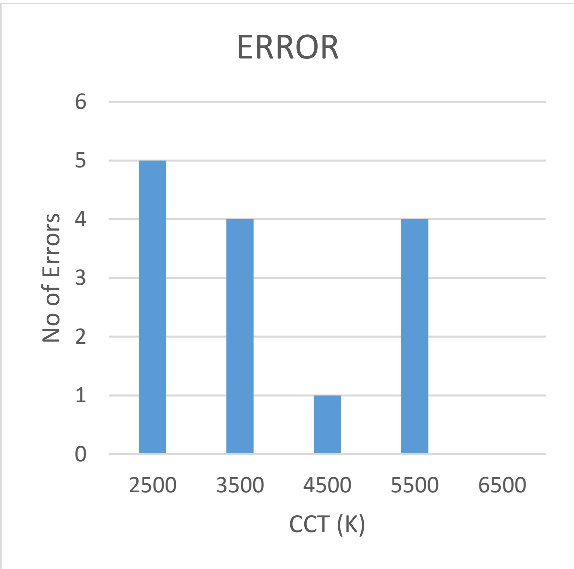
Fig 4.10 *Graphical representation of results of subject 10*

Subject 11

CCT	DIRECTION of Opening of Landolt's Rings	RESPONSE TIME	ACTUAL COUNTS	ERROR	FALSE-POSITIVE
.2500	LEFT	102	46	5	0
3500	DOWN	91	41	4	0
4500	UP	79	44	1	0
5500	RIGHT	83	47	4	0
6500	UP	80	45	0	0

Table 4.11 *Datasheet of subject 11*





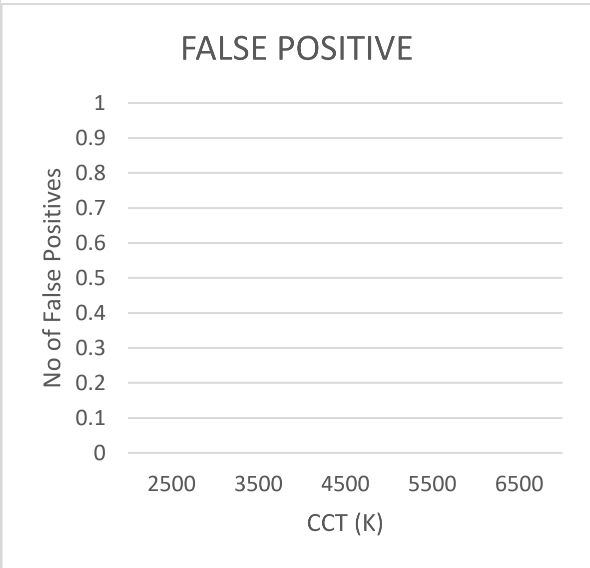
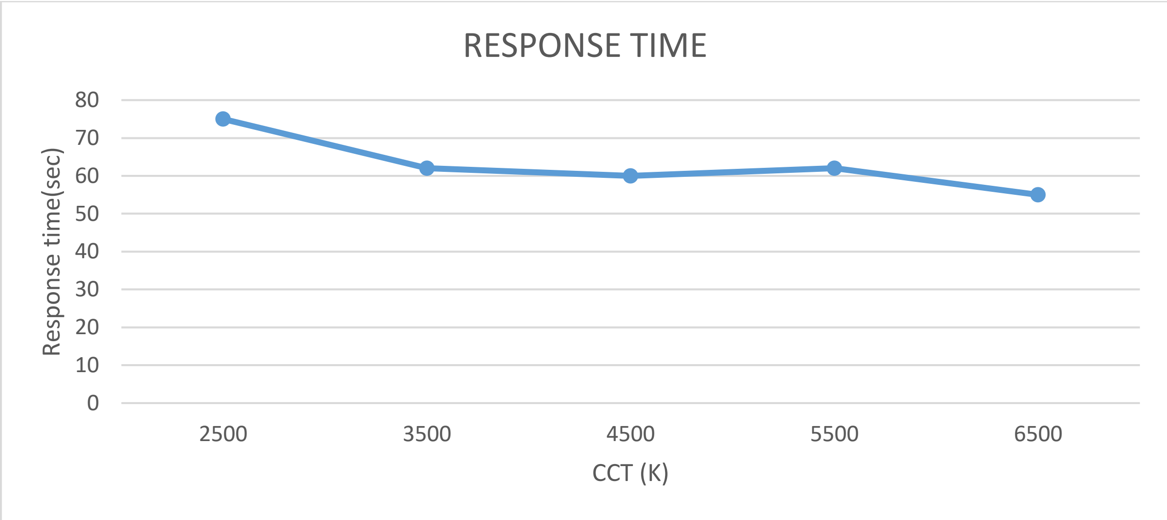


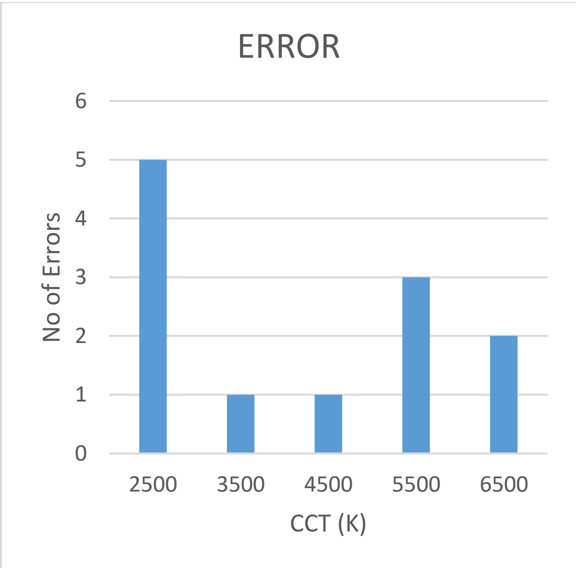
Fig 4.11 *Graphical representation of results of subject 11*

Subject 12

CCT	DIRECTION of Opening of Landolt's Rings	RESPONSE TIME	ACTUAL COUNTS	ERROR	FALSE-POSITIVE
2500	LEFT	75	46	5	0
3500	DOWN	62	48	1	0
4500	UP	60	44	1	0
5500	RIGHT	62	48	3	0
6500	DOWN	55	47	2	0

Table 4.12 *Datasheet of subject 12*





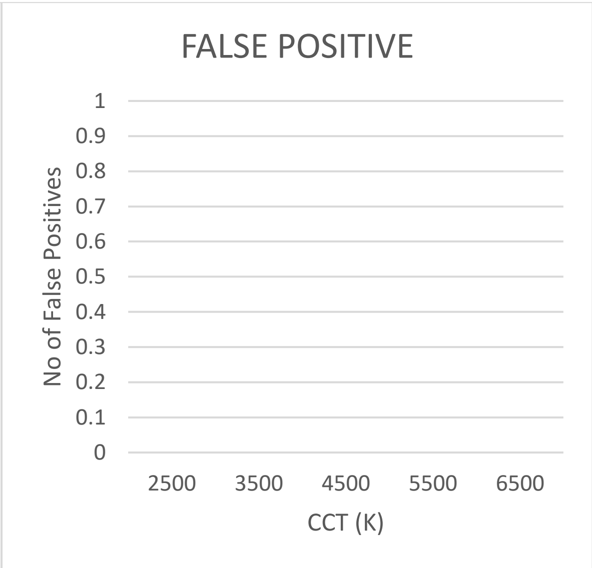
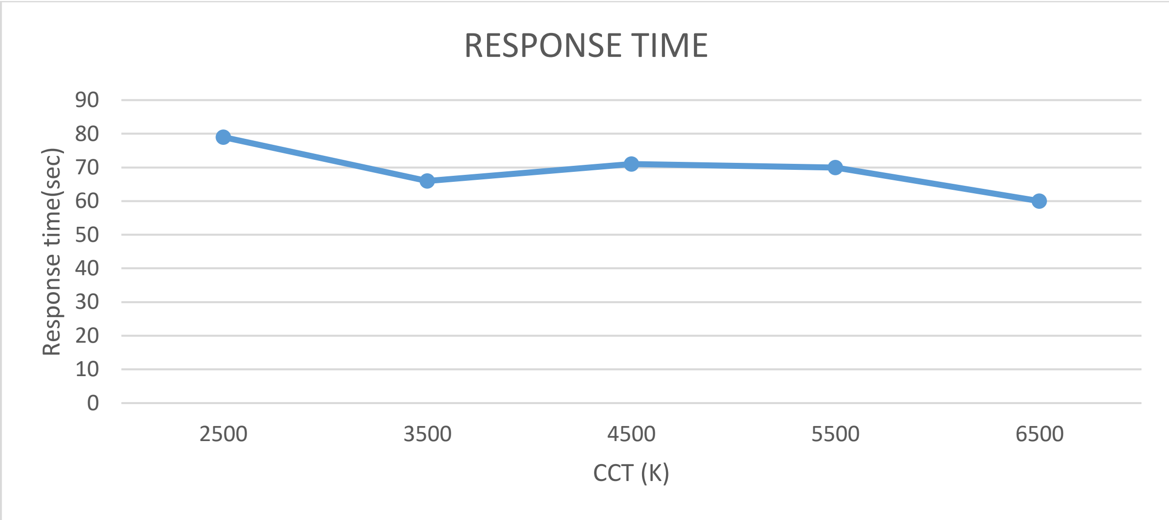


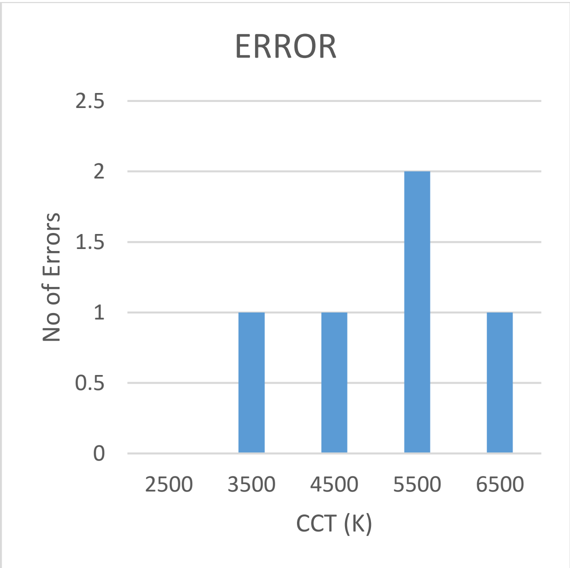
Fig 4.12 *Graphical representation of results of subject 12*

Subject 13

CCT	DIRECTION of Opening of Landolt's Rings	RESPONSE TIME	ACTUAL COUNTS	ERROR	FALSE-POSITIVE
2500	RIGHT	79	51	0	0
3500	DOWN	66	44	1	0
4500	LEFT	71	50	1	0
5500	UP	70	47	2	0
6500	RIGHT	60	50	1	0

Table 4.13 *Datasheet of subject 13*





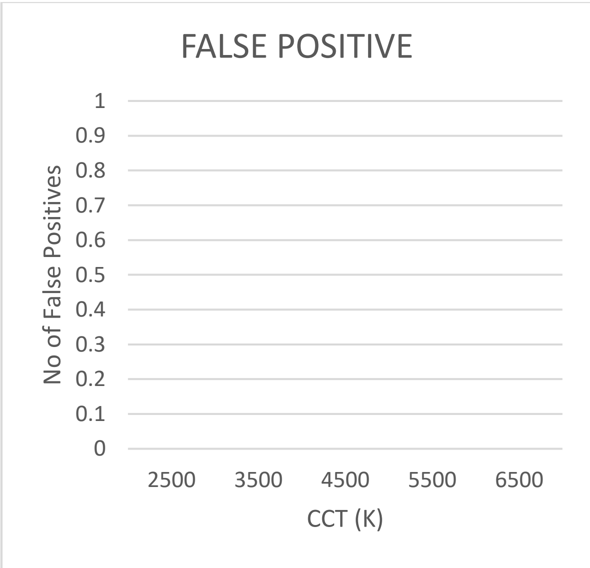
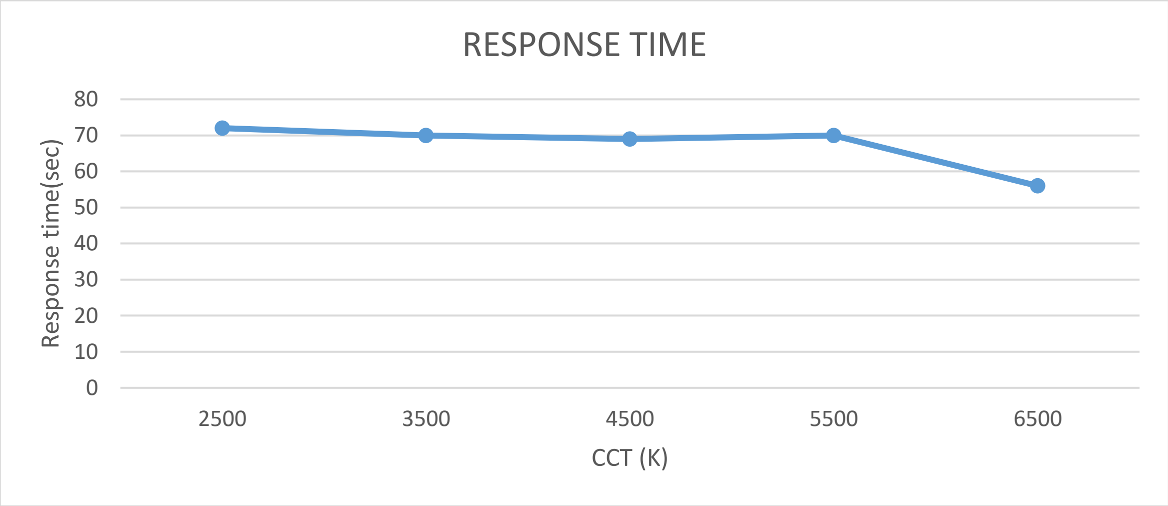


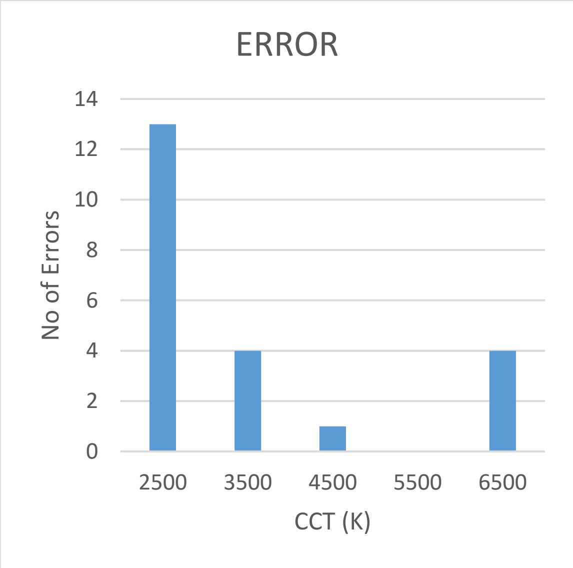
Fig 4.13 *Graphical representation of results of subject 13*

Subject 14

CCT	DIRECTION of Opening of Landolt's Rings	RESPONSE TIME	ACTUAL COUNTS	ERROR	FALSE-POSITIVE
2500	RIGHT	72	38	13	0
3500	DOWN	70	41	4	0
4500	LEFT	69	50	1	0
5500	UP	70	48	0	3
6500	RIGHT	56	47	4	0

***Table 4.14** Datasheet of subject 14*





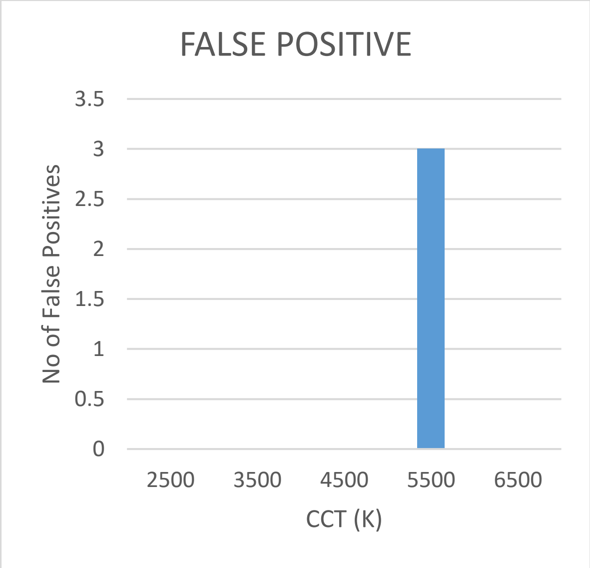
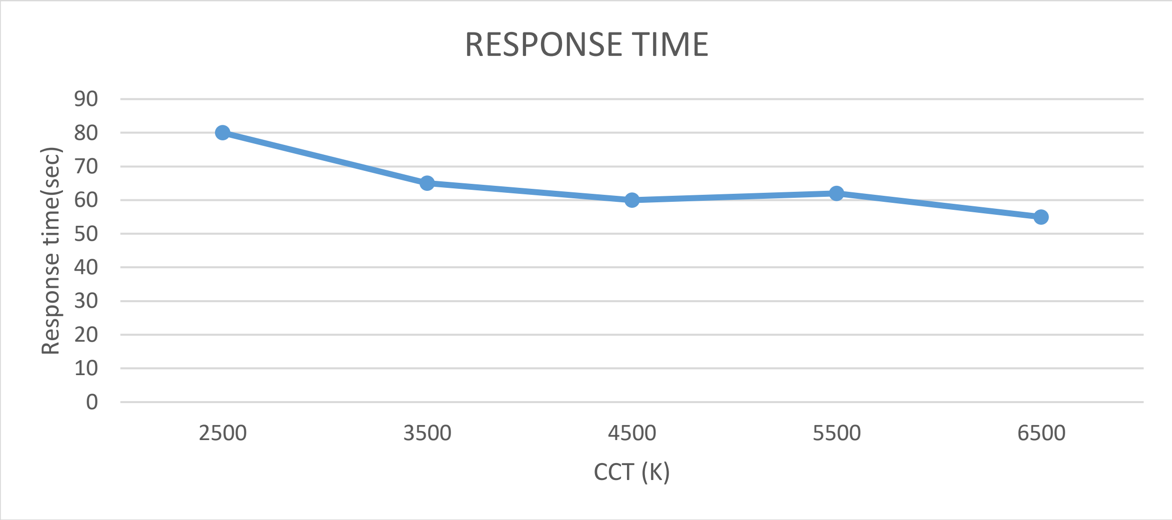


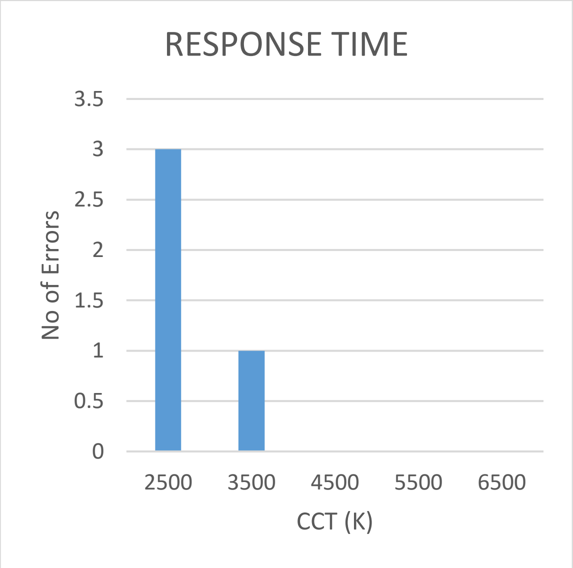
***Fig 4.14** Graphical representation of results of subject 14*

Subject 15

CCT	DIRECTION of Opening of Landolt's Rings	RESPONSE TIME	ACTUAL COUNTS	ERROR	FALSE-POSITIVE
2500	LEFT	80	48	3	0
3500	RIGHT	65	50	1	0
4500	UP	60	45	0	0
5500	DOWN	62	45	0	0
6500	RIGHT	55	51	0	0

Table 4.15 *Datasheet of subject 15*





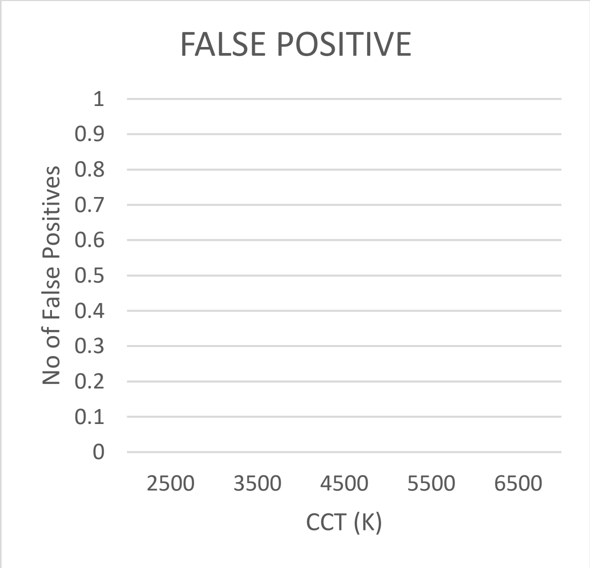


Fig 4.15 *Graphical representation of results of subject 15*

CHAPTER 5: DISCUSSION & CONCLUTION

This experiment was carried out with varied CCT ranges of 2500K, 3500K, 4500K, 5500K, and 6500K. There was a considerable difference in response times between the circumstances under different CCTs. When the CCT is increased from 2500K to 4500K, the average time reaction drops initially. Average time response detection is high at CCT 5500K and even lower at CCT 6500K. The average time response changes with CCT ranges of 2500K, 3500K, 4500K, 5500K, and 6500K, according to this graphical representation. The number of misses and false positives that occurred in a normal task at a certain time was determined using the results of the second investigation using different CCT ranges of 2500K, 3500K, 4500K, 5500K, and 6500K.

This entire thesis project has been summarised in an abstract study aimed at determining the impact of colour temperature on task performance. The goal of this research is to figure out how CCT affects task performance and human activity. The experiment is focused on a two-part abstract investigation. The first part tries to estimate the total time needed to count the Landolt rings for a specific direction opening, and the second part tries to estimate the number of false positives and misses for the same task. Both portions were completed for each CCT taken into consideration.

The experiment is done by using 5 different CCTs ie. 2500K, 3500K, 4500K, 5500K, & 6500K. The average data of those 15 subjects are shown below

CCT	RESPONSE TIME	ERROR	FALSE-POSITIVE
2500	82.13	5	0
3500	74.14	2.8	0
4500	69.28	2.2	0
5500	70.35	1.6	0.53
6500	63.57	2.1	0.133

Table 5.1 *Average experimental data*

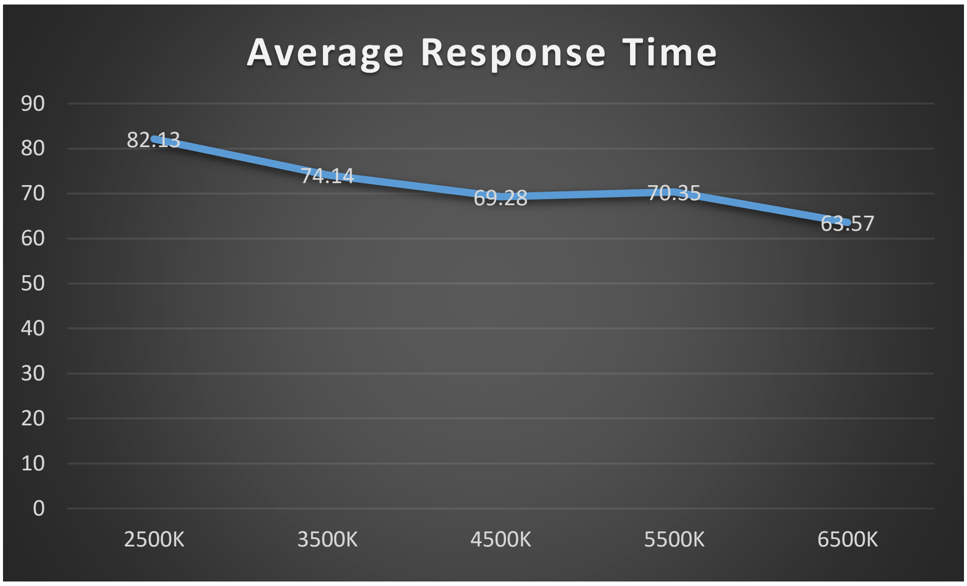


Fig 5.1 *Average response time at different CCTs*

Fig shows that the average response time decreases from 82.13sec to 74.14sec at 2500K to 3500K CCT and then also decreases from 74.14sec to 69.28sec at 3500K to 4500K CCTs but with lower slope. After that it increases slightly from 69.28sec to 70.35sec at 4500K to 5500K CCT and finally, it decreases rapidly from 70.35sec to 63.57sec at 5500K to 6500K CCT. From this graphical representation, it can be concluded that human response time depends on CCT and it is lowest at 6500K CCT in other words human needs lesser time to do their jobs in 6500K.

Fig 5.2 *Average number of errors*

The number of errors is maximum at 2500K and minimum at 5500K. At first, the number of errors decreases from 5 to 1.6 at 2500K to 5500K CCT. Then the number of errors increases from 1.6 to 2.1 at 5500K to 6500K CCT. From this average data, it can be concluded that at 5500K CCT one can do its job more correctly.

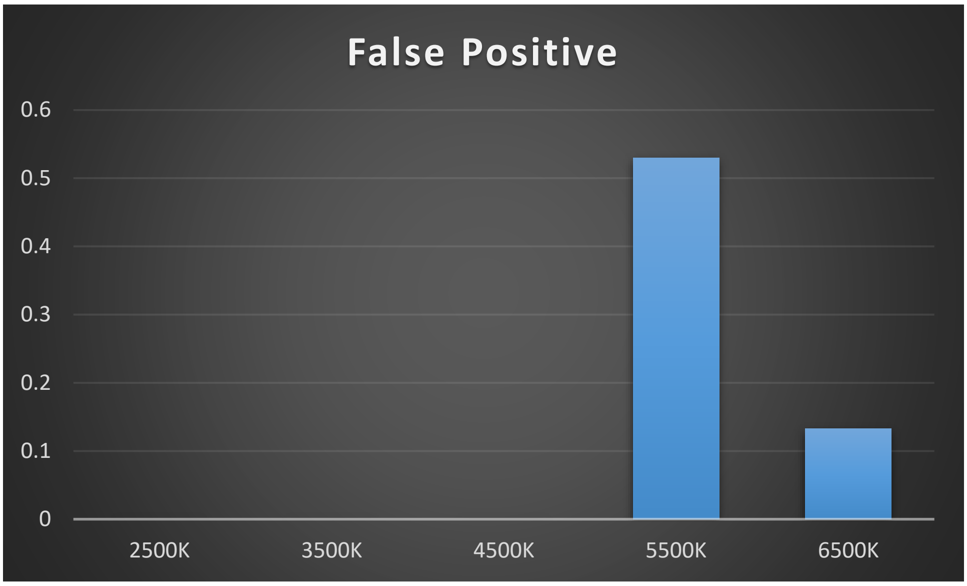


Fig 5.3 *Average number of false positives*

Fig shows the average number of false positives at these 5 CCTs. There is no false positive at 2500K, 3500K & 4500K CCTs but it is maximum at 5500K.

CHAPTER 6: FUTURE SCOPE OF WORK

In the present study, the influence of colour temperature on task performance has been measured. 15 participants are managed to come and instructed to do the task i.e: counting Landolt's Rings from the chart.

In future, the whole experiment can be modified as well as improved in many aspects.

- Only 15 participants were enrolled in the current study. It can be further expanded by adding more participants. As a result, statistical analysis, i.e. ANOVA results, can be more importantly included in this study.

- It can be extended by including an age group factor and gender variation also. As the vision, as well as the whole mind and physic, varies with ageing and gender too. Therefoe, if the experiment includes different age groups, it can be seen how the results differ between a teenager and someone over 30 or 50.

- Considering the effect of measured peripheral glare sources on on-axial visual acuity during simple tasks, the work can be further analyzed.

- The whole experiment is done in a dark room with very less or without any disturbance, therefore, in future, it can experiment in a common area like classrooms or office spaces where other peoples are also present.

- In this study, we used correlated colour temperature as a stimulus. Additionally, this experiment can be performed with different compositions of light spectrum, illumination level, and background luminance level also.

- Activity time measurements can be performed using an electroencephalograph (EEG) device to obtain the brain's response immediately after detecting an object i.e: Landolt's rings of a certain opening. This technique can also be employed to conduct this entire experiment where we can underst the effects of different color temperatures through the corresponding brain signals while performing a specific task.

CHAPTER 7: REFERENCES

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CHAPTER 8: INSTRUMENTS ANNEXURE

8.1 KONICA MINOLTA CL-70F CRI Illuminance Meter

A low-cost spectrometer-based illumination meter called the CL-70F measures electrical flash with an accumulation-type sensor. It is the perfect option for measuring the Spectral Power Distribution (SPD), Spectral compositions, Illuminance, Correlated Colour Temperature (CCT), and Colour Rendering Index (CRI) of a variety of light sources because of its extremely high colour measurement precision and high-resolution CMOS sensor.

Throughout the duration of the experiment, this tool was utilized to check the lamp's colour consistency. Before the trial began, each lamp's light output's chromaticity and spectrum makeup were measured daily.

Fig 8.1 *KONICA MINOLTA CL-70F CRI Illuminance Meter*

8.1.1 Features

Main features of CL-70F

- Spectral sensor.
- Measure CRI.
- Compact, easy to carry and battery operated.
- Colour touch screen.

Lighting design and continuous maintenance are only two of the usual lighting jobs that the lightweight CL-70F body is made for. The CL-70F gives entry-level access to cutting-edge

light measurement features by measuring CRI and providing spectral data. The CL-70F is a potent tool for professional image and entertainment sectors when used in conjunction with a flash sync connection, which permits spectral measurements of flashlights.

8.1.2 Colour Rendering Index measurement

Access to measurement information for the Colour Rendering Index (CRI) is made simple by the CL-70F. The display presents a simple bar graph of the Ra value together with each individual index (R1 to R15).

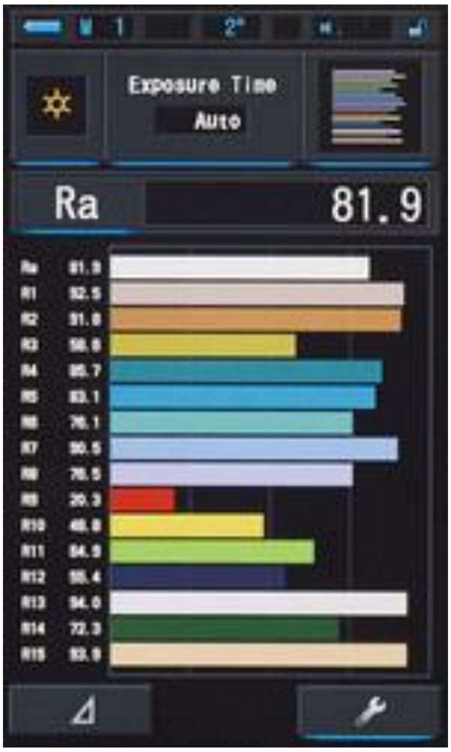

Fig 8.2 *Colour Rendering Index*

8.1.3 Measurement of correlated color temperature (Tcp)

The variables that are often used to characterise the colour of light sources, correlated colour temperature and the difference from the blackbody locus Δuv, may be measured using the CL-70F. The absolute temperature (in Kelvin) at which a blackbody would produce a specific hue of light is known as the colour temperature of light. The “blackbody locus” is a curve that allows the colours of light emitted by a blackbody at various temperatures to be plotted. Since many light sources’ output does not coincide with the blackbody locus exactly “correlated colour temperature” which are referred to as (CCT). Normally, the difference from the blackbody locus ∆uv is provided in addition to the associated colour temperature when characterising a colour using correlated colour temperature.

8.1.4 Spectral Power Distribution

The CL-70F provides easy access to Colour Rendering Index (CRI) measurement data. The display shows the SPD value over the wavelength. The Y scale is normalised to 1.

Fig 8.3 *Spectral Power Distribution*

8.1.5 Rotating Receptor Head

The rotating receptor head improves screen visibility and comfortable use of the instrument.

Fig 8.4 *Rotating Receptor Head*

8.1.6 Zero Adjustment

Without a receptor cap, it is simple to modify this device's zero setting. To calibrate the dark, turn the diffusor's ring counter-clockwise.

Fig 8.5 *Zero Adjustment Without receptor Cap*

8.1.7 Additional Features

It provides Utility software CL-SU1w with the software CL-SU1w which is included as a standard accessory, one can modify instrument settings, store & group data and make further analyses of the measured data.

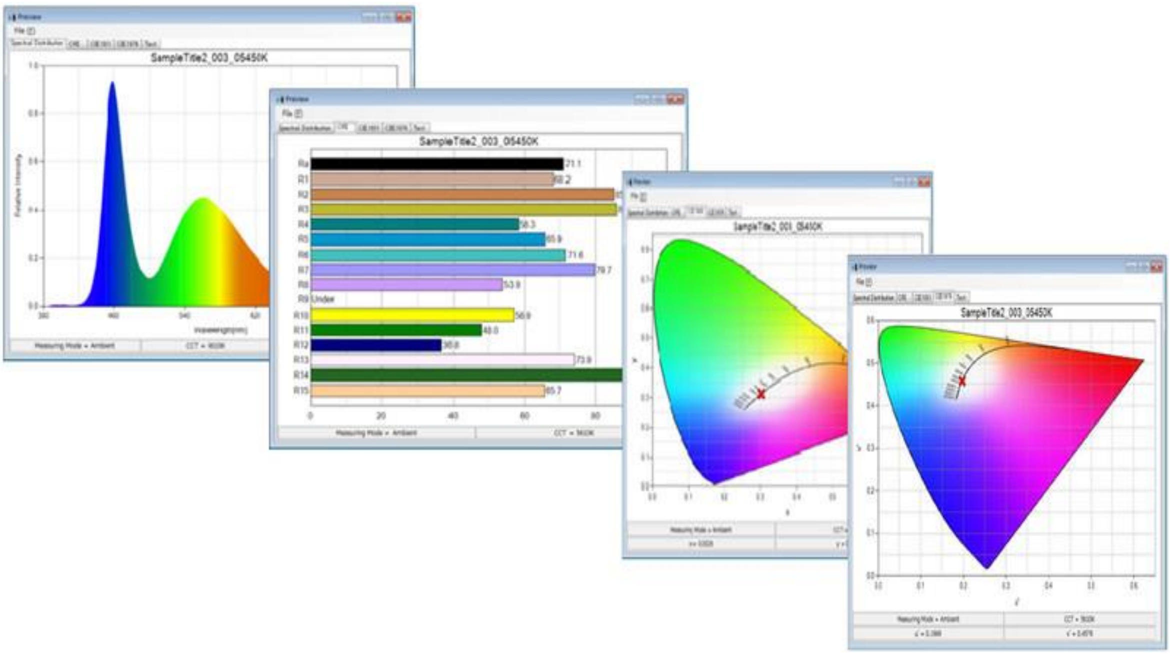

Fig 8.6 *Stored Data in CL-SU1w Software*

8.2 Philips Wiz Wi-Fi Enabled B22 9-Watt LED Smart Bulb

Wi-Fi-enabled LED from Philips Smart bulbs (Shown in figure 80) that are simple to use, practical, and reasonably priced provide total control over the lighting. Simply connect them to an established Wi-Fi network to make high-quality Philips lights smarter. These bulbs can generate 16 million colours. Also, CCT can vary from 2500 K to 6500 K . Utilise the WiZ lighting app or a voice assistant that is compatible with controlling the lights. For the device to work wirelessly, a WiFi connection is necessary. The Philips Smart Wi-Fi LED smart lamp works with WiZ products and applications in addition to Alexa, Google Assistant, and Siri Shortcuts. In this study 4 Philips Led bulbs had been used.

Fig 8.7 *Philips Wiz Wi-Fi Enabled B22 9-Watt LED Smart Bulb*

8.2.1 Product Description

Bulb	Characteristics
Intended use	Indoor
Lamp shape	A19
Socket	B22
Technology	LED
Type of glass	Frosted
Dimmable	Wireless Dim
Bulb	**Dimensions**
Height	11.8 cm
Weight	0.07 kg
Width	06 cm

Durability	
Average life (at 2.7 hrs/day)	25 year(s)
Lumen maintenance factor	0.7
Nominal lifetime	25,000 hour(s)
Number of switch cycles	50,000

Light Characteristics	
Beam angle	120 degree(s)
Color rendering index (CRI)	90
Color temperature	2700-6500 K
Light Color Category	Color & Tunable White
Nominal luminous flux	825 lumen
Starting time	< 1s
Warm-up time to 60% light	Instant full light
Color Code	927-965, CCT of 2700K-6500K
Other Characteristics	
Lamp current	100 mA
Efficacy	90.1 lm/W

Packaging Information	
Product family	LED
EAN	8718699732561
EOC	871869973256100
Product Title	Philips Smart WiFi LED Full-color 9w Led Bulb B22

Power Consumption	
Power factor	0.9
Voltage	220-240 V
Wattage	9 W
Wattage equivalent	60 W

8.3 Stop-Watch

To measure the response time, a stopwatch was used. This is an analog stopwatch and recorded time in sec.

8.3.1 Product Specifications

Brand	**Eisco**
Item Dimensions L x W x H	16 x 50 x 70 Millimeters
Human Interface Input	Dial

Fig 8.8 *Stop-watch*