

ESRA KÜRKÇÜ

THE EFFECTS OF COLOR TEMPERATURE ON PERFORMANCE
A COLOR TASK IMPLEMENTATION

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THE EFFECTS OF COLOR TEMPERATURE ON PERFORMANCE AND
MOOD OF USERS: A COLOR TASK IMPLEMENTATION MODEL

A Master's Thesis

by
ESRA KÜRKÇÜ

Department of
Interior Architecture and Environmental Design
İhsan Doğramacı Bilkent Üniversitesi
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MOOD OF USERS: A COLOR TASK IMPLEMENTATION MODEL

The Graduate School of Economics and Social Sciences
of
İhsan Doğramacı Bilkent University

by

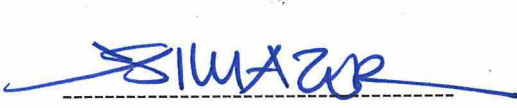
ESRA KÜRKÇÜ

In Partial Fulfillment of the Requirements for the Degree of
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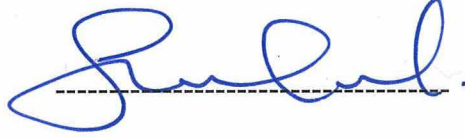
THE DEPARTMENT OF
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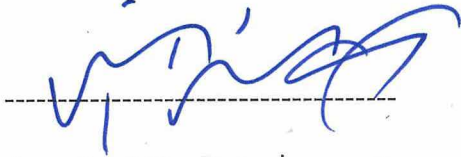


Asst. Prof. Dr. Semiha Yilmazer
Principal Supervisor



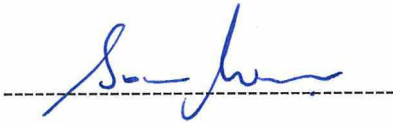
Dr. Sibel Ertez Ural
Co-Supervisor

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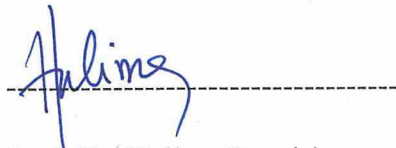
Asst. Prof. Dr. Çağrı İmamoğlu
Examining Committee Member

I certify that I have read this thesis and have found that it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Fine Arts in Interior Architecture and Environmental Design.



Prof. Dr. Banu Manav
Examining Committee Member

Approval of the Graduate School of Economics and Social Sciences



Prof. Dr. Halime Demirkan
Director

ABSTRACT

THE EFFECTS OF COLOR TEMPERATURE ON PERFORMANCE AND MOOD OF USERS: A COLOR TASK IMPLEMENTATION MODEL

Kürkçü, Esra

MFA, Department of Interior Architecture and Environmental Design

Advisor: Assist. Prof. Dr. Semiha Yılmaz

Co-advisor: Dr. Sibel Ertez Ural

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This study aimed to explore the effects of color temperatures on color task performance, and also to propose a color task implementation model to be used in future research. In the study, three attributes of color were the focus in the color differentiation task. The study was conducted with 100 participants as with-in subjects design, in a full-scale office set-up under two different color temperature; warm white light (2700K and cold white light (4000K. The speed and accuracy of the color task were examined as an indication of task performance. The mood change of participants was assessed by Watson's Positive and Negative Affect Schedule (PANAS mood measurement, self-satisfaction was assessed by Office Lighting Survey (OLS and perceived performance was assessed by questionnaire. The results showed that the total time spent for the color tasks performances have no significant

difference between 2700K and 4000K. It also showed that total accuracy of color task performances is statistically better under 4000K, compared to 2700K. Whereas color temperatures did not affect value differentiation task performance significantly, hue and chroma differentiation tasks performance were significantly better under 4000K color temperature. In terms of the effects of color temperature on mood, it is found that 4000K color temperature affected participants mood in a positive way. Also, self-satisfaction and perceived performances of participants are significantly better under 4000K color temperature.

Keywords: Color Temperature, Color Differentiation Task, Mood, Office Environment, Task Performance

ÖZET

IŞIĞIN RENK SICAKLIĞININ KULLANICILARIN PERFORMANSI VE DUYGU DURUMU ÜZERİNE ETKİLERİ: RENK İŞİ UYGULAMA MODELİ

Kürkçü, Esra

MFA, İç Mimarlık ve Çevre Tasarımı Bölümü

Tez Danışmanı: Yard. Doç. Dr. Semiha Yılmaz

2. Tez Danışmanı: Dr. Sibel Ertez Ural

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Bu çalışmanın amacı ışığın renk sıcaklığının renk işi performansı üzerine etkisini araştırmak ve gelecek araştırmalarda kullanılacak renk işi uygulaması önermektir. Bu çalışmada renk ayırt etme işlerinde rengin üç boyutuna odaklanılmıştır. Çalışma 100 katılımcıyla, tekrar ölçümlü araştırma deseni ile, tam ölçekli ofis düzeneğinde iki farklı renk sıcaklığı; sıcak beyaz ışık (2700K) ve soğuk beyaz ışık (4000K) altında gerçekleştirilmiştir. İş performansının göstergesi olarak renk işindeki hız ve doğruluk incelenmiştir. Katılımcıların duygu değişimi Watson' ın Pozitif Etki Ve Negatif Etki İzlenesi ile, kişisel memnuniyet Ofis Aydınlatma Anketi ile, algılanan/beklenen performans ise anket ile ölçülmüştür. Elde edilen sonuçlar, renk işi performansları için harcanan sürelerin 2700K ve 4000K arasında anlamlı bir fark olmadığını göstermektedir. Sonuçlar ayrıca renk işi performanslarındaki doğruluğun 4000K

altında 2700K’e kıyasla anlamlı bir şekilde daha iyi olduğunu göstermektedir. Değer ayırt etme performansına aydınlatma koşullarının anlamlı bir etkisi olmamasına rağmen, renk türü ve renk doygunluğu ayırt etme performansları 4000K renk sıcaklığı altında anlamlı bir şekilde daha iyidir. Renk sıcaklığının duygu durumuna etkisi açısından; 4000K renk sıcaklığı katılımcıların duygu durumunu olumlu bir şekilde etkilediği saptanmıştır. Katılımcıların kişisel memnuniyeti ve algılanan/beklenen performansları da 4000K renk sıcaklığı altında anlamlı bir şekilde daha yüksektir.

Anahtar Sözcükler: Duygu Durumu, Işık Renk Sıcaklığı, İş Performansı, Ofis Ortamı, Renk Ayırt Etme İşi

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I dedicate this thesis to my parents Saliha and Macit Kürkçü.

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CHAPTER I

INTRODUCTION

Over the last decades, the concept of work environment has changed and working area of employees and working hours are highly influenced by this change. Average working hour for an employee is approximately nine hours per day and most of this time is spent within the office buildings (Xu, 2013). It is found that physical conditions of an indoor environment can affect office workers' health, well-being, comfort, satisfaction and productivity (Roulet et al., 2006; Fotios & Cheal, 2011). To improve the quality of work life, the workplace design becomes a very important factor. For instance, the new offices should provide not only working facilities but also personal comfort. There are three types of comfort; physical comfort; based on basic human needs like safety and hygiene, functional comfort; ergonomic support for work related tasks such as appropriate lighting, and psychological comfort; the feeling of belonging to a workspace. When workspace quality is assured of these three comfort types, work performance can be maintained at high levels. Work performance is affected by environmental conditions such as temperature and humidity, furniture ergonomics, acoustics, lighting and visual conditions

(Vischer,2008). Lighting parameters such as luminance values and the color of the light source are extremely important aspects of the office lighting environment. An adequate luminance value provides good visibility of task and comfort, and the color of the light source affects the appearance of room furniture, work instruments. Therefore, a well-designed office lighting enables the employees to see and carry out their tasks accurately, quickly and easily (IESNA, 1993; Boyce,2006; Fotios& Cheal, 2011). In the office environments, mood, well- being and task performance have directly related each other. When lighting conditions affect workers psychologically; mood and feelings of workers affect task performance (Rea, 2000).

Since color is generated by light, lighting conditions also affect color vision and color appearance and visual performance. Visual tasks are separated from each other according to their difficulties. Tasks involving color take part in difficult tasks. Appropriate luminance values and color of the light provide good color visibility and improves visual performance for color including tasks (Van Bommel & Van den Beld, 2004; Luo, 2011; Holtzschue, 2012). The color tasks, mentioned in the literature review, are generally based on color discrimination performance which is analyzed by Farnsworth- Munsell 100- hue test. The arranging set of colors in the FM 100 test have the same value and chroma levels and the test just assesses hue differentiation ability (Cranwell, Pearce, Loveridge& Hurlbert, 2015). However, colors are perceived fully and accurately depending upon the recognition of three attributes which are hue, value, and chroma (Cooper, 1941). For this reason, there is still a need for considering and understanding all three attributes of color in color task performance studies in the office environment. Also, there are no significant studies about the effects of lighting conditions on the combination of color task

performance and mood. Therefore, this study has potential of filling the gap in the literature.

1.1. Aim of the Study

The main purpose of this study is proposing a new kind of color task implementation model and replacing text-based task performance methods with color based one. It also aimed to investigate effects of color temperature on color differentiation (hue, chroma, and value) performances and mood. In the literature, although there are numerous experimental studies based on lighting conditions and task performance, there is no significant research regarding the effect of color temperature on work performance of people whose instruments are color oriented tasks in the office environment. So, this study aims to fulfill the gap in the literature. The findings of the study can be helpful for workers who deal with colors in an indoor environment, interior designers and light designers who are able to create well designed office environments and enhance productivity, satisfaction, and mood of workers in workplaces.

1.2. Structure of the Thesis

The thesis contains four chapters. The first chapter is a brief introduction to study based on effect of office environments especially luminous environment of offices on users' task performance, mood, comfort, and satisfaction. In addition, lighting and

color relationship are mentioned. This chapter also describes the aim of the study and the structure of the thesis.

The second chapter is a comprehensive literature review. This chapter consists of three main parts based on lighting and color studies. In the first part, the effect of office lighting on human comfort, task performance, and mood are investigated under the headings of the luminous environment, visual task considerations, and psychological aspects of lighting in offices. In the second part, the color is analyzed by basic color theory, color order systems, perception and vision of color. Also, the effects of lighting on color perception and appearance are explained. Lastly, previous studies based on color and lighting are investigated under the headings of color task considerations.

The third chapter is the main part of the study based on the experimental study. In this chapter, the aim of the study, research questions and hypotheses are given. The method of the study is described by explaining the experimental setup, identification of participant groups, and process of the experiment firstly. Then the design of the experimental study; color task implementation method and questionnaires are described respectively. Also, in this chapter, statistical analysis methods and evaluation of the data are presented. Lastly, findings of the study are discussed in relation to the previous studies about the topic mentioned in the second chapter.

The last chapter is the conclusion. This chapter contains the important aspects of results and limitations of the study.

CHAPTER II

LIGHTING AND COLOR

2.1. Lighting in Office Environments

In the office environments, the main subjects are work and work-related activities such as reading, typing, and computer based works. The lighting conditions in an office environment, as one aspect of the indoor work environment, affect workers both physiologically and psychologically. A well-designed lighting enables workers to carry out the tasks accurately, quickly and easily and therefore increase the performance of workers. It can also increase comfort, health, well-being, and mood of the workers. (Fisk, 2000; Roulet, 2006; Veitch, 2008; Boyce, 2014).

Lighting condition can change the visibility of the task, the atmosphere of the office room and motivation of workers so office lighting can support visual performance and enhance psychological conditions (Fotios, 2011).

2.1.1. The Luminous Environment

One of the key factor that affects work performance, mood and health of occupants is the luminous environment (Boyce, 2010; Park, Chang, Kim, Jeong& Choi, 2010).

A good luminous environment enables workers to focus on the job and prevents the distractions (Egan& Olgyay,2002). Lighting parameters such as the color of the light source and luminance values are extremely important aspects of the office lighting environment (IESNA, 1993).

The color of the light source affects the appearance of room furniture, people and work instruments as a whole of the atmosphere of an office environment. The most important characteristics of the color of the light source are correlated color temperature (CCT), color rendering index (CRI), and spectral power distribution (SPD). CCT is the measurement of the color appearance of a light source which is determined by its color temperature in Kelvin (K). The color of the light changes according to its temperature; at 0K, it appears black, around 1000K red, around 2500K yellow, around 4500K white and around 6500K bluish white. An ordinary cool white fluorescent lamp has 4100K, and the warm white fluorescent lamp has 2700K and 3000K (Nassau, 1997). CRI refers to the color rendering properties of a light source and it is based on the average magnitude of the color shifts of objects compared to the natural color of objects. Low CRI of lighting causes limited information on color shifts. However, while the light sources have the same CRI they may not have the same color rendering according to their CCT and SPD. SPD refers to the wavelength of light sources in the visible region of the electromagnetic

spectrum (360 to 770 nanometers) (see Figure 1). SPD of the light source has a significant impact on the recognition of color and color rendering properties of the light source (IESNA, 1993; Fotios& Cheal, 2011; Luo, 2011; Kuhn, Johansson, Laike& Govén, 2013; Aste, Tagliabue, Palladino, & Testa, 2015).

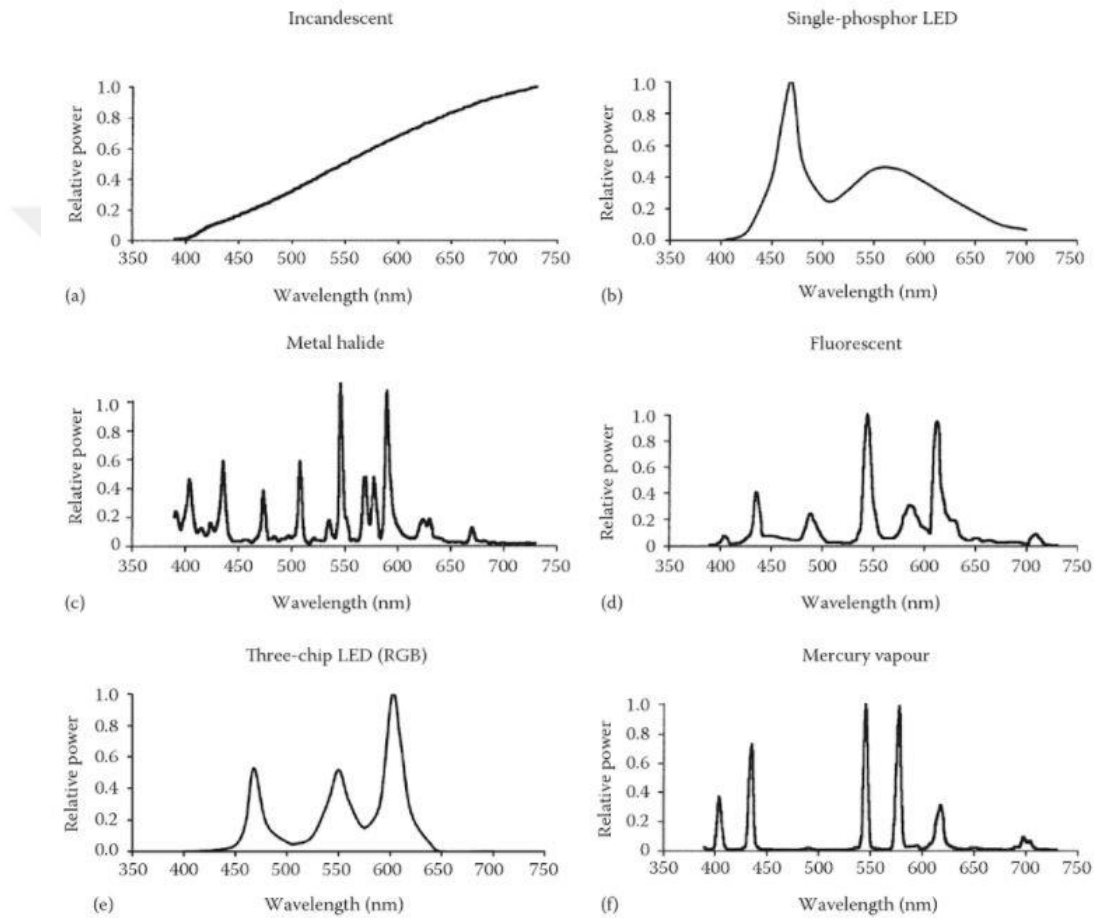


Figure 1: Spectral power distribution of different light sources

(Source: Boyce, P. R. (2014). *Human factors in lighting*. Crc Press.)

The other parameter of the office lighting environment is luminance values. In order to provide good visibility and comfort, there should be adequate luminance values since inadequate and excessive luminance reduces visibility, causes discomfort,

eyestrain, and headaches. Luminance refers to the measurement of the amount of light which is perceived by the human eye and illuminance refers to the measurement of the amount of light on a given surface area which is perceived as the brightness of an illuminated area and measured in lux. In order to ensure human comfort, illumination must prevent glare, reflection, and shadows and provide luminous differences and color contrast (IESNA, 1993; Smith & Parmenter, 2016; Aste, Tagliabue, Palladino, & Testa, 2015).

Luminous differences and color contrast are one of the important aspects of the luminous environments which enable good vision. In order to discriminate the details of objects or tasks, there should be a contrast between objects and immediate surroundings. Smith and Parmenter (2016) claims that luminance and illuminance values affect the contrast considerably. Also, veiling reflection which is caused by high luminance affects contrast reduces the ability to distinguish the details of the task, therefore, affects task performance. The other effect of improper luminance is glare. When the illuminance (brightness) differences become excessive in the field of view, glare can occur and it causes impaired vision and discomfort. The high illuminance value on desk surface and low illuminance on the task cause shadow and it also reduces the ability to distinguish the details of tasks. In order to provide proper contrast, prevention of reflection, glare and shadow recommended illuminance ratios should be considered (see Figure 2). It is important to supply adequate luminance and luminance difference to enable good visibility and improve the visual environment (The Chartered Institution of Building Services Engineers (CIBSE), 1984).

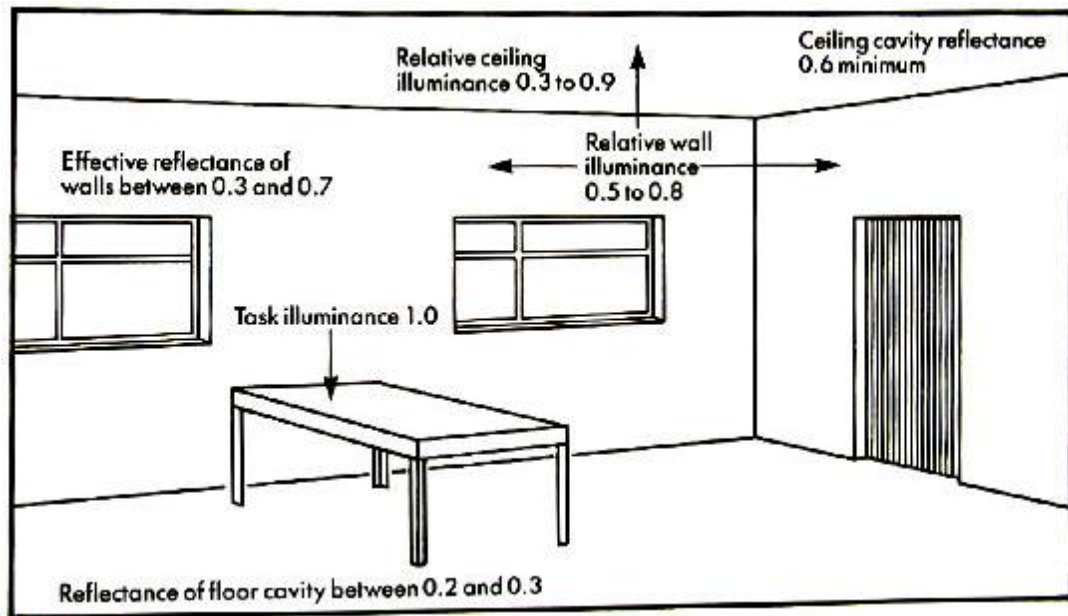


Figure 2: Recommended illuminance ratios and surface reflectance

(source: CIBSE, C. (1984). Code for interior lighting. *London: The Chartered Institute of Building Services Engineers.*)

An office environment which is poorly designed in terms of luminous environment can cause impaired vision, discomfort and health problems such as eyestrain and headaches. Therefore, in such office environments, visual performance is affected negatively. Likewise, properly designed luminous environments have positive effects on visual impression of the workplaces and task performances by increasing task visibility and stimulating mood of workers (Van Bommel & Van den Beld, 2004; Boyce, 2006).

2.1.2. Visual Task Considerations

In office environments, workers spend most of their time on visual tasks. Visual task performance is mainly based on detection, recognition, and identification problems.

Visual performances are defined as the speed and accuracy of processing visual information. In order to detect, recognize and identify visual tasks and increase performances of the workers, offices should provide optimum lighting conditions.

The main parameters that affect the visual task considerations are quality of light (related to the proper visibility of the task) and quantity of light (related to the illumination level of an efficient visual performance) (Egan& Olgyay,2002; Rea, 2000; Fotios, 2011).

In the literature, there are numerous studies demonstrating the effects of various lighting condition on subjective impressions and visual task performance (Harrington,1954; Steffy, 2002; Manav,2007; Izsó, Láng, Laufer, Suplicz & Horváth, 2009).

Early studies about the effects of lighting conditions on subjective impressions found that the higher CCT conditions generate higher brightness perception and facilitate better work performance compared to lower ones in comparison of 3000K, 3500K and 4000K (Harrington,1954; Steffy, 2002). A study which was conducted by Manav (2007), investigated the effects of CCT and illuminance level on the subjective impression which was evaluated by perceived brightness, the impression of spaciousness, change in saturation levels of colors and being comfortable and relax.

The experiment was conducted in a full-scale office room. Three different CCTs (2700K, 4000K and combination of 2700K and 4000K) and four different illumination levels (500lux, 750lux, 1000lux and 2000lux) were used for the study. The results showed that 2000lux illumination level was preferred for the impression of spaciousness and comfort, brightness and saturation evaluations. Comparison of CCTs showed that for the impression of spaciousness and comfort 4000K was preferred, and for relaxation and saturation evaluations 2700K was preferred. There was no significant effect of CCT found on perceived brightness. Another research by Izsó et al. (2009) was compatible with Manav's study in terms of relaxation. It found that the combination of low CCT (2700K) and low illuminance level (100lux) created relaxing environment compared to the combination of high CCT (4000K) and high illumination level (1300lux).

Ju, Chen and Lin (2012) made another research on effects of CCT on spatial brightness perception. In the experiment, a total of nine lighting conditions; a combination of three different CCT (3000K, 5000K, and 8000K) and three different illumination levels (100 lux, 300 lux, and 1000 lux) were used. The study found that the higher CCT generated the higher spatial brightness perception compared to lower CCTs (Ju, Chen& Lin, 2012).

Wei et al. (2014) conducted a field study investigating effects of CCT (3500K and 5000K) and lumen output (2330lm and 3000lm) of fluorescent lighting on visual comfort, brightness perception, satisfaction, and self- reported productivity. The results showed that higher CCT (5000K) was perceived brighter than the lower one (3500K). However, visual comfort, satisfaction, and self- reported productivity were

better under 3500K compared to the 5000K color temperature. Participants evaluated 5000K as too cool (Wei et al., 2014).

Another study conducted by Boyce (2006) consists of two experiments which investigated the effects of different lighting quality on performance, health, and well-being of workers. The results showed that there was no significant effect of lighting quality on task performance although the expected changes in performance were associated with task visibility, practice, and fatigue.

Ödemiş, Yener and Camgöz (2004) carried out a study which investigated the effects of different lighting types (wall washing, cove lighting, and uplighting) on visual task performance. The experiment was conducted in a test chamber. The performance was tested by matching task and measured by speed and accuracy of the task. The results of the study showed that lighting conditions did not have significant influence on the performance of participants.

To evaluate the effects of different color temperatures on worker's alertness, visual comfort level, preferences and task performance, Shamsul, Nur Sajidah and Ashok (2013) carried out a study using three different light's color temperature; warm white (WW) light (CCT=2700K), cool white (CW) light (CCT=4000K) and artificial daylight (DL) (CCT=6200K). The experiment was conducted in a controlled experiment laboratory. Visual comfort and preference were tested by Office Lighting Survey and task performance was tested by typing task and measured by speed and accuracy of the task. The results of the study showed that subjective alertness level

was significantly decreased under 2700K and there was no significant difference between 4000K and 6200K. In term of task performance, typing speed of participants was significantly faster under 4000K and 6200K compared to 2700K and under 6200K light participants made fewer errors and it was followed by 4000K. They made the highest percentage of typing errors under 2700K light. Although participants felt most comfortable under 6200K, they mostly preferred 4000K for office lighting. The study suggested 4000K and 6200K lighting were more beneficial for the computer-based task in office environments. Another study by Sivaji, Shopian, Nor, Chuan and Bahri (2013) also investigated the effects of CCT of lighting (2700K, 4000K and 6200K) on task performances, alertness, visual comfort, and preferences. Similarly, visual comfort and preference were tested by Office Lighting Survey and task performance was tested by typing task and measured by speed and accuracy of the task. The results of the study are conflicted with Shamsul et al.'s study and found that visual comfort level and preferences showed that participants were most comfortable under the 4000K light. They found that subjective alertness level was highest under 2700K light. There was no significant difference found under different CCT of lights in terms of visual task performance.

Another study conducted by Chellappa et al. (2011) investigated effects of different color temperatures (2500K, 3000K, and 6500K) of fluorescent light on alertness and cognitive performance. The results of the study showed that higher CCT causes higher subjective alertness and better cognitive performance.

2.1.3 Psychological Aspects of Lighting in Offices

Although in workplaces the main importance is given to task performances, a lighting design should not only meet the visual task requirements for reading and typing tasks but also satisfy psychological needs of users; provide long-term user satisfaction and consider workers' well-being. Lighting plays a significant role in the perception of space (reinforcing the subjective impression of space), activity, and mood (Kaufman, 1987). An optimal lighting condition can increase comfort, health, well-being, and task performances (Roulet et al., 2006; Veitch et al., 2008). The term 'comfort' consists of three categories: physical comfort, functional comfort, and psychological comfort. Physical comfort involves basic human needs such as safety and hygiene. Functional comfort is related with ergonomic support of performance on work-related tasks for users such as appropriate lighting conditions. Psychological comfort is highly related with feelings about the workspace. When workspace quality is assured of these three comfort levels, satisfaction, well-being and a better mood are provided for occupants (Vischer, 2008) (see figure 3). There is a direct relationship between mood and feelings of health and well-being. Mood and feelings related to the workspace affect the task, therefore, task performance (Rea, 2000).

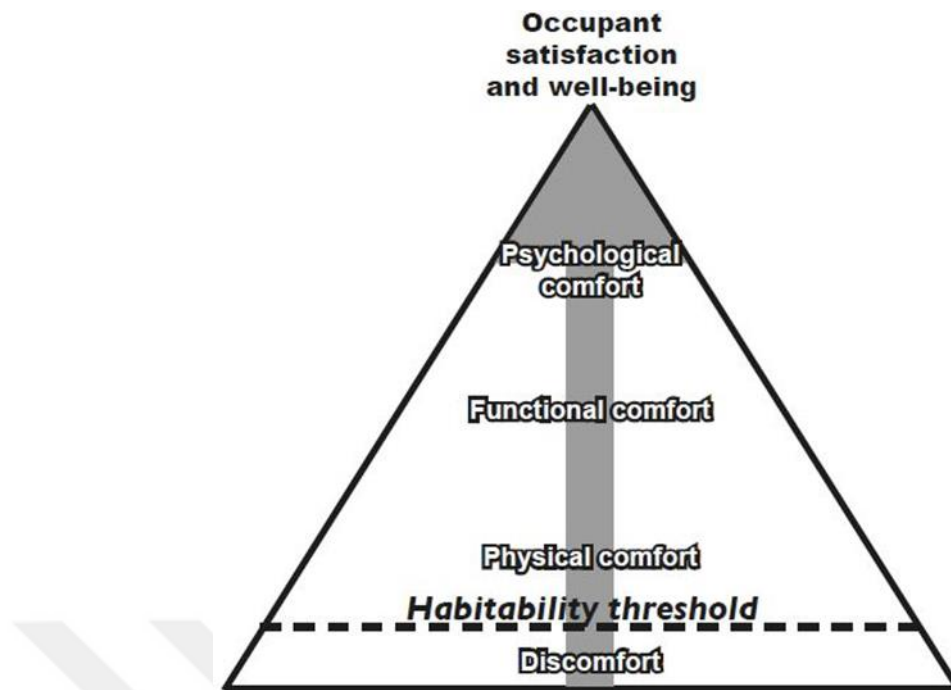


Figure 3: Environmental comfort model of workspace quality

(source: Vischer, J. C. (2008). Towards an environmental psychology of workspace: How people are affected by environments for work. *Architectural science review*, 51(2), 97-108.)

In the literature, there are several studies focused on the effects of different lighting conditions on psychological aspects. A study which was conducted by Knez and Enmarker (1998), investigated the effects of office lighting on subjects' mood, cognitive performance among the gender by memory tasks, problem-solving task, a judgment task, mood and room lighting questionnaire. The experiment was conducted in a chamber was furnished as a real office space. Two color temperatures; 3000K and 4000K CCT were investigated. Both of the lightings have the same CRI (95) and illumination level (1500 lux). The results showed that preservation of positive mood and decrease in negative mood was observed under 3000K for male participants and under 4000K for female participants. While female participants evaluated the 4000K color temperature as the warmest and 3000K as

coolest light, male participants evaluated the lighting opposite to females. For the cognitive performance, there was no significant difference found between the color temperatures.

Park, Chang, Kim, Jeong, and Choi (2010) explored the effects of different color temperature conditions on the psychological aspects and subjective mood. Brightness perception, subjective impression, and work performance were analyzed by field tests and photo-image test under four different color temperature fluorescent lamps (3000K, 4000K, 5000K and 6000K) with the same illuminance value (580 lux) in an office space, living room, and bedroom. The study found that people prefer different color temperatures depending on the purpose of space, and different color temperature conditions for specific activities performed in that space. In the office environment, the results of the field and photo image test showed that 4000K is the most preferred color temperature and work performance is better under the 4000K compared to other color temperatures. Brightness perception showed that 5000K was rated as the brightest color temperature and 6000K was the darkest one for the office environment. The mood results showed that under higher color temperatures; participants were more alive, concentrative, and tensioned and less sleepy, tedious, and undesirable compared to lower color temperatures.

Another study by Lee, Moon and Kim (2014) examined visual response and mood under a variety of lighting conditions, including different target illuminance levels and color temperature conditions in office environments. Visual perception and annoyance tests were conducted in a full-scale mock-up space where six office lighting conditions, a combination of 500 lux and 750 lux with 3000K, 4000K and

6500K were set up for computer and paper-based reading tasks. The results of the study showed that combination of 3000K and more than 500 lux illumination levels cause visual discomfort by glare and brightness. Participants preferred a combination of 500 lux and 6500K lighting condition, and 500-750 lux and 4000K lighting condition for better visual satisfaction when performing office tasks. The study also found that visual comfort was the most important factor on mood. Lower color temperatures generated better mood at lower illuminance levels, while higher color temperatures were preferred at higher illuminance levels.

Borisuit, Linhart, Scartezzini& Münch (2015) have carried out a study investigating whether realistic office daylighting and electric lighting have effects on visual comfort, alertness, and mood. The Visual Analogue Scale (VAS) was used for assessments of visual comfort and subjective alertness, mood and well-being and Office Lighting Survey (OLS) was used for detailed visual comfort assessments. Since daylight was a variable of the study, illumination level, color temperature and CRI were changed throughout the day. In the first half of the afternoon, color temperature values were higher compared to the end of the afternoon. Their results showed that subjective assessments on alertness, physical well-being and mood becomes worse towards the end of the afternoon. They also found that daylight availability is the indicator of work satisfaction for both visual and non-visual functions.

Gou, Lau& Qian (2015) conducted a study evaluating the effects of naturally lit and artificially lit environments on participants' mood and task performance. The experiment was conducted in a test chamber which was divided into two rooms. One

room was lit by daylight and the other was lit by 4000K artificial light. The mood of the participants was measured by Watson's Positive and Negative Affect Schedule (PANAS). Results showed that naturally lit environment gave a better first impression of space to participants. However, after applying task performance, it was seen that 4000K artificial lighting generated higher Positive Affect (PA) and lower Negative Affect (NA) compared to natural lit environment.

2.2. Fundamentals of Color

“Color is that part of perception that is carried to us from our surroundings by differences in the wavelengths of light, is perceived by the eye, and is interpreted by the brain” (Nassau, 1997:3). The color is not a physical substance it is a visual sensation which is generated by light as a physiological response. Colors are perceived fully and accurately depending upon the recognition of three attributes which are hue, value, and chroma (see figure 4). In order to make use of color efficiently, it is necessary to learn to distinguish in every color sample according to these attributes. Hue is the name of the color such as red, green, blue, yellow, purple, etc. Chroma is the degree of intensity (strength) of the color. It changes in between neutral gray to strongest chroma obtainable in any hue and gives the measurements of the lack of white, gray and black for a color. Value is the strength of light and it changes in between black and white (Cooper, 1941; Nassau, 1997).

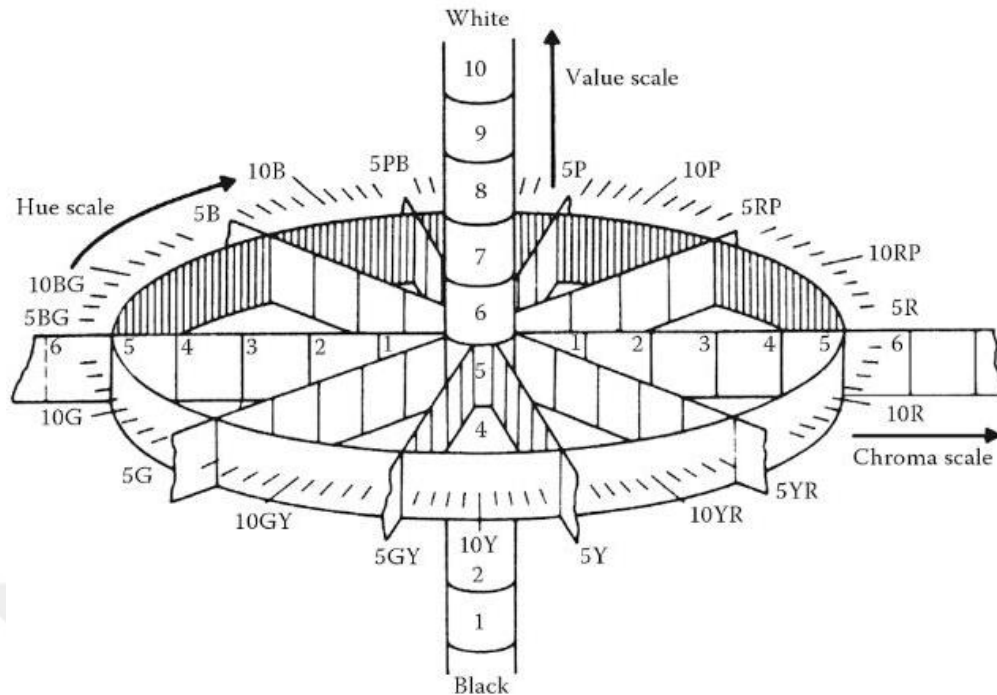


Figure 4: A diagram of hue, chroma and value in their relation to one another

(Source: Boyce, P. R. (2014). *Human factors in lighting*. Crc Press.)

To deal with color effectively, basic color theory categories which are the color wheel and color schemes should be learned. The color wheel is a circle that shows hues according to their spectral (natural) order (see figure 5). The order of colors in the wheel is fixed and presented in a continuous circle. A color wheel consists of sort of all visible hues. There are three primary hues; blue, red, and yellow. All the colors are derived from these hues. With the mixture of the primary hues, secondary hues are obtained which are purple, green, and orange. Each secondary hue is the visual midpoint of two primary colors. When the primary and secondary hues are mixed, their midpoints originate the intermediate colors. The intermediate hue names are based on their creator primary and secondary colors; yellow-orange, red-orange, red-violet, blue-violet, blue-green, and yellow-green. The basic color wheel is made up

from six hues, the combinations of primary and secondary hues and expanded spectrum color wheel is made up from twelve hues, the combination of primary, secondary and intermediate hues (Holtzschue, 2012; Matters, 2012).

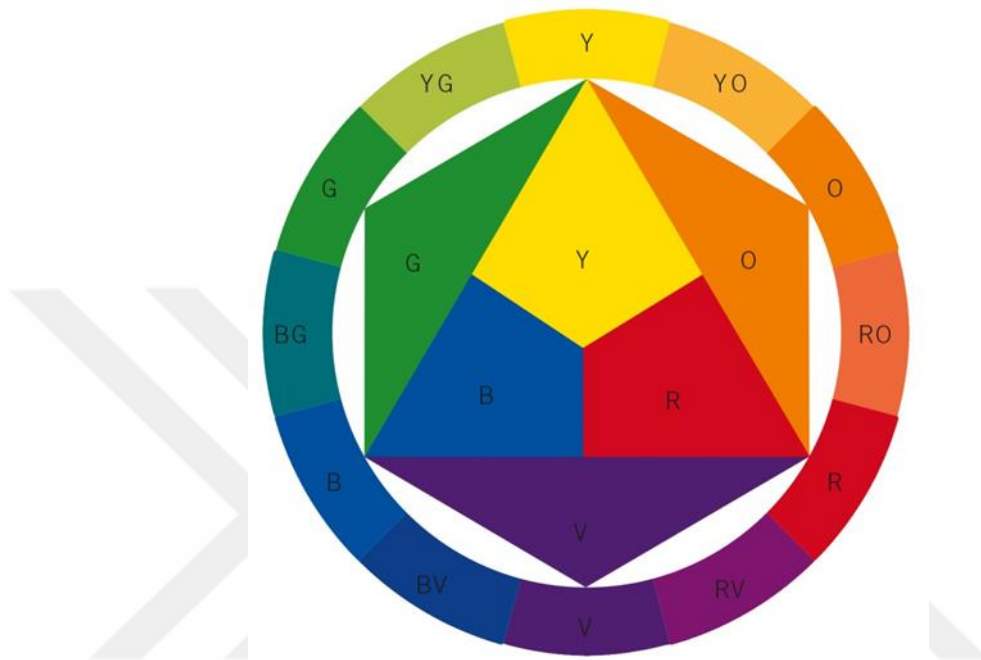


Figure 5: The color wheel

(Source: Holtzschue, L. (2012). *Understanding color: an introduction for designers*. John Wiley & Sons.)

Color schemes are developed utilizing the color wheel. There are four basic color schemes; achromatic, monochromatic, analogous, and complementary. The achromatic color scheme does not consist of any hue. It comprises just grayscale colors; white, grays, and black. The monochromatic color scheme consists of single hue only and varied tints and shades of that hue such as dark red, red, and light red. The analogous color scheme consists of three hues which are adjacent to each other

on the expanded spectrum color wheel such as green, yellow green, and yellow. The complementary color scheme consists of colors which are located directly opposite to each other on the color wheel such as orange and blue (Holtzschue, 2012; Matters, 2012).

2.2.1. Color Order Systems

There are more than 17 million different colors being used in design software and distinguished by human eyes. In order to classify and identify the colors, no single color-order system can be truly inclusive so different color systems have been developed. Color order systems are based on the appearance of colors on three-dimensional arrangements. Color order systems organize the confusion of the color range by presenting colors in an order based on the relationship between each other. Each color can be described related to the position of the color in the notation. There are different color order systems; CIE Lab System, HSB System, The COLORCURVE, The DIN (Deutsche Industrie Normung- German Standardization Institute), Hungarian color order system, NCS and Munsell color order systems. Munsell color system is the most accepted color system among the others and most of the color courses give education based on Munsell system (Nassau, 1997).

Munsell color system based on three attributes of color; hue, chroma, and value. The system comprises of five Principal Hues; red (5R), yellow (5Y), green (5G), blue (5B), and purple (5P) and five Intermediate Hues; yellow-red (5YR), green-yellow (5GR), blue-green (5BG), purple-blue (5PB), and red-purple (5RP). The principal hues are visually equidistant from each other and divided the color wheel into five

equals distant. The intermediate hues are the midpoint of the two analogous principal hues. The combination of principal hues and the intermediate hues are generated the major hues. Through sub-dividing each major hue into ten sections; secondary intermediate and special intermediate hues are generated. Munsell's 100 hues circuit consists of 10 major hues, 10 secondary intermediate hues, and 80 special intermediate hues. The hue circuit has the equal chroma level for each hue. The chroma scale is ranged from neutral gray to highest chroma. The value scale is ranged from white to black with ten equal steps (Cooper, 1941).

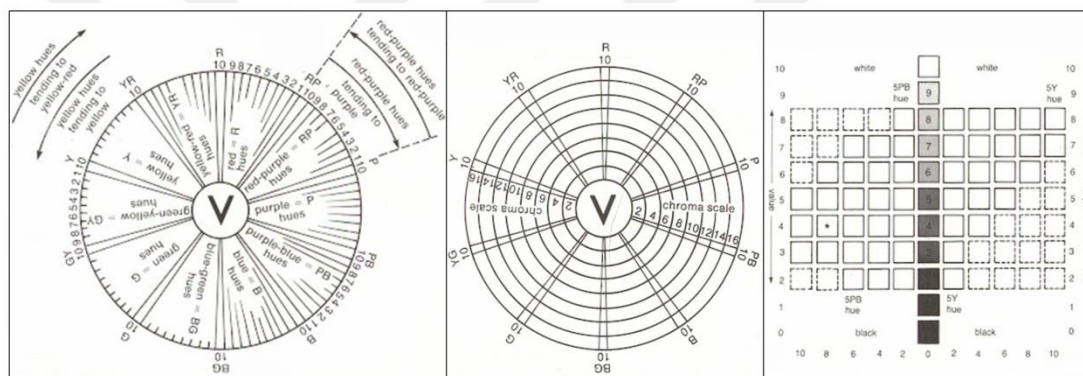


Figure 6: Munsell's hue, chroma and value charts

(Source: Gohl, E. P. G., & Vilensky, L. D. (1989). *Textile science*. Longman Cheshire.)

2.2.2. Color Vision

The color is a visual sensation and the eye is the sense organ that receives light, detects environments and objects. Retina of the eye get a stimulus, transmits the stimulus to the brain and identifies the stimulus as color in the brain. In the retina, there are two types of photoreceptors; the rods and cones. The function of rods is to

create a vision in low- level light situation without a color appearance. The cones operate details and color vision (Van Bommel & Van den Beld, 2004). The human color vision system is trichromatic with three sensor types which are sensitive to light of different wavelengths; red, green, and blue. All of the colors are seen by the combinations of these wavelengths. Reduced number of cones causes color blindness in which people lose ability to differentiate between colors. People, who have just one type of cone are not able to perceive colors they only perceive shades of gray. They are defined as monochromatic color blind (Bleicher, 2012). For the normal color vision people, the color experience was explained by Holtzschue (2012:3) as:

The beginning of every color experience is a physiological response to a stimulus of light. Colors are experienced in two very different ways. The colors on a monitor screen are seen as direct light. The colors of the physical world — of printed pages, objects, and the environment — are seen as reflected light. The perception of colored light is a straightforward experience: light reaches the eye directly from a light source. The experience of real-world color is a more complex event. Real-world colors are seen indirectly, as light reflected from a surface. For tangible objects and printed pages, light is the cause of color, colorants (like paints or dyes) are the means used to generate color, and the colors that are seen are the effect.

Human eyes can recognize about 150 distinct colors (hues) whether they are seen as direct or reflected light. Color vision enables people to distinguish slight differences between colors such as blue and blue-green, or green and green-yellow (Holtzschue, 2012). A color difference whether it based on hue, chroma or value can also be distinguishable. However, in addition to whole color appearance, the ability to see the difference between the attributes of color may not be the same. It is possible that someone who discriminates difference between value differences (grayscale) may not be able to discriminate chromatic difference (Holtzschue, 2012). Among the color attributes, chroma differences are the least accurately distinguished ones

whereas value differences are the most accurately distinguished ones. Value differences, even the slight differences are detected easily compared to hue and chroma. Large hue differences detected more easily than smaller ones. Identification of yellow hue differences is more difficult than the others (Melgosa, Rivas, Hita & Vienot, 2000).

2.2.3. Color and Lighting

Since color is generated by light, every variation in light has the potential to alter the color perception. Most of the lamps used for general lighting, produce white light which enables all colors to be visible. For a good color visibility amount of light; illuminance level and characteristics of light; SPD, CRI, and CCT have an important impact (Luo, 2011; Holtzschue, 2012).

Illuminance level of a light does not affect the appearance of color but it affects the visibility of color. An inadequate light level causes having difficulties to see colors and an uncontrolled and excessive light also impair color perception. Glare destroys the color perception abilities and can cause temporary blindness (Holtzschue, 2012).

All the white light sources do not generate the same white light. Each type of lamp emits different wavelength according to its spectral distribution curve. The curve provides a visual profile for source color: the light can be seen as pure white, cool white (stronger in green or blue), or warm white (stronger in the yellow-red range). A lamp may not emit all the primaries (red, green and, blue) equally, it can emit

some primaries at a higher level of energy than the others or some primaries can be missed completely. Differences in spectral distribution determine how various kinds of lamps render the colors of objects (Holtzschue, 2012).

CRI gives information of color rendering properties of a light source. When illuminated subjects are color, CRI assumes faithful color rendition and has the ability to judge colors as realistic or natural compared to a reference source, so in order to make a good color judgment, the CRI should be as high as possible. Good color rendering index also enables colors to appear natural and enables to discriminate similar colors. Lower CRI values cause colors to appear unnatural when illuminated by the lamp (Rea, 2008; van der Burgth & van Kemenade, 2010).

The whiteness of a color of light is measured by the color temperature of the lamp. However, it does not show how a light source will render the colors of objects. CCT has an important impact on the appearance of color. Particular CCTs enable colors to be more visible, clear and have an appropriate appearance. Under lower CCT red, red-yellow, and yellow colors have good color visibility whereas, under higher CCT green-yellow, green, blue, blue-green, and purple colors have good color visibility (Hong et al., 2017).

2.2.4. Previous Studies on Color Task Performance

There are certain difficulties of visual tasks in the office environments; moderately difficult tasks such as accounting, reading, and typing tasks and difficult tasks such

as color inspection works and color related tasks. A sufficient lighting condition improves visual performance (Van Bommel & Van den Beld, 2004).

In the literature, there are a number of studies regarding the effects of lighting on color task performance. Different light sources and characteristics of light sources (CCT, SPD, and CRI) on color task performance are examined. Jiang, Lei and Jin (2014) studied spectrum effects on color visual performance under mesopic (night) vision. The research was conducted in an experiment room under three types of light sources (high-pressure sodium, phosphor-converted white LED, and RGB LED). The light sources differed in terms of their SPD (590nm, 450nm, and 460nm), CRI (-23,5, 68, and 49,2) and CCT (1935K, 5045K and 6670K). In the experiment, participants viewed a set of color objects and are asked to evaluate in which light the color of objects seemed most natural, most saturated, and suitable for street lighting. The results of the experiment showed that colors were seen most natural under white LED. In the color matching task, white LED light was found better in terms of accuracy and RGB LED was found better in terms of consumed time on matching performance (Jiang, Lei& Jin, 2014).

Another research conducted by Veitch, Whithead, Mossman& Pilditch (2014) investigated the effects of three SPD on color perception by Farnsworth- Munsell 100 hues test performance, judgments of skin color attractiveness and preferences for the saturation of printed images. The experiment was conducted in a light booth under three lighting setups: filtered quartz halogen lamp (HQ), LED lamp with low Ra (LED A), and LED lamp with high Ra (LED B). The lighting setups had the same illuminance level (400lux), same CCTs (3500K) and different SDPs (650nm, 530nm,

and 465nm). The results showed that color discrimination performance and two perceptual judgments were better under HQ and LED B compared to LED A and there was no significant difference between LED B and HQ.

Royer, Houser, and Wilkerson (2012) conducted a research on color discrimination performance. They used Munsell FM-100 hues test under four different lighting sources having 2700K CCT; RGB LED, two fluorescent lamps, and a tungsten-halogen lamp. The performance was calculated based on total error score of FM-100 hues test. The results showed that among the light sources participant's performance was worse under RGB LED light whereas there was no difference between fluorescent lamps and tungsten-halogen lamp although they have different SPD and CRI levels.

The study conducted by Cheng, Ju, Sun & Lin (2016) investigated the effects of CCT on color differentiation performance and preference. The difference of the study from the previous ones was the participants who were elderly people. The experiment was conducted under two different CCTs; 2800K and 6000K and three different illuminance levels; 30lux, 100lux, and 1000lux. Like the other studies color differentiation performance was assessed by FM-100 hues test. The results showed that higher CCT of light source provided better color differentiation performance and higher illuminance levels perceived as more comfortable and brighter.

Another study investigated the effects of CCT on melatonin production and visual performance in working environment. Seven CCTs (1600K, 1950K, 2750K, 3900K,

6100K, 7100K, and 14000K) were compared with 6500K in terms of particular color discrimination and melatonin synthesis. All the tested lights had 200lux fixed illumination level and reference light source had 2500lux. Color discrimination was assessed by Munsell FM-100 hues test and its results showed that CCTs lower than 2000K are not suitable for color discrimination in workplaces. Error score of the Munsell FM-100 hues test was the least under 6100K and highest under 1600K lighting. While in between 1600K to 6100K the error score was decreasing, from 6100K to 14000K error score increased (Kranenburg, Franke, Methling & Griefahn, 2017).

2.3. Munsell FM-100 Hue Test

The studies about color task performance were mostly based on Farnsworth Munsell 100 Hue test. The test was designed to assess color vision problems and color discrimination ability of observers. In the test, there are 85 colored caps from the whole hue spectrum split across four trays. The test requires participants to arrange these caps into color graded order between two fixed reference caps at the first and last caps in the trays (See Figure 7). The 85 color caps have the same chroma and value levels and vary only in hue with as slight differences between neighboring caps (Rigby, Warren, Diamond, Carter, & Bradfield, 1991; Cranwell et al., 2015). However, chroma and value differences are as important as hue differences since colors are perceived depending upon recognition of these three attributes. Therefore, in this study, color task was created based on Munsell FM-100 Hue Test and it was developed regarding the chroma and value attributes.

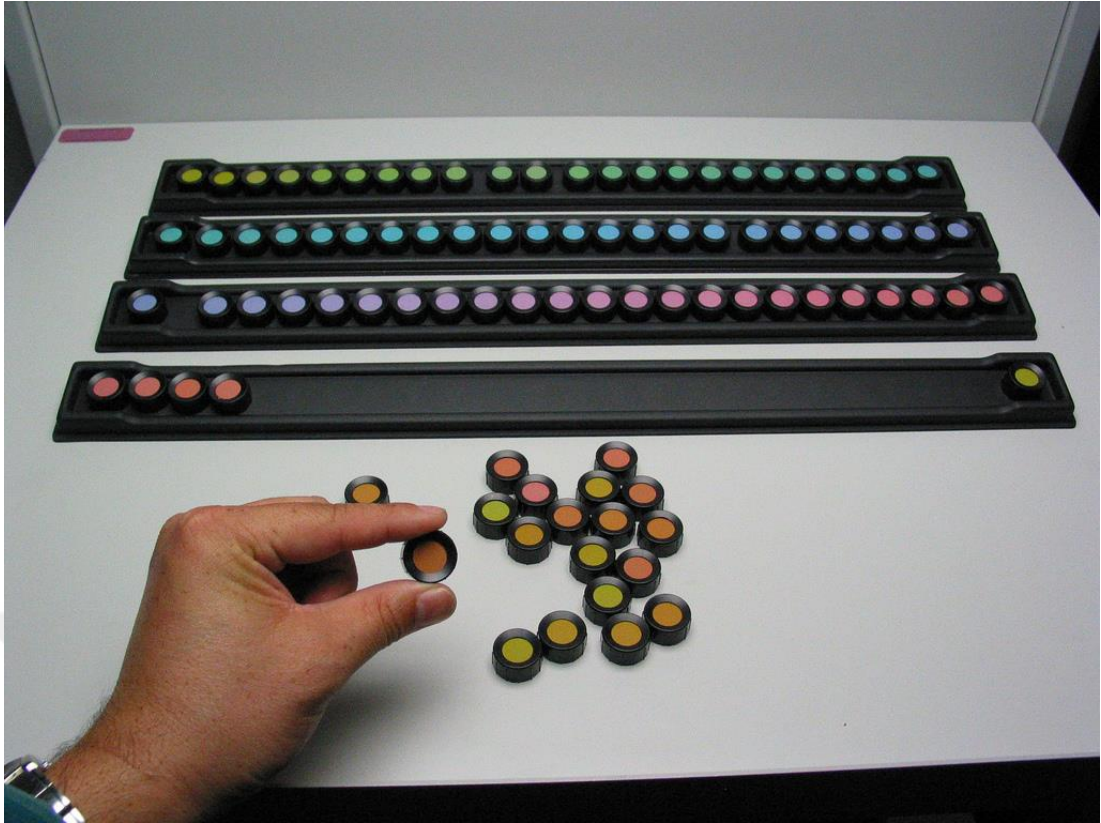


Figure 7: Munsell FM-100 Hue Test

CHAPTER III

EXPERIMENTAL STUDY

3.1. Aim of the Study

To understand the effects of color temperature on performance of workers, a lot of experimental studies were done as mentioned in Chapter II. However, most of the studies used typing and problem-solving tasks as an instrument and there was no significant research about work performance of people whose instruments are color oriented task in office environment. The main purpose of this study is to see the effects of different color temperatures on color based tasks. For this purpose, a color task implementation model to be used in future color task performance experiments was designed. It is also aimed to investigate the effects of color temperature on three attributes of color (hue, chroma and value) differentiation performances and mood. Understanding the differences between 4000K and 2700K color temperatures in color task performance, users' mood and satisfaction from the office lighting quality can be helpful for workers who deal with colors in office environments and light designers to improve workers' performance and well-being.

3.1.1. Research Questions and Hypotheses

In order to reach the aim of the study four research questions were formulated. The research questions of the study are as follows:

Q1: Is there any significant difference of color task performance under different color temperatures?

Q2: Are existing color task models sufficient to measure task performance in terms of three attributes (hue, chroma, value) of colors?

Q3: Do color attributes of the color task affect the performance?

Q4: Is there any significant effect of color temperatures and color task performance on mood of participants?

The hypotheses that are formulated in response to the research questions are as follows:

H1: Color task performance is higher under 4000K compared to 2700K color temperature.

H2: A new color task implementation model is needed to measure color task performance.

H3: Among the color attributes value differentiation is effective on color task performance.

H4: There is a positive correlation between color task performance and mood.

3.2. Methodology

3.2.1. Experimental Set-up

The study was conducted in a full-scale experiment room at the department of Interior Architecture and Environmental Design at Bilkent University. The experiment room was set up as a real office room. The dimensions of the room were 4.00 m length, 4.10 m wide and 3.20 m height. Since daylight is affected from position of the sun and weather conditions, it changes throughout the day. In order to eliminate daylight factor and control the effect of artificial light on the performance of worker, windows were covered with 5mm black foam board and daylight penetration to the room was prevented. Previous studies found that wall and furnisher colors affect performance of worker (Ozturk et al., 2012). In order to control the environmental effects on the task performance, in this study sliding plywood panels were constructed on two sides of office walls which were in the visual field of the participants and painted matte neutral gray color. All the furniture and floor were covered with gray fabrics. The ceiling was painted matte white color. Any material and color in the office space generate no specular reflection.

In the experimental office room, there was an office desk with an office chair, two armchairs and one file cabinet for the folders. The layout of the office room was arranged according to participants' visual field. They saw the achromatic wall panels during the experiment. As the orientation of the worker to the task influences of the effect of veiling reflection (CIBSE,1984), the color task performance test was

conducted on 40 degrees inclined setup to establish an offending zone for reflection with the 40-degree sitting line of sight and 60-degree cone of vision (IESNA,1993).

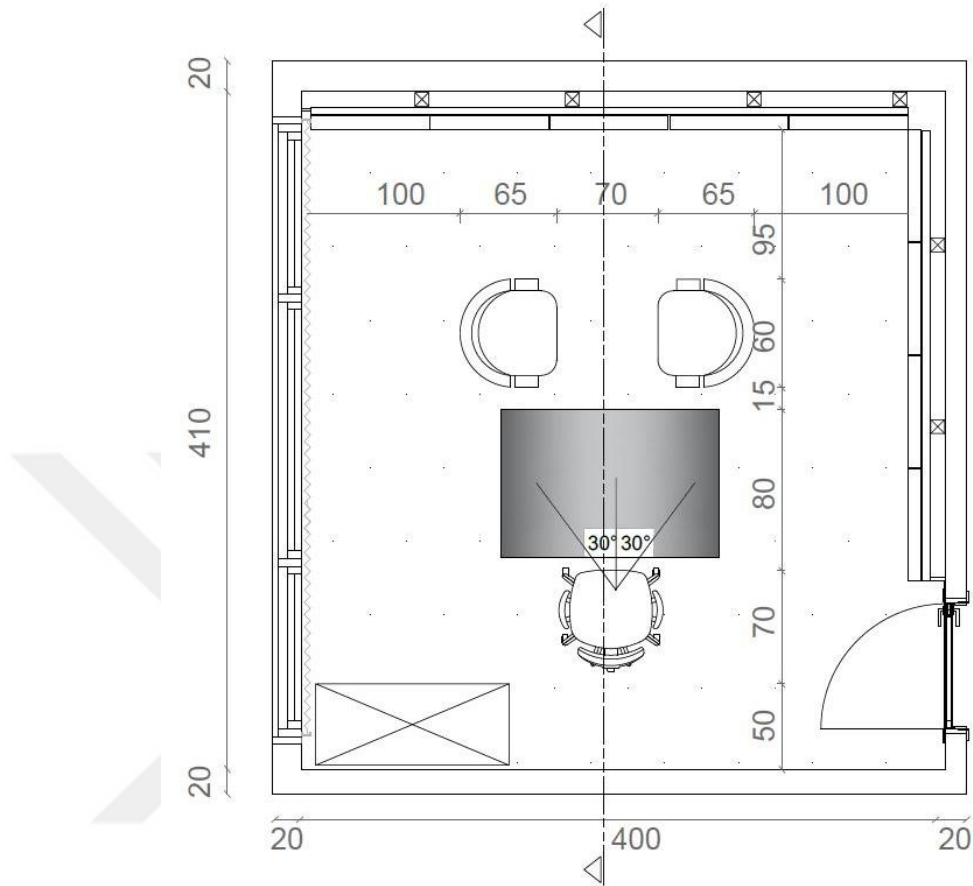


Figure 8: Plan of the experiment room

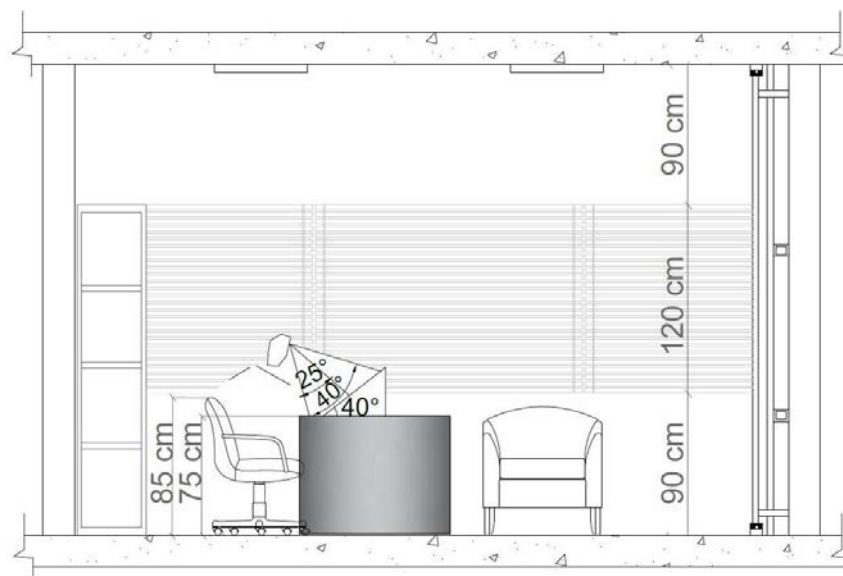


Figure 9: Section of the experiment room

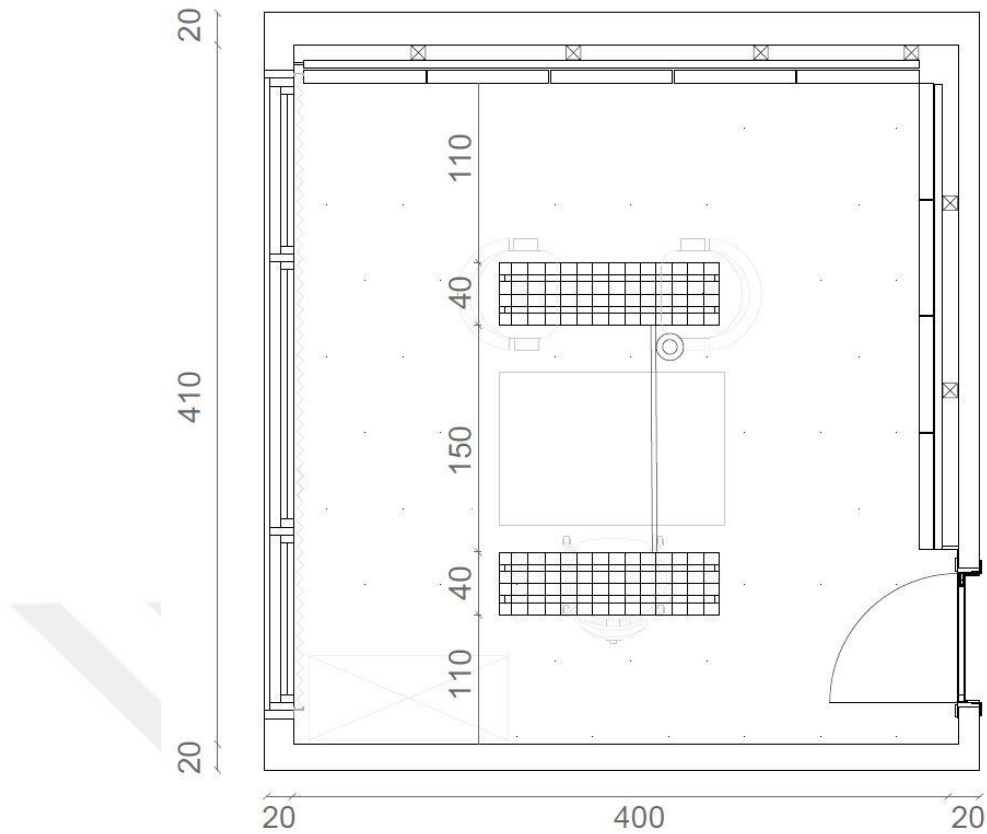


Figure 10: Reflected ceiling plan of the experiment room

The existing general direct (downward) lighting by the luminaries of recessed troffer with parabolic louvers was used as artificial lighting fixture of the room. Two fluorescent lighting fixtures were placed in the middle of the ceiling at appropriate distances to meet required illuminance levels (300-500 Lux) for office tasks (IESNA, 1993). The experiment was conducted under two lighting set-ups; four OSRAM fluorescent lamps LUMILUX T8 36W/827 (2700K warm white light) and four OSRAM fluorescent lamps LUMILUX T8 36W/840 (4000K cold white light). Both of the lighting equipment had the same luminous flux; 3100 Lm. The illuminance level was measured by using Konica Minolta T-1 Illuminance Meter Meter (range of 0.01 to 99,900 lux) on the working surface. The average illuminance value for 4000K recorded 426 lux and for 2700K was 424 lux. The SPD of fluorescent lamps

are also similar (See Figure 12, Figure 13). When accurate color judgments are necessary good color rendering index (CRI) is required. In this case, CRI should be in between 80-90 Ra (CIBSE, 1984). Both of the lighting equipment were chosen according to their CRI level which is in the good color rendering group: 1B (Ra: 80...89).

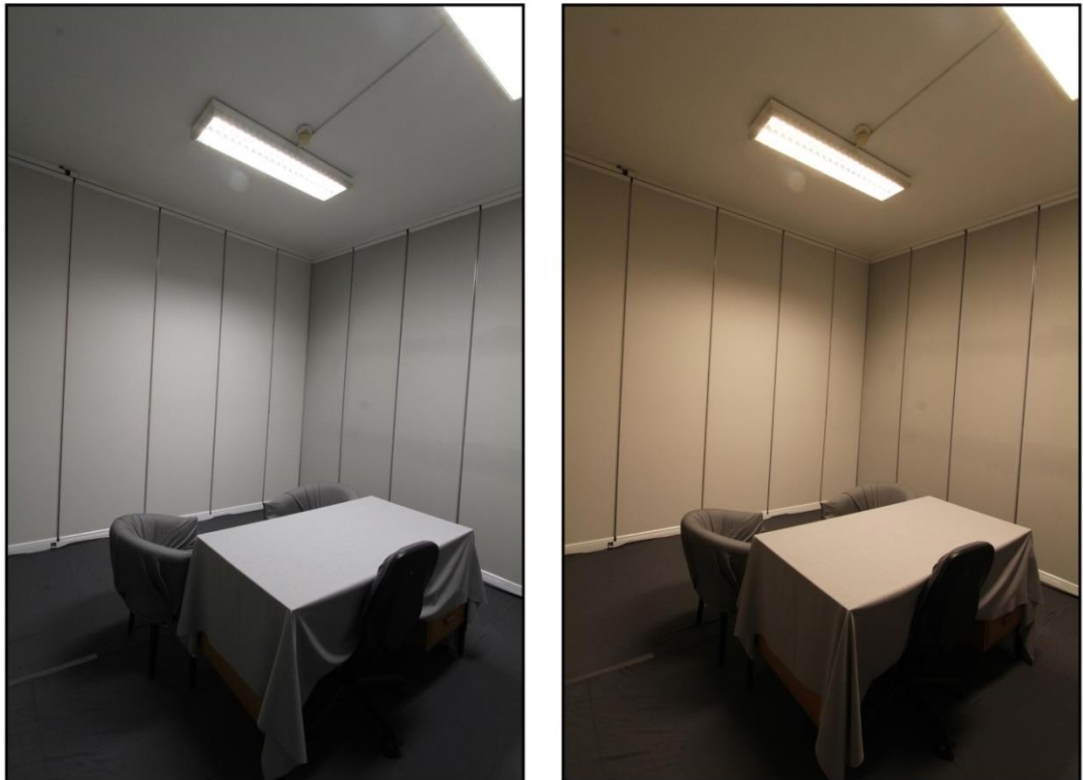


Figure 11: Office set up under 4000K (left side) and 2700K (right side) fluorescent lighting

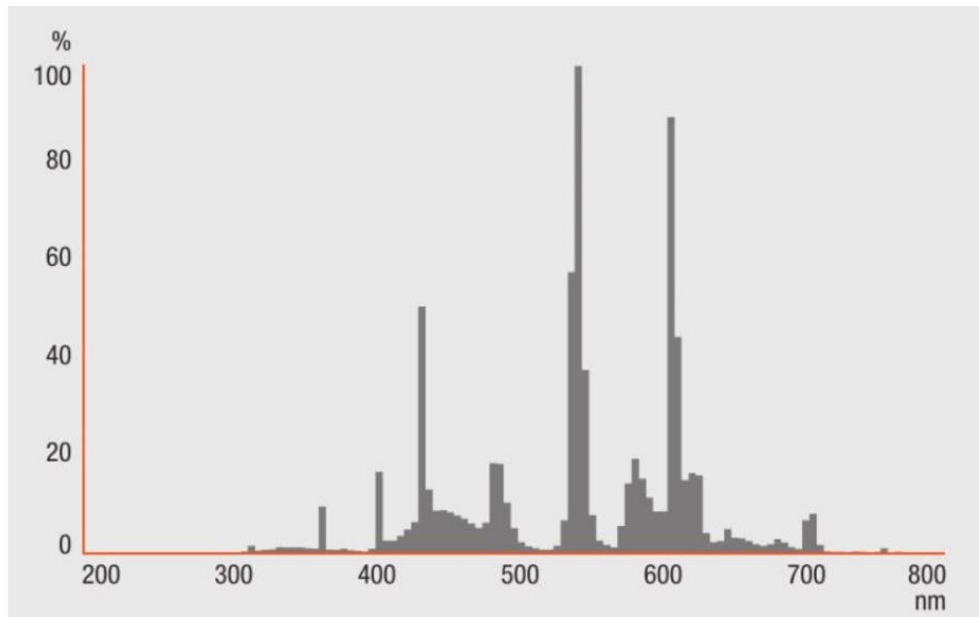


Figure 12: Spectral Power Distribution of 4000K fluorescent lamp

(Source: https://www.osram.com/osram_com/products/lamps/fluorescent-lamps/fluorescent-lamps-t8/fluorescent-lamps-t8-special-versions/lumilux-t8-1-m/index.jsp?productId=ZMP_60437)

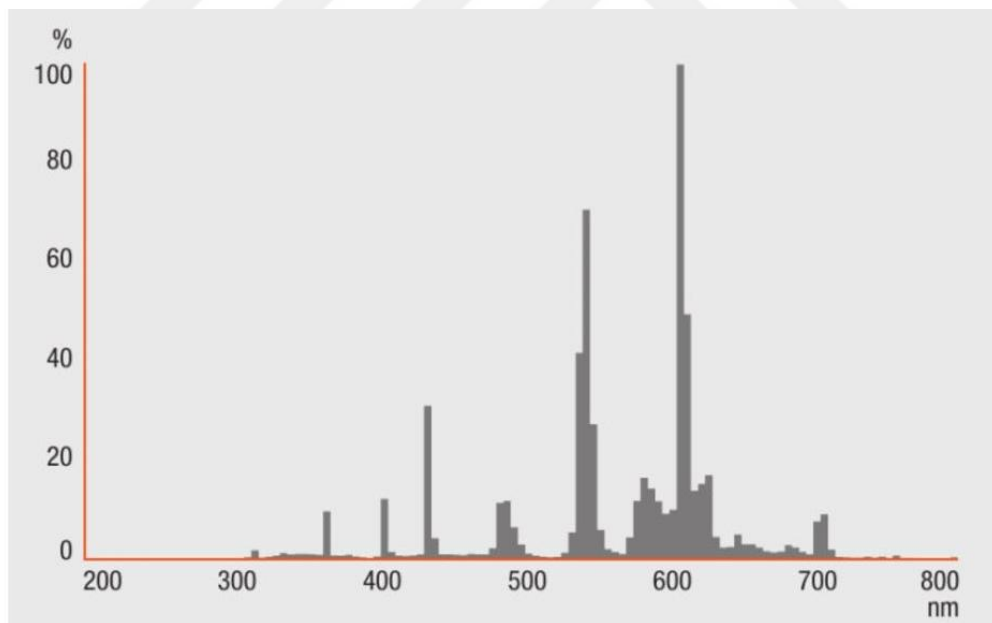


Figure 13: Spectral Power Distribution of 2700K fluorescent lamp

(Source: https://www.osram.com/osram_com/products/lamps/fluorescent-lamps/fluorescent-lamps-t8/lumilux-t8/index.jsp#)

3.2.2. Sample Group

The sample group was chosen from Department of Interior Architecture and Environmental Design at Bilkent University, Ankara, Turkey. Total of 100 students, 73 females and 27 males participated in the experiment voluntarily from the department. The mean age of participants was 23,14 ranging from 19 to 31 years. Participants carried out the task performance one by one and the color task performance and questionnaire took almost 45 minutes for each participant. Firstly, it was decided to conduct a repeated measures design; the same participant group was repeatedly tested because when separate groups carry out the experiment, individual differences among participants such as age, sex, and personal characteristics affect the results of the study and it cannot be eliminated. However, this design has a disadvantage; when the same participant group was tested once again, they may improve their performance with practice since they learn more about the task or become more familiar and relaxed in the experimental situation. The chances of the performance between the conditions are called practice effects (Shaughness et al., 2012). To control the practice effect, a counterbalancing technique was designed. In order to counterbalance practice effect, which may cause increase in speed of participants when they perform the task second time and mislead the results, order of conditions was systematically varied so that each condition was presented equally in each ordinal position (Shaughness et al., 2012).

Participants were divided randomly into two groups; half of the participants, between 1 to 50 participants, completed the color task performance at 2700K for the first time

and at least one-week period carried out the same color task at 4000K lighting setup. The other half, between 51 to 100 participants, completed the color task performance at 4000K for the first time and at least one-week period carried out the same color task at 2700K lighting setup, thus under both experimental setups, an equal number of participants involved experiment at first order without any knowledge of the task.

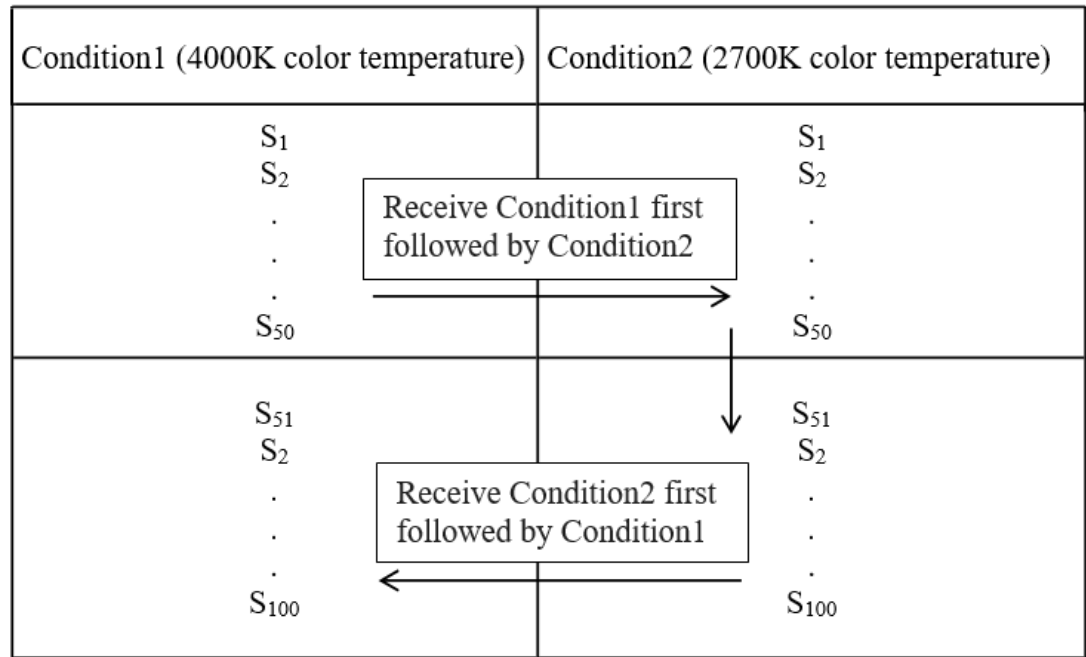


Figure 14: Order of lighting setups and participant groups

3.2.3. Experimental Procedure

The experiment was conducted in a certain order. Participants were taken to the experiment one by one and first of all Ishihara color blindness test was applied. If they had a color vision problem they could not participate in the experiment. After two-minute adaptation to the condition, surveyor gave information about the procedure of the experiment. Firstly, participants' mood was measured by Watson's

PANAS mood test. Then, participants were given the color task and asked to arrange the color chips in correct order. The color task was composed of five hue differentiation tasks, five chroma differentiation tasks and one value differentiation task. In order to eliminate practice effect, participants received the total of 11 color tasks randomly by using random number generator application. Color tasks were performed on matte Plexiglas sheet to make it easy to check the answers. Since performance is measured by speed and accuracy of task workers done and their satisfaction from their work (Gaska et al., 2016, Jiang et al., 2014, Öztürk et al., 2012), surveyor recorded both the time spent and answers. In this study, speed of task refers to the duration of the time that participants completed each color task and accuracy of task refers to the number of correct chip placement. After completing the color task performance, Watson's PANAS Mood test was repeated, OLS office lighting satisfaction test and self- satisfaction questionnaire were applied. All answers of the questionnaire were recorded by surveyor. When participants completed the experiment under first color temperature, they were appointed for the repetition of the experiment under the other color temperature. The experiment took two months started at March 15th, 2017 and finished at May 18th, 2017.

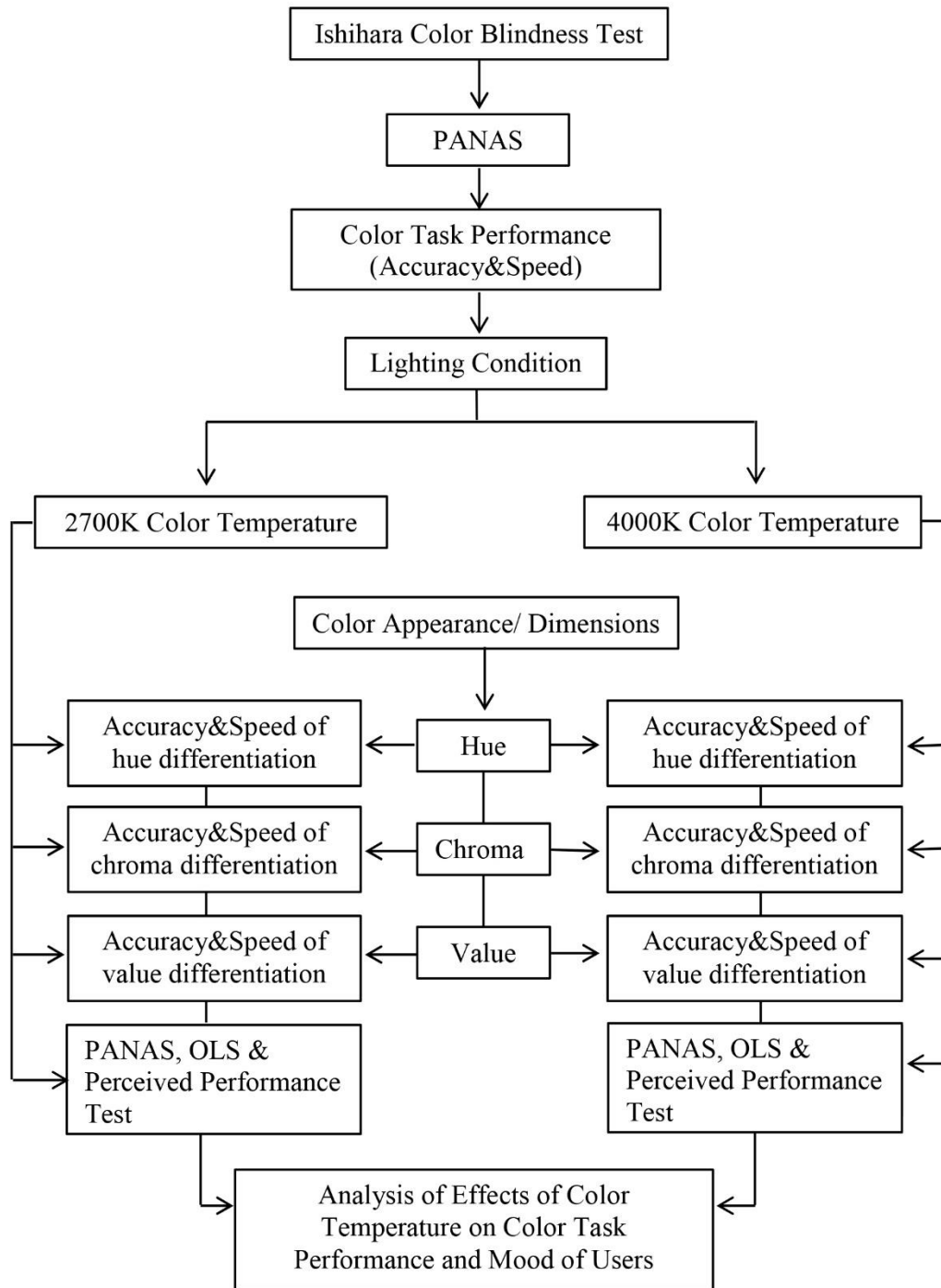


Figure 15: Schematic Illustration of the Experimental Procedure

3.2.4. Design of Experimental study

The experimental study consists of two parts; color task implementation model and questionnaires. Color task implementation model is explained under the sections of hue differentiation task, chroma differentiation task, and value differentiation task. Questionnaires are explained under the sections of Watson's mood measurement test Positive Affect Negative Affect Schedule (PANAS), self- satisfaction test by Office Lighting Survey (OLS) and perceived performance test.

3.2.4.1. Color Task Implementation Model

It is known that color temperature of lighting is highly related with task performance and affect the perception of color (Egan& Olgyay, 2002). The experiment based on two-dimensional color differentiation tasks. Since colors are perceived depending upon the recognition of three attributes which are hue (name of the color), value (lightness of color) and chroma (degree of strength of color), the color tasks were designed in order to assess how three attributes of colors are differentiated. The color tasks were prepared by using Munsell system since the participants received their basic design education based on Munsell System. Three types of color task (hue differentiation, chroma differentiation, value differentiation) were designed with Adobe Photoshop CS6, printed out high quality (600 dpi) by HP DESIGNJET Z6200 Photo Production Printer on matte paper and cut into 20 pieces with the dimensions of 2cm (length) to 4cm (height). The size of the chips was determined based on previous research which was studied unique hue selection and used color chips 2x4

cm (Shamey, 2015). In order to find out in which range color differentiation is more sensitive, each chip differs one and other 5% levels.

3.2.4.1.1. Hue Differentiation Task

In the Munsell color system, there are five Principal Hues (red, yellow, green, blue and purple) which are visually equidistant from each other. These hues divide the hue circle into five equal distances. Each principal hue has 20 steps distant to the other principal hue (Cooper, 1941). To assess hue differences, five principal hues and their evenly-graded alteration from one hue to another were used. Hue differentiation task contains five sets; red to yellow, yellow to green, green to blue, blue to purple and purple to red. Tasks assess color differentiation performance on all of the hues in the 100-hue circuit and hue differentiation sensitivity.

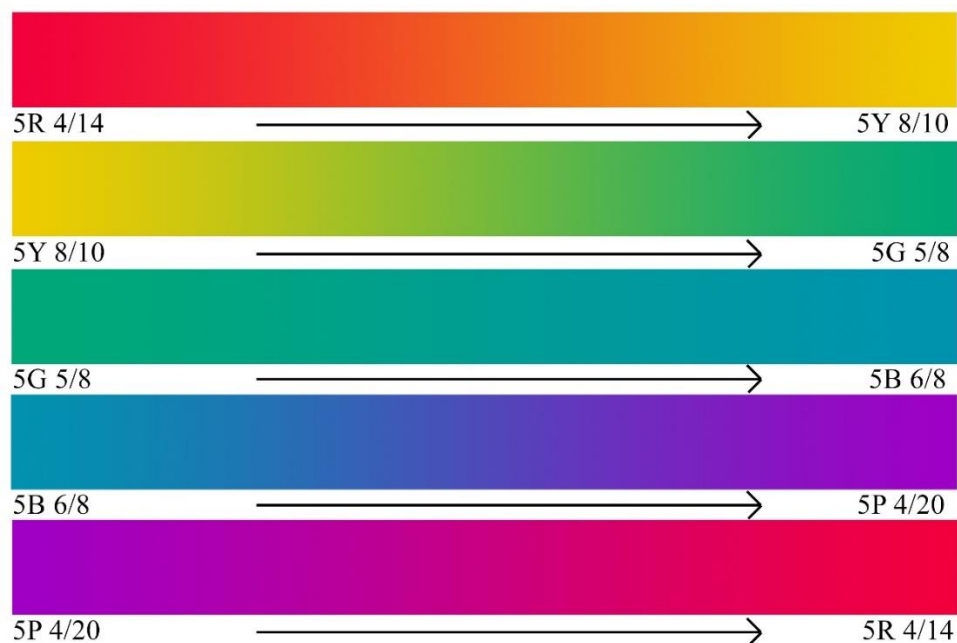


Figure 16: Hue differentiation tasks

3.2.4.1.2. Chroma Differentiation Task

Colors are classified into three main types according to chroma attribute;

Maximum/Strong Color (a color of very strong chroma), Moderate Color (found near the fourth to sixth step of chroma), Weak Color (reduced chroma found in the neighborhood of second or third steps of chroma). The strongest possible chroma varies depending on the hues, and at different levels of value. A hue reaches its maximum color at its “home” value. For example; Yellow is strongest only when it has a prominent level of lightness and it can be divided into more distinguishable steps whereas purple-blue is strongest when it has a low level of lightness (Cooper, 1941). Chroma differentiation task also contains five sets based on Principal Hues. Each set evenly-graded from maximum color to its equaled achromatic gray (home value). Tasks assess color differentiation performance and sensitivity between weak color to maximum color.

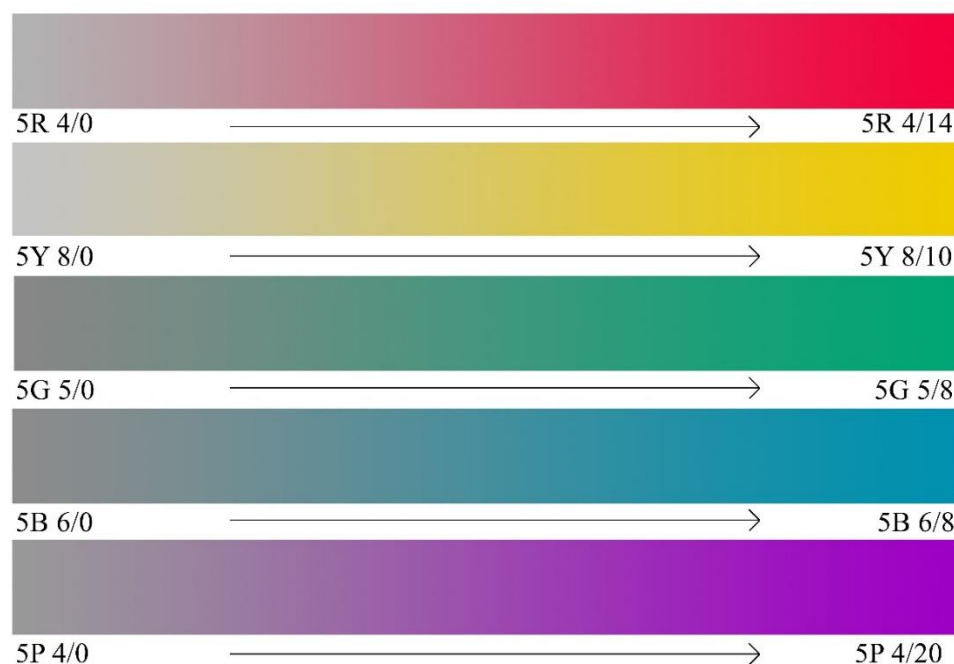


Figure 17: Chroma differentiation tasks

3.2.4.1.3. Value Differentiation Task

In the Munsell Color Sphere, the five Principle Hues are evenly distributed between black and white. The top of the Color Sphere is White and the bottom is Black, and the axis between black and white is neutral grays scale which is placed at the center of the Sphere. Since white has the full lightness level and black has the full darkness level any color can be seen in neither white nor black. But in-between darkest gray to lightest gray, there are distinguishable degrees of light strength and colors can be seen at these levels (Cooper, 1941). Value differentiation task is based on evenly-graded steps from white to black. This task also assesses color differentiation performance and sensitivity.



Figure 18: Value differentiation task

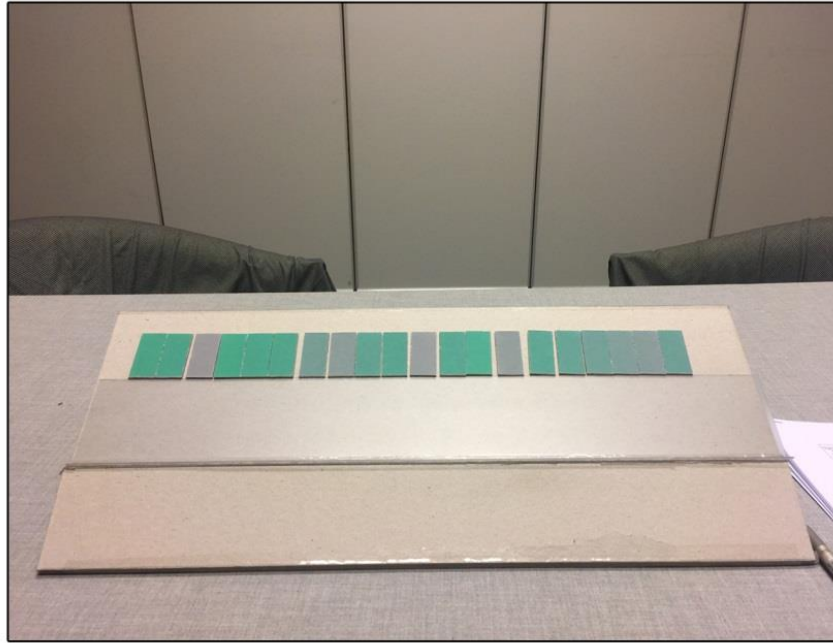


Figure 19: Example of color task administration method (random arrangement)

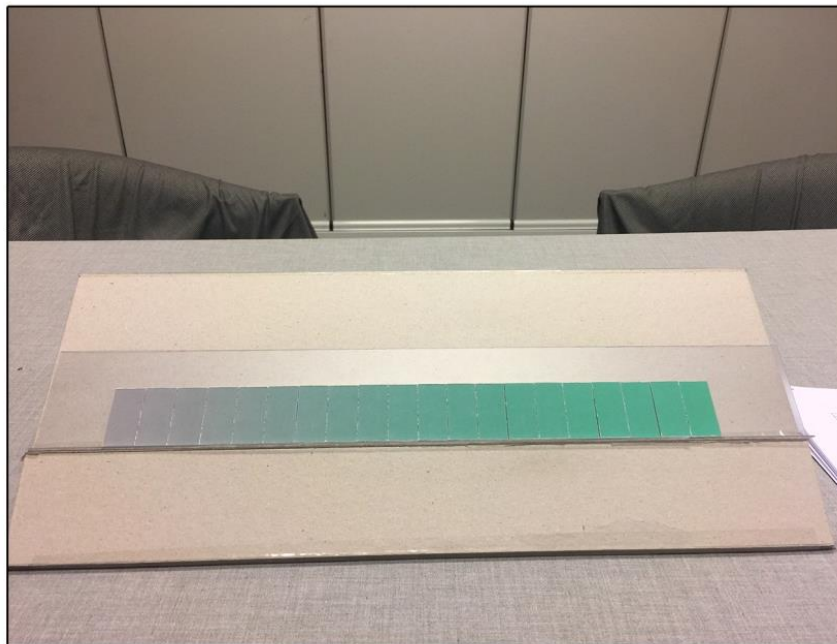


Figure 20: Example of color task administration method (correct arrangement)

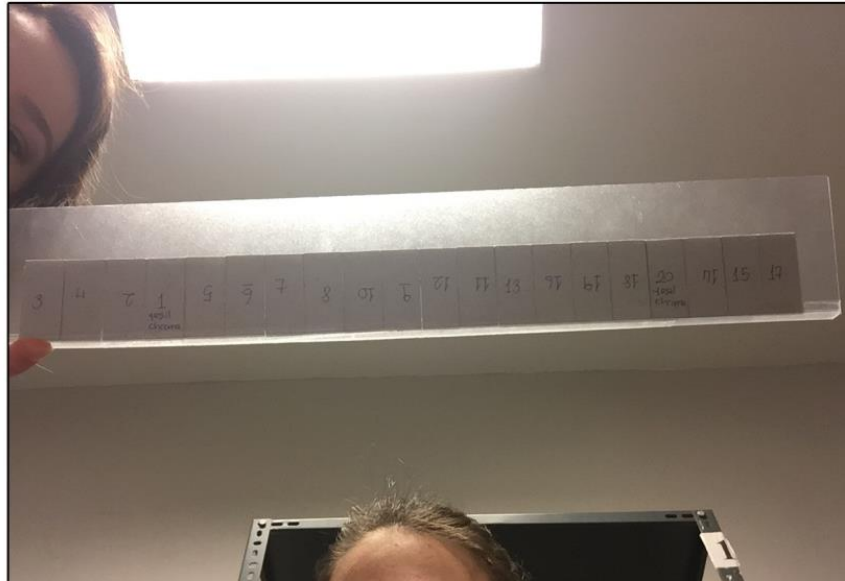


Figure 21: Example of color task administration method (checking the answers)

3.2.4.2. Questionnaire

The questionnaire consisted of three parts; Watson's mood measurement test Positive Affect Negative Affect Schedule (PANAS), self- satisfaction test by Office Lighting Survey (OLS) and perceived performance test.

3.2.4.2.1. Watson's Mood Measurement Test Positive Affect Negative Affect Schedule (PANAS)

In the literature, although there are a number of mood scales, they are showing low reliability, inadequacy, or poor convergent. Watson's PANAS (Positive Affect and Negative Affect Schedule) is a reliable, brief and easy to administer self- reported mood measurement (Gou et al., 2015; Knez, 1998; Buelow, 2015; Watson et al.,

1988). PANAS comprises two mood factors which are strongly negatively correlated with each other; Positive Affect (PA) and Negative Affect (NA). It consists of two 10-item mood scales. PA is related with the feelings of enthusiasm, activeness and alertness. NA is related with general dimensions of subjective distress and unpleasant conditions. The items of PA scale are interested, excited, strong, enthusiastic, proud, alert, inspired determined, attentive and active and the items of the NA scale are distressed, upset, guilty, scared, hostile, irritable, ashamed, nervous, jittery and afraid (See Appendix A, Figure A1). PANAS measures mood of the participant on 5-point scale which were labeled “very slightly or not at all”, “a little”, “moderately”, “quite a bit” and “extremely”. Participants’ mood was measured twice, before and after color task performance, in order to assess whether difficulty of task affected the mood or not. The mood change was measured by the difference between first and second mood score. That measurement indicates to what extent the environmental condition in the experiment moderated the mood change related to the task (Gou et al., 2015).

3.2.4.2.2. Self-satisfaction Test by Office Lighting Survey (OLS)

Office Lighting Survey (OLS) is a questionnaire-based office lighting satisfaction assessment method designed by Eklund and Boyce in 1996. The survey consists of 30 questions; seven questions about demographic information; 10 questions in agree-disagree format, eight questions 5-point scale format, two questions yes-no format and three open ended questions. The questions are based on lighting quality assessments such as lighting level, light distribution, glare, CRI and CCT, and task

satisfaction. OLS is a simple, rapid to administer and score questionnaire, and it provides considerable diagnostic information (Eklund & Boyce, 1996) (See Appendix A Figure A2, A3, A4, A5).

In the study, the questions in the survey which required being in a real office environment, required conducting a task performance different than color task such as reading, typing, and filing were not evaluated.

3.2.4.2.3. Perceived Performance Test

Perceived performance test was designed as questionnaire based test. In this test, participants were asked to evaluate their performance on the given tasks to obtain self-reports of the task under 4000K and 2700K color temperature. The test contains three 5-point scale questions to evaluate participants' expected success, self-speed and self- accuracy.

What do you think about your degree of success in the tasks you performed?	Excellent ← → 5 4 3 2 1 Poor
How do you rate your speed in the task performance?	Excellent ← → 5 4 3 2 1 Poor
How much do you think you are respond to the task correct order?	Excellent ← → 5 4 3 2 1 Poor

Figure 22: Perceived Performance Test

3.3 Findings

Statistical Package for the Social Sciences (SPSS) 23.0 was used to analyze the data of the study. Findings of the statistical analysis were given in respect to the research questions of the study (see research questions in Section 3.1.1).

In order to understand whether a parametric or non-parametric test should run, first of all, Shapiro Wilk-W test was used. It is the most powerful normality test for all sample sizes and distribution types (Razali& Wah, 2011). It assesses whether the data come from a normal distribution or not. Since all P- values of data are lower than 0.05, data are not normally distributed so non-parametric tests are used. To analyze continuous (interval/ratio) and ordinal variables, Wilcoxon Signed-Rank Test was used and to analyze dichotomous (nominal) variables, McNemar test is used. These tests investigate any change in scores when participants are subjected to more than one condition was used to compare two sets of scores. In order to compare more than two sets of scores, Friedman test is used which tests the difference between several related samples (Cramer, 1998).

In order to analyze the color task performance difference between 4000K and 2700K in an office environment, Wilcoxon Signed-Rank Test was used. Since performance is measured by speed and accuracy of task workers done and their satisfaction from their work (Gaska et al., 2016, Jiang et al., 2014, Öztürk et al., 2012, O'Donnell et al., 2011), in this study; speed of task which refers to time spent for completing each color task and accuracy of task which refers to arranging the color chips in correct order with the fewest errors were investigated.

3.3.1 Effects of Color Temperature on Color Task Performance

The effects of color temperatures on color task performance were assessed under two color temperatures; 4000K and 2700K color temperature. The results of the Wilcoxon sign-rank test showed that there is a significant difference between red chroma differentiation performances ($z = -2,188$, $p = 0,029$), green chroma differentiation performances ($z = -4,810$, $p = 0,000$), yellow chroma differentiation performance ($z = -3,180$, $p = 0,01$), red-yellow hue differentiation performances ($z = -3,652$, $p = 0,000$), green-blue hue differentiation performances ($z = -4,310$, $p = 0,000$), and blue-purple hue differentiation performances ($z = -2,214$, $p = 0,027$) in terms of accuracy. Under 4000K participants arranged the color chips in correct order more accurately compared to 2700K. Although blue chroma differentiation performance ($z = -1,94$, $p = 0,052$), Yellow-Green Hue differentiation performance ($z = -1,760$, $p = 0,078$), Purple-Red Hue differentiation performance ($z = -1,368$, $p = 0,171$), and value differentiation performance ($z = -2,214$, $p = 0,027$) were better under 4000K compared to 2700K, they were not statistically significant (See Table 1). Participants made the most correct arrangement in red chroma differentiation task under 4000K and the most wrong arrangement in purple chroma differentiation task under 2700K color temperature (See Figure 23).

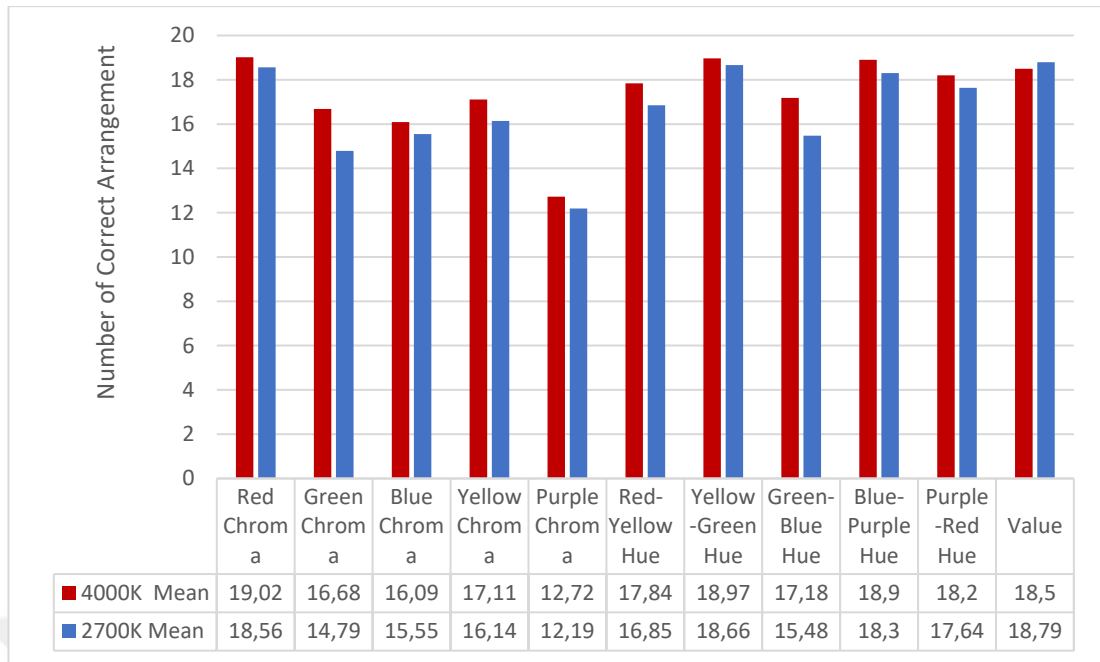


Figure 23: Bar chart of color task performance differences in terms of accuracy

In the experiment, participants spent the most time on blue-green hue differentiation performance under 4000K and the least time in value differentiation performance under 2700K color temperature (See Figure 24). When the time spent for completing each color task was compared between the color temperatures; it was found that there was no significant difference between red chroma differentiation performances ($z = -0,419$, $p = 0,675$), green chroma differentiation performances ($z = -0,169$, $p = 0,866$), blue chroma differentiation performances ($z = -1,020$, $p = 0,308$), yellow chroma differentiation performance ($z = -0,742$, $p = 0,458$), red-yellow hue differentiation performances ($z = -1,197$, $p = 0,231$), yellow-green hue differentiation performances ($z = -0,029$, $p = 0,977$), green-blue hue differentiation performances ($z = -0,772$, $p = 0,440$), blue-purple hue differentiation performances ($z = -1,515$, $p = 0,130$), purple-red hue differentiation performances ($z = -0,048$, $p = 0,962$) and value differentiation performances ($z = -0,698$, $p = 0,485$) in terms of speed of task. However, there was a

significant difference between purple chroma differentiation performances ($z=-2,004$, $p=0,045$), where the participants spent significantly more time under 2700 K compared to 4000K (See Table 1).

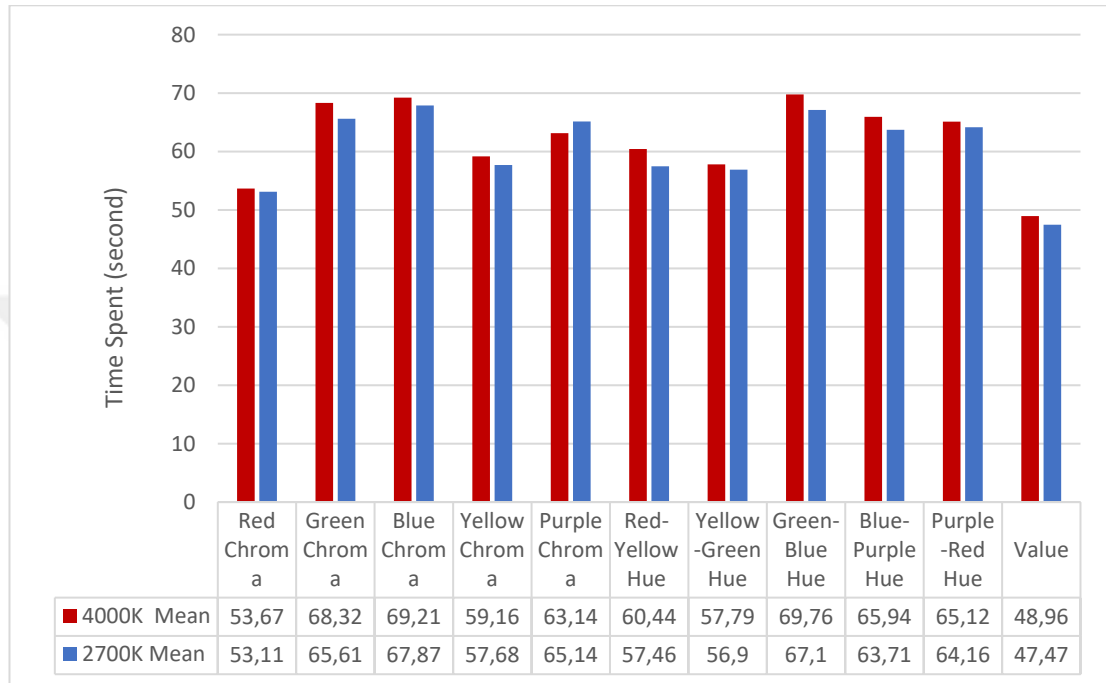


Figure 24: Bar chart of color task performance differences in terms of speed

Since task performance was evaluated as the combination of accuracy and speed of task, the results showed that participants' red, green, yellow, purple chroma differentiation performances and red-yellow, green-blue, blue-purple hue differentiation performances were better under 4000K than 2700K. However, blue chroma differentiation performance, green- yellow hue and purple- red hue differentiation performance and value differentiation performance did not show any significant change between 2700K and 4000K color temperatures.

Table 1: Statistical Comparison of Accuracy and Speed of Color Task Performances

		4000K		2700K		Wilcoxon	
		Mean	SD	Mean	SD	z	p
Red Chroma	Accuracy	19,02	1,341	18,56	1,690	-2,188 ^a	,029
	Speed (Time spent/sec.)	53,67	21,402	53,11	15,906	-,419 ^a	,675
Green Chroma	Accuracy	16,68	2,155	14,79	2,938	-4,810 ^a	,000
	Speed (Time spent/sec.)	68,32	27,162	65,61	19,652	-,169 ^b	,866
Blue Chroma	Accuracy	16,09	2,375	15,55	2,790	-1,947 ^a	,052
	Speed (Time spent/sec.)	69,21	25,014	67,87	22,847	-1,020 ^b	,308
Yellow Chroma	Accuracy	17,11	1,999	16,14	2,474	-3,180 ^a	,001
	Speed (Time spent/sec.)	59,16	21,220	57,68	17,355	-,742 ^b	,458
Purple Chroma	Accuracy	12,72	2,005	12,19	2,083	-1,646 ^a	,100
	Speed (Time spent/sec.)	63,14	39,428	65,14	26,052	-2,004 ^a	,045
Red-Yellow Hue	Accuracy	17,84	1,916	16,85	2,181	-3,652 ^a	,000
	Speed (Time spent/sec.)	60,44	23,889	57,46	18,610	-1,197 ^b	,231
Yellow-Green Hue	Accuracy	18,97	1,553	18,66	1,865	-1,760 ^a	,078
	Speed (Time spent/sec.)	57,79	21,647	56,90	19,409	-,029 ^a	,977
Green-Blue Hue	Accuracy	17,18	2,855	15,48	3,489	-4,310 ^a	,000
	Speed (Time spent/sec.)	69,76	25,975	67,10	24,632	-,772 ^b	,440
Blue-Purple Hue	Accuracy	18,90	1,474	18,30	2,298	-2,214 ^a	,027
	Speed (Time spent/sec.)	65,94	28,167	63,71	28,302	-1,515 ^b	,130
Purple-Red Hue	Accuracy	18,20	1,959	17,64	3,249	-1,368 ^a	,171
	Speed (Time spent/sec.)	65,12	26,342	64,16	24,730	-,048 ^b	,962
Value	Accuracy	18,50	1,352	18,79	1,585	-1,898 ^b	,058
	Speed (Time spent/sec.)	48,96	18,232	47,47	15,516	-,698 ^b	,485

^a based on negative ranks (scores under 2700K < scores under 4000K)

^b based on positive ranks (scores under 2700K > scores under 4000K)

When color tasks were analyzed based on the attributes of color; total hue differentiation tasks accuracy ($z=-6,232$, $p=,000$) and chroma differentiation tasks accuracy ($z=-6,426$, $p=,000$) were significantly better under 4000K compared to 2700K color temperature. Under 4000K participants made more accurate color chip arrangement compared to 2700K. However, when the color is in gray scale (value differentiation), participants distinguished the color steps better under 2700K compared to 4000K but it is not statistically significant ($z=-1,898$, $p=,058$). In terms of time spent for completing color tasks, there is no significant difference of three attributes of color between mentioned color temperatures. When accuracy and speed of the color tasks were grouped for color task performance, it can be seen that, there is a statistically significant difference in hue and chroma differentiation performance under 2700K and 4000K. Moreover, the total color differentiation performance in terms of accuracy of task is significantly better under 4000K than 2700K color temperature ($z=-8,394$, $p=,000$) but the time spent for completing all color tasks did not change significantly between the mentioned color temperatures ($z=-1,177$, $p=,239$) (See Table 2, Figure 25).

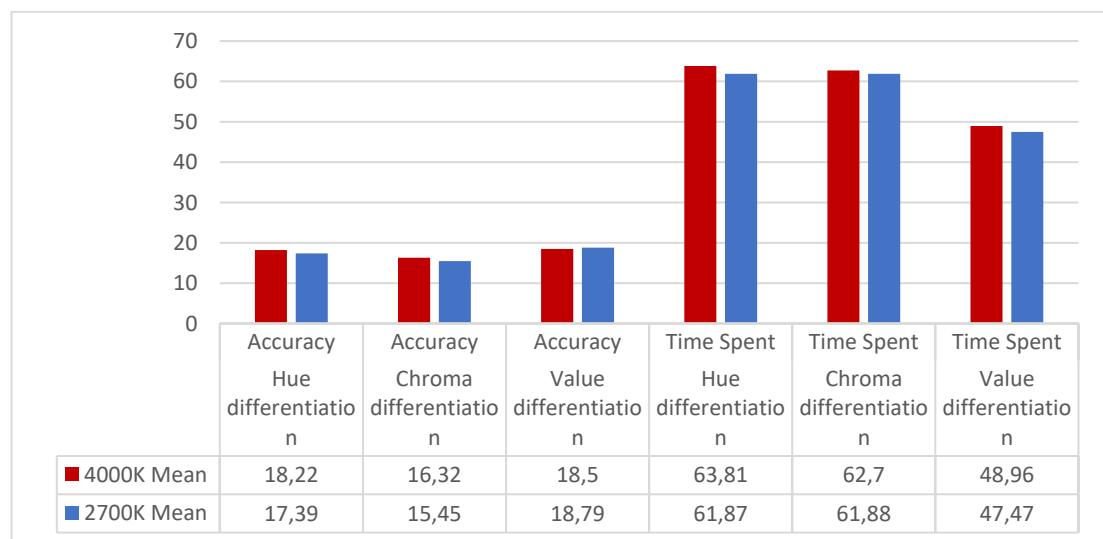


Figure 25: Color task performance differences based on attributes of color

Table 2: Statistical Comparison of 2700K and 4000K with Accuracy and Speed of Three Attributes of Color Task Performances

		4000K		2700K		WILCOXON	
		Mean	SD	Mean	SD	z	p
Hue differentiation	Accuracy	18,22	2,114	17,39	2,912	-6,232 ^a	,000
	Speed (Time spent/sec.)	63,81	25,554	61,87	23,667	-1,722 ^a	,085
Chroma differentiation	Accuracy	16,32	2,865	15,45	3,186	-6,426 ^a	,000
	Speed (Time spent/sec.)	62,70	28,158	61,88	21,351	-,282 ^b	,778
Value differentiation	Accuracy	18,50	1,352	18,79	1,585	-1,898 ^b	,058
	Speed (Time spent/sec.)	48,96	18,232	47,47	15,516	-,698 ^a	,485
Total color differentiation	Accuracy	17,38	2,619	16,63	3,164	-8,394 ^b	,000
	Speed (Time spent/sec.)	61,96	26,526	60,56	22,364	-1,177 ^b	,239

^a based on negative ranks (scores under 2700K < scores under 4000K)

^b based on positive ranks (scores under 2700K > scores under 4000K)

3.3.1.1 Color Differentiation Sensitivity

Although all of the color chips differ from each other 5% chroma, hue or value levels, their perceived differentiation were not the same. In order to understand the color differentiation sensitivity, standard deviation values were used since it assesses the average distance of each score from the average (Argyrous, 2011). Standard deviation values indicated that under 4000K color temperature; on red chroma, yellow chroma, green chroma differentiation tasks participants had difficulties in differentiating maximum colors whereas they could differentiate weak and moderate colors easily. On blue chroma differentiation task while they had difficulties in distinguishing maximum and weak color they did not have any problem of distinguishing moderate colors. The difficulties in distinguishing maximum colors were more severe than weak colors. Purple chroma differentiation task was the

hardest one for participants as they could not distinguish moderate and maximum color but they could distinguish weak colors. On the yellow- green hue differentiation task participants just had difficulties in distinguishing chips near the green color. Similarly, on the blue- purple hue differentiation task participants had difficulties in distinguishing last two chips of purple color. On the red-yellow, green-blue and purple-red hue differentiation tasks while participant distinguished intermediate hues, they had difficulties in distinguishing colors in the principal hues zone near the two ends. On value differentiation task participants had difficulties in distinguishing the chips near the black and white color.

Under 2700K color temperature; on the red chroma differentiation task participants had difficulties in differentiating maximum colors whereas they could differentiate weak and moderate colors easily. On green and blue chroma differentiation tasks they had difficulties in distinguishing maximum, moderate and weak colors. The difficulties in distinguishing maximum color were more severe than moderate and weak colors in blue differentiation task. On purple chroma differentiation task participants could not distinguish moderate and maximum color but they distinguished weak colors. On red-yellow hue differentiation task participants mainly had difficulties in distinguishing reddish colors. On the yellow-green hue, blue-purple hue and purple-red hue differentiation tasks while participant distinguished intermediate hues, they had difficulties in distinguishing colors in the principal hues zone near the two ends. Green-Blue hue differentiation task was the hardest hue task for participants; they had difficulties in distinguishing both principal and intermediate hues. Like value differentiation task performance under 4000K, participants had difficulties in distinguishing the chips near the black and white color under 2700K color temperature (See Table 4).

Table 3: Mean Values of Color Chips

Means		Chip 1	Chip 2	Chip 3	Chip 4	Chip 5	Chip 6	Chip 7	Chip 8	Chip 9	Chip 10	Chip 11	Chip 12	Chip 13	Chip 14	Chip 15	Chip 16	Chip 17	Chip 18	Chip 19	Chip 20
Red Chroma	2700K	1,03	1,97	3,00	3,99	5,01	6,00	7,00	8,00	8,99	10,01	10,99	12,00	13,00	13,96	14,94	16,07	16,81	18,17	19,35	19,65
	4000K	1,02	1,98	3,00	4,00	4,98	5,98	7,00	8,00	9,00	10,00	10,99	11,98	12,92	13,96	15,02	15,95	16,99	18,12	19,14	19,77
Green Chroma	2700K	1,15	1,95	2,98	3,94	5,01	5,99	6,98	8,08	8,98	10,16	11,09	12,09	13,38	14,05	15,12	16,21	17,52	18,27	18,55	18,50
	4000K	1,12	1,92	2,98	3,98	5,00	6,00	7,02	7,98	9,04	10,02	11,03	11,93	13,07	14,00	15,06	16,11	17,43	18,25	18,90	19,16
Blue Chroma	2700K	1,17	1,90	2,98	3,97	4,98	6,02	6,99	8,04	9,00	10,07	10,93	12,08	13,19	14,37	15,40	16,57	16,97	17,76	18,39	19,32
	4000K	1,32	1,86	2,85	3,97	5,00	6,02	6,98	8,00	9,03	9,99	11,00	12,05	13,05	14,04	15,22	16,21	17,36	18,11	18,66	19,28
Yellow Chroma	2700K	1,27	2,12	3,14	4,04	4,99	6,01	7,00	8,00	8,97	9,99	11,02	13,01	12,93	13,89	14,99	15,89	16,75	17,85	18,42	19,32
	4000K	1,06	2,06	3,00	4,00	5,00	6,00	6,99	8,01	8,98	10,03	10,99	12,01	12,99	13,90	15,13	16,15	16,90	17,94	18,88	19,60
Purple Chroma	2700K	1,01	1,99	3,00	4,00	5,02	5,99	6,99	8,14	9,26	10,15	11,37	12,39	14,49	15,42	15,55	16,52	16,53	17,12	17,36	17,70
	4000K	1,01	1,99	3,00	4,00	5,00	6,00	7,02	8,00	9,05	10,11	11,30	12,79	14,15	15,63	15,95	16,45	16,07	17,16	17,69	17,64
Red-Yellow	2700K	2,42	2,53	2,49	3,51	4,62	5,60	6,80	7,97	9,00	10,01	10,99	12,03	13,01	13,98	14,98	16,00	17,00	18,07	19,04	19,89
	4000K	1,74	1,93	2,52	3,96	4,93	5,92	7,00	8,00	9,00	10,01	11,00	12,01	12,98	14,00	15,01	15,99	17,00	18,05	19,13	19,82
Yellow-Green	2700K	1,18	2,01	2,82	3,99	5,02	6,02	6,96	8,00	9,02	10,00	10,98	12,00	13,00	14,02	14,99	16,01	17,09	18,04	19,10	19,75
	4000K	1,33	1,87	2,84	3,96	5,01	6,01	7,00	7,98	9,00	10,02	11,00	11,99	12,99	14,02	14,98	16,00	17,00	18,01	19,09	19,90
Green-Blue	2700K	1,53	1,94	2,92	3,69	5,06	5,89	6,98	7,99	9,10	9,93	11,05	12,04	13,02	14,00	15,06	16,24	16,86	18,31	19,13	19,26
	4000K	1,36	1,99	2,83	3,99	4,91	5,97	6,95	8,01	9,03	10,00	10,98	12,01	13,04	14,02	14,99	15,99	17,12	18,35	19,01	19,47
Blue-Purple	2700K	1,20	1,94	3,06	4,00	5,00	5,98	6,97	7,95	8,91	10,05	10,99	11,95	13,02	14,01	15,05	16,11	17,04	18,21	19,12	19,44
	4000K	1,03	1,97	3,00	4,00	5,01	5,99	7,02	7,98	9,00	10,05	10,95	12,02	13,02	13,97	15,04	15,95	17,06	18,05	19,16	19,73
Purple-Red Hue	2700K	1,23	1,99	2,85	3,94	5,04	6,00	6,96	7,99	9,03	10,02	11,01	11,95	13,10	13,94	15,03	16,02	17,10	18,09	18,94	19,77
	4000K	1,18	2,07	2,91	3,96	4,88	6,00	7,00	8,00	9,04	9,97	10,99	12,01	13,2	13,97	15,00	16,02	17,05	18,07	19,11	19,75
Value	2700K	1,31	2,09	2,79	3,96	5,00	6,00	7,00	8,00	9,00	9,99	11,01	12,00	13,00	14,00	14,99	15,01	16,96	19,19	19,12	19,85
	4000K	1,12	2,11	2,83	3,98	4,02	6,00	6,98	8,02	9,00	9,99	11,01	11,99	13,01	14,00	15,00	16,00	16,94	17,82	18,73	19,79

Table 4: Standard Deviations of Color Chips

Std. Deviation		Chip 1	Chip 2	Chip 3	Chip 4	Chip 5	Chip 6	Chip 7	Chip 8	Chip 9	Chip 10	Chip 11	Chip 12	Chip 13	Chip 14	Chip 15	Chip 16	Chip 17	Chip 18	Chip 19	Chip 20
Red Chroma	2700K	,171	,171	,000	,100	,100	,000	,000	,000	,100	,100	,100	,142	,142	,243	,343	,432	,581	,521	,642	,642
	4000K	,141	,141	,000	,000	,141	,141	,000	,000	,000	,000	,100	,142	,100	,281	,266	,245	,330	,414	,493	,489
Green Chroma	2700K	,435	,386	,348	,445	,225	,225	,141	,273	,426	,762	,805	,793	,1,162	,845	,1,094	,1,018	,1,359	,1,503	,1,678	,1,904
	4000K	,327	,442	,141	,141	,000	,000	,141	,141	,197	,376	,264	,383	,326	,402	,633	,549	,1,066	,1,048	,980	,1,022
Blue Chroma	2700K	,514	,362	,200	,361	,141	,141	,174	,243	,318	,383	,408	,706	,1,070	,1,178	,1,255	,1,281	,1,359	,1,215	,1,517	,1,469
	4000K	,665	,427	,458	,300	,000	,141	,141	,000	,171	,225	,201	,297	,479	,530	,894	,1,018	,1,142	,1,063	,966	,1,232
Yellow Chroma	2700K	,570	,284	,447	,281	,100	,100	,000	,000	,171	,266	,245	,174	,256	,567	,611	,946	,1,266	,1,209	,1,072	,1,122
	4000K	,239	,239	,000	,000	,000	,000	,100	,100	,171	,171	,100	,100	,100	,333	,521	,626	,971	,933	,988	,876
Purple Chroma	2700K	,100	,100	,000	,000	,141	,174	,100	,985	,1,419	,539	,1,397	,1,669	,2,389	,2,345	,2,204	,2,513	,2,181	,2,147	,2,139	,2,213
	4000K	,100	,100	,000	,000	,000	,000	,200	,000	,330	,510	,1,411	,1,597	,2,213	,2,168	,2,397	,2,249	,2,128	,2,219	,2,121	,2,342
Red-Yellow	2700K	,1,821	,1,259	,1,059	,1,141	,940	,1,146	,910	,171	,000	,100	,100	,223	,174	,284	,141	,000	,000	,256	,425	,314
	4000K	,807	,797	,549	,517	,339	,000	,000	,000	,100	,142	,174	,141	,000	,100	,100	,000	,261	,418	,411	,807
Yellow-Green	2700K	,479	,482	,479	,100	,141	,245	,197	,000	,141	,201	,141	,000	,000	,141	,174	,174	,534	,243	,503	,609
	4000K	,620	,506	,526	,281	,100	,174	,201	,141	,000	,141	,201	,174	,100	,141	,141	,000	,000	,100	,312	,302
Green-Blue	2700K	,881	,789	,734	,706	,528	,399	,200	,100	,302	,355	,386	,448	,471	,512	,617	,712	,766	,775	,950	,1,031
	4000K	,882	,611	,620	,482	,452	,460	,219	,100	,264	,246	,200	,100	,243	,284	,389	,362	,640	,702	,659	,870
Blue-Purple	2700K	,853	,694	,422	,246	,000	,200	,413	,626	,818	,359	,100	,297	,141	,225	,592	,584	,400	,640	,715	,946
	4000K	,171	,171	,000	,000	,100	,100	,141	,141	,000	,219	,219	,141	,245	,223	,243	,219	,371	,297	,507	,548
Purple-Red Hue	2700K	,566	,522	,539	,312	,243	,318	,243	,100	,171	,284	,266	,330	,389	,278	,223	,619	,503	,473	,839	,468
	4000K	,435	,607	,621	,448	,477	,000	,000	,000	,197	,223	,100	,100	,200	,171	,000	,200	,261	,517	,469	,539
Value	2700K	,615	,420	,518	,171	,000	,000	,000	,000	,000	,100	,100	,000	,000	,000	,100	,100	,197	,450	,502	,458
	4000K	,498	,424	,362	,141	,141	,000	,141	,141	,000	,100	,100	,100	,100	,000	,000	,000	,312	,458	,685	,563

Std. Deviations greater than 0.317 under 2700K

Std. Deviations greater than 0.317 under 4000K

3.3.1.2. Effects of Color Attributes on Color Task Performance

According to Munsell (1912), perception of colors depends upon the recognition of three attributes which are hue, chroma and value. Apart from the whole color appearance, the ability to see difference between the attributes of color may not be the same with each other (Holtzschue, 2012). In order to understand the difference among color attributes, Freidman Test was used. The test assesses whether there is a difference between more than two related groups or not. According to Freidman results under 4000K color temperature, there was a statistically significant difference among hue, chroma and value differentiation performance in terms of accuracy of tasks ($\chi^2(2) = 30,091$, $p = 0,000$) and in terms of time spent for task ($\chi^2(2) = 37,943$, $p = 0,000$). Similarly, under 2700K color temperature, there was a statistically significant difference among hue, chroma and value differentiation performance in terms of accuracy of tasks ($\chi^2(2) = 55,556$, $p = 0,000$) and in terms of speed of task ($\chi^2(2) = 40,246$, $p = 0,000$) (See Table 5).

Table 5: Performance Differences among Color Attributes

	Freidman Test		
	Chi-Square	<i>df</i>	<i>p</i>
4000K Accuracy	30,091	2	,000
4000K Speed (Time Spent/sec.)	37,943	2	,000
2700K Accuracy	55,556	2	,000
2700K Speed (Time Spent/sec.).	40,246	2	,000

Although Friedman test shows whether there is a difference between related groups or not, it does not show where the differences actually occur. In order to examine where the differences actually occur, separate Wilcoxon signed-rank tests were used on combinations of color attributes; Hue-Chroma, Hue-Value and Chroma-Value.

The results of the Wilcoxon sign-rank test showed that there was a significant difference between hue and chroma differentiation tasks ($z=-11,500$, $p=,000$), value and hue differentiation tasks ($z=-2,595$, $p=,009$) and chroma and value differentiation tasks ($z=-13,634$, $p=,000$) in terms of accuracy of tasks under 4000K color temperature. Value differentiation performance was the most effective one among the color attributes, which is followed by hue differentiation task, and, the worst one was chroma differentiation performance in terms of accuracy of task (See Table 6).

Also, there was a significant difference between value and hue differentiation tasks ($z=-15,713$, $p=,000$) and chroma and value differentiation tasks ($z=-15,730$, $p=,000$) in terms of speed of tasks under 4000K color temperature. However, between speed of hue and chroma differentiation tasks there was no significant difference ($z=-1,362$, $p=,173$). Participants spent least time on value differentiation task so value differentiation task was the most effective one among color attributes in terms of speed of tasks. When accuracy and speed of the color tasks were grouped for color task performance, it can be seen that the sequence of color attributes' performance was, value differentiation performance, hue differentiation performance and chroma differentiation performance under 4000K color temperature (See Table 6).

Table 6: Performance Differences among Color Attributes under 4000K Color

Temperature

	Accuracy 4000K		WILCOXON		Speed 4000K (Time Spent/sec.)		WILCOXON	
	Mean	SD	z	p	Mean	SD	z	p
Hue	18,22	2,114	-11,500 ^a	,000	63,81	25,554	-1,362 ^a	,173
Chroma	16,32	2,865			62,70	28,158		
Value	18,50	1,352	-2,595 ^a	,009	48,96	18,232	-15,713 ^b	,000
Hue	18,22	2,114			63,81	25,554		
Chroma	16,32	2,865	-13,634 ^b	,000	62,70	28,158	-15,730 ^b	,000
Value	18,50	1,352			48,96	18,232		

^a based on negative ranks

^b based on positive ranks

Similar to performance under 4000K, under 2700K color temperature; there was a significant difference between hue and chroma differentiation tasks ($z=-10,237$, $p=,000$), value and hue differentiation tasks ($z=-9,693$, $p=,000$) and chroma and value differentiation tasks ($z=-16,472$, $p=,000$) in terms of accuracy of tasks. Value differentiation performance was the most effective one among the color attributes and subsequently, hue differentiation task, the least effective one was chroma differentiation performance in terms of accuracy of task (See Table 7).

Also, there was a significant difference between value and hue differentiation tasks ($z=-15,475$, $p=,000$) and chroma and value differentiation tasks ($z=-15,227$, $p=,000$) in terms of speed of tasks under 2700K color temperature. However, between speed of hue and chroma differentiation tasks there was no significant difference ($z=-0,841$, $p=,401$). Participants spent least time on value differentiation task, therefore, value differentiation task was the most effective one among color attributes in terms of

speed of tasks. When accuracy and speed of the color tasks were grouped for color task performance, it can be seen that the sequence of color attributes performance was value differentiation performance, hue differentiation performance and chroma differentiation performance under 2700K color temperature (See Table 7).

Table 7: Performance Differences among Color Attributes under 2700K Color Temperature

	Accuracy 2700K		WILCOXON		Speed 2700K (Time Spent/sec.)		WILCOXON	
	Mean	SD	z	p	Mean	SD	z	p
Hue	17,39	2,912	-10,237 ^a	,000	61,87	23,667	-,841 ^b	,401
Chroma	15,45	3,186			61,88	21,351		
Value	18,79	1,585	-9,693 ^a	,000	47,47	15,516	-15,475 ^b	,000
Hue	17,39	2,912			61,87	23,667		
Chroma	15,45	3,186	-16,472 ^a	,000	61,88	21,351	-15,227 ^b	,000
Value	18,79	1,585			47,47	15,516		

^a based on negative ranks

^b based on positive ranks

3.3.2 Effects of Color Temperature on Mood

The effects of color temperature on mood were analyzed with Watson's mood measurement test (PANAS). The PANAS was analyzed with Positive Affect (PA) scores and Negative Affect (NA) scores. PA score was calculated by adding up positive adjectives score which can be 50 at most. NA score was calculated by adding up negative adjectives score which can be 10 at least. It was expected to get higher score from PA which shows high energy, full concentration and pleasurable

engagement and get lower score from NA which shows general attributes of subjective distress and unpleasant conditions (Watson & Clark, 1997). In order to understand the difference between before the task performance PANAS- after the task performance PANAS values, Wilcoxon signed-rank test was used. The results of the test showed that there was no significant difference between before and after PA scores ($z=-1,259$, $p=,208$) and there was a significant difference between before and after NA scores ($z=-5,314$, $p=,000$) under 4000K color temperature. According to the results, when positive mood of participants did not change significantly, negative mood of participants decreased significantly after the color task performance under 4000K color temperature (See Table 8).

Table 8: Before and After PANAS Values under 4000K Color Temperature

4000 K						WILCOXON	
	n	Mean	S.D	Minimum	Maximum	<i>z</i>	<i>p</i>
Before PA	100	31,69	7,069	15	46	-1,259 ^a	,208
After PA	100	32,51	8,096	15	48		
Before NA	100	14,24	4,918	10	34	-5,314 ^b	,000
After NA	100	12,46	3,732	10	25		

^a based on negative ranks

^b based on positive ranks

Similar to results of 4000K color temperature; the results of the Wilcoxon signed-rank test showed that there was no significant difference between before and after PA scores ($z=-0,102$, $p=,919$) and there was a significant difference between before and after NA scores ($z=-4,615$, $p=,000$) under 2700K color temperature. According to the results, when positive mood of participants did not change significantly, negative

mood of participants decreased significantly after the color task performance under 2700K color temperature (See Table 9).

Table 9: Before and After PANAS Values under 2700K Color Temperature

2700 K						WILCOXON	
	n	Mean	S.D	Minimum	Maximum	<i>z</i>	<i>p</i>
Before PA	100	31,52	7,676	13	48	-,102 ^a	,919
After PA	100	31,33	8,291	11	48		
Before NA	100	15,01	5,357	10	35	-4,615 ^b	,000
After NA	100	13,58	5,941	10	37		

^a based on negative ranks

^b based on positive ranks

In order to analyze which PANAS items were perceived significantly different before and after the color task performance, Wilcoxon signed-rank test was used. According to test results, under 4000K color temperature, participants' negative mood of distressed ($p=,000$), irritable ($p=,000$), ashamed ($p=,025$), nervous ($p=,050$) and afraid ($p=,008$) decreased significantly; positive mood of alert ($p=,031$), attentive ($p=,000$) and active ($p=,008$) increased significantly. Under 2700K color temperature, negative mood of distressed ($p=,000$), upset ($p=,000$), irritable ($p=,011$), nervous ($p=,014$), and jittery ($p=,025$) decreased significantly; while positive mood of excited ($p=,018$) increased significantly and determined ($p=,010$) decreased significantly. As a result, the change of positive mood under two color temperatures showed 4000K affected participants' mood in a positive way since 4000K color temperature aroused positive moods more than 2700K (See Table 10).

Table 10: Statistical Comparison of 4000K and 2700K PANAS Values

		Wilcoxon signed-rank test					
		4000K			2700K		
		Mean	Difference	Sig.	Mean	Difference	Sig.
Interested	Before	3,84	0,10	,274	3,65	0,12	,287
	After	3,74			3,53		
Distressed	Before	2,17	0,63	,000	2,50	0,63	,000
	After	1,54			1,87		
Excited	Before	3,00	0,09	,528	2,66	-0,28	,018
	After	2,91			2,94		
Upset	Before	1,72	0,19	,069	1,86	0,35	,000
	After	1,53			1,51		
Strong	Before	3,28	0,14	,093	3,19	0,11	,270
	After	3,14			3,08		
Guilty	Before	1,12	0,01	,739	1,13	0,02	,763
	After	1,11			1,11		
Scared	Before	1,17	0,07	,178	1,12	-0,05	,448
	After	1,10			1,17		
Hostile	Before	1,09	0,05	,380	1,11	0	1,000
	After	1,04			1,11		
Enthusiastic	Before	3,51	0,13	,127	3,28	0,05	,606
	After	3,38			3,23		
Proud	Before	2,91	-0,2	,086	3,02	-0,03	,536
	After	3,11			3,05		
Irritable	Before	1,66	0,32	,000	1,71	0,25	,011
	After	1,34			1,46		
Alert	Before	2,78	-0,25	,031	2,72	- 0,13	,350
	After	3,03			2,85		
Ashamed	Before	1,29	0,19	,025	1,18	- 0,06	,312
	After	1,10			1,24		
Inspired	Before	2,84	-0,07	,771	2,88	0,04	,650
	After	2,91			2,84		
Nervous	Before	1,46	0,15	,050	1,59	0,1	,014
	After	1,31			1,44		
Determined	Before	3,16	-0,07	,620	3,35	0,28	,010
	After	3,23			3,07		
Attentive	Before	3,15	-0,43	,000	3,43	- 0,04	,547
	After	3,58			3,47		
Jittery	Before	1,35	0,04	,648	1,63	0,21	,025
	After	1,31			1,42		
Active	Before	3,22	-0,26	,003	3,34	0,07	,354
	After	3,48			3,27		
Afraid	Before	1,21	0,13	,008	1,18	-0,07	,314
	After	1,08			1,25		

3.3.3 Effects of Color Temperature on Self- Satisfaction

The effects of color temperature on self-satisfaction were analyzed with Office Lighting Survey (OLS). OLS assesses the user satisfaction from lighting condition with dichotomous (nominal) variables and ordinal variables. To compare dichotomous variables under two color temperatures McNemar test was used. The test mainly examines the number of cases which changes the answer in one condition to the other. McNemar test calculates the p-values either exact p- value or asymptotic p-value depending on the number of discordant pairs in crosstabulation table (Cramer, 1998). To compare ordinal variables Wilcoxon Signed-Rank Test was used.

According to McNemar Test results, there was a significant difference between perceived comfort under 4000K and 2700K color temperature ($\chi^2(2) = 6,894$, $p = 0,009$). Participants worked more comfortable under 4000K compared to 2700K. While 33 participants evaluated 4000K color temperature as comfortable and 2700K as uncomfortable, 12 participants evaluated 2700K color temperature as comfortable and 4000K as uncomfortable for working activity (See Appendix C Table C1). Both color temperatures have the same illuminance values and their brightness levels were not perceived as uncomfortably bright ($\chi^2(2) = 3,361$, $p = 0,067$), whereas 2700K was perceived as uncomfortably dim compared to 4000K color temperature ($p=0,000$) significantly. 19 participants evaluated 4000K color temperature as not uncomfortably dim whereas they evaluated 2700K as uncomfortably dim (See Appendix C Table C1). Perceived skin tone was also significantly different under 4000K and 2700K color temperatures ($\chi^2(2) = 42,561$, $p = 0,000$). Although both

fluorescent lamps had the same CRI, while under 4000K CCT 60 participants evaluated their skin tone as natural, under 2700K color temperature they evaluated it as unnatural. They emphasized that under 2700K their skin color seemed more yellowish than real tone (See Appendix C Table C1). There was also a significant difference in color distinguishing difficulty between 4000K and 2700K color temperatures ($\chi^2(2) = 28,983$, $p = 0,000$). While 50 participants had difficulties distinguishing between colors under 2700K, they reported that they did not have problem under 4000K color temperature (See Appendix C Table C1). Since color task performance was conducted in the same location and illuminance level was also the same (selected according to recommendation value for workspaces), there was no significant difference in lighting distribution ($\chi^2(2) = 3,704$, $p = 0,054$), perceived shadows on task ($p=0,143$), and reflection from the light that hinder the work ($p=0,523$) between 4000K and 2700K color temperatures (See Table 11).

Table 11: Self-Satisfaction Comparison of 4000K and 2700K by McNemar Test

	McNemar Test
	<i>P</i> value
Overall lighting is comfortable	,009
The lighting is uncomfortably bright	,067
The lighting is uncomfortably dim	,000^a
The lighting is poorly distributed	,054
The lighting causes deep shadows	,143 ^a
Reflection from the light fixture hinder my work	,523 ^a
My skin is an unnatural tone under the lighting	,000
Do you have difficulty distinguishing between colors?	,000

^a Binomial distribution used/ exact p value

According to Wilcoxon Test results, there was a significant difference between rating of electrical lighting under 4000K and 2700K color temperatures ($z=-3,315$, $p = 0,001$). While 67 participants rated 4000K color temperature as more than neither bad nor good (give 4-5 out of 5), 39 participants rated 2700K color temperature as more than ‘neither bad nor good’ (See Appendix Table C2). There was a significant difference between satisfaction levels from the lighting of the office under 4000K and 2700K color temperatures ($z=-4,162$, $p = 0,000$). Under 4000K, 63 participants and under 2700K, 38 participants evaluated their satisfaction from the lighting as ‘fairly satisfied’ and ‘very satisfied’ (See Appendix Table C4). Although both fluorescent lamps have the same illuminance values, there was a significant difference in perceived amount of light ($z=-3,159$, $p = ,002$) and amount of light appraisal ($z=-3,464$, $p = ,001$) under 4000K and 2700K color temperatures. Under 4000K, 56 participants and under 2700K, 40 participants evaluated the amount of light as ‘just about right’ (See Appendix Table C5) and under 4000K, 76 participants and under 2700K, 55 participants evaluated the amount of light as ‘good’ and ‘excellent’ (See Appendix C Table C6) (See Table 12).

Table 12: Self-Satisfaction Comparison of 4000K and 2700K by Wilcoxon Test

	WILCOXON	
	<i>z</i>	<i>p</i>
Electrical Lighting (1=Bad, 5=Good)	-3,315 ^a	,001
Glare from lights (1=high glare, 5=no glare)	-1,798 ^a	,072
Overall, how satisfied are you with the lighting at the office (1=not at all satisfied, 5=very satisfied)	-4,162 ^a	,000
How would you describe the amount of light available to you? (1=much too dim, 5=much too bright)	-3,159 ^a	,002
Would you say that the amount of light for the work that you do? (1=poor, 4=excellent)	-3,464 ^a	,001

^a based on negative ranks

^b based on positive ranks

3.3.4 Effects of Color Temperature on Perceived Performance

In order to analyze perceived performance difference between 4000K and 2700K, Wilcoxon Signed-Rank Test was used. The perceived performance results of participants showed that there was a significant difference in expected success ($z=-2,060$, $p=,039$) and expected accuracy ($z=-2,103$, $p=,035$) between 4000K and 2700K color temperatures (See Table 12). Under 4000K, 62 participants and under 2700K, 55 participants evaluated their expected success as ‘good’ and ‘excellent’ (See Appendix C Table C7). Under 4000K, 57 participants and under 2700K, 54 participants evaluated their expected accuracy as ‘good’ and ‘excellent’ (see appendix table). There was no significant difference in expected speed of task between mentioned color temperatures ($z=-1,490$, $p=,136$) (See Appendix C Table C7) (See Table 13).

Table 13: Perceived Performance Comparison between 2700K and 4000K

(1=Poor, 5=Excellent)	WILCOXON	
	<i>z</i>	<i>p</i>
What do you think about your degree of success in the tasks you performed?	-2,060 ^a	,039
How do you rate your speed in the task performance?	-1,490 ^a	,136
How much do you think you are respond to the task correct order?	-2,103 ^a	,035

^a based on positive ranks

3.4 Discussion

In this study, a color task implementation method was proposed to assess the effects of color temperature on user's performance and mood. In order to measure the performance, a color task implementation method was designed and to assess the effects of color temperatures and task performance on users' mood, Watson's PANAS mood measurement test utilized. In the literature, the luminous environment was investigated in terms of its effects on task performance and mood of workers in the office environment. Also, fundamentals of color, color and light relationship, and effects of lighting on color task performance were examined.

As it was mentioned previously, among a series of color temperatures, literature findings showed that 4000K has been preferable color temperature for reading-based performance in office environment. The results revealed that the accuracy of performances differs significantly under 2700K and 4000K while the speed of color task performances have no significant difference under the mentioned color temperatures. Effects of color temperatures on color task performance, mood, participants' self-satisfactions and perceived performances were discussed. In addition to that, impact of color attributes (hue, chroma, and value) on color task performance was also examined.

In this study, under 4000K participants made more accurate arrangements for all hue differentiation tasks, all hue differentiation tasks, and value differentiation task compared to 2700K. However, the difference in accuracy between 4000K and 2700K

color temperatures was significant in red, green, yellow chroma differentiation tasks and red-yellow, green-blue, blue- purple hue differentiation tasks. The time spent for completing each color task comparison did not show any significant difference between mentioned color temperatures (except purple chroma differentiation task). Under 2700K, participant spent more time for completing purple chroma differentiation task. Accuracy and speed of task combination was evaluated as task performance; whereas red, green, yellow, purple chroma differentiation performances and red-yellow, green-blue, blue-purple hue differentiation performances were better under 4000K compared to 2700K color temperature, blue chroma differentiation performance, green- yellow hue and purple- red hue differentiation performance and value differentiation performance did not change significantly between the color temperatures.

Although Knez (1998) found no significant difference between 3000K and 4000K color temperatures in terms of cognitive performance, it was stated by Manav (2007) and later supported by Park et al. (2010) 4000K was the most preferred color temperature. Manav (2007) compared the effects of two different color temperatures; 2700K and 4000K, while Park et al (2010) reported the results of three subjective evaluations of different color temperatures on work performance. The study, conducted by Shamsul et al. (2013) found that in terms of typing performances (performance refers to the speed and accuracy of processing visual information), subjects performed significantly better under 4000K and 6200K color temperatures than 2700K color temperature in terms of speed of task. Besides, less typing errors were made under 6200K and followed by 4000K color temperature. It was stated that 4000K and 6200K lightings were more beneficial for computer-based tasks in office

environments. A similar study, conducted by Sivaji et al (2013), found that computer-based typing task performances were not significantly differed among 2700K, 4000K, and 6200K color temperatures. Additionally, according to Kraneburg et al. (2017) study, visual performance based on color differentiation (FM-100 hue test) performance was increasing in between 1600K to 6100K color temperatures and decreasing in between 6100K to 14000K color temperatures. That is, they found that the visual performance was better under 3900K than 2750K color temperature.

The result of this study; effects of the color temperatures on task performance are associated with studies in the literature except the studies conducted by Knez (1998) and Sivaji et al., (2013). However, in the literature, it was also stated that a properly designed luminous environment increases visibility of task thus increases the task performance (Van Bommel & Van den Beld, 2004; Boyce, 2006). According to Hong et al. (2017), particular color temperatures enable colors to be more visible. They state that under lower color temperatures red, red-yellow, and yellow colors have good color visibility whereas, under higher color temperatures green-yellow, green, blue, blue-green, and purple colors have good color visibility. The results of this study found that red, red-yellow and yellow colors performance were also better under 4000K compared to 2700K color temperature of light. Additionally, when color tasks are analyzed based on the attributes of color, it was revealed that, total hue differentiation tasks performance and chroma differentiation tasks performance were significantly better under 4000K compared to 2700K color temperature whereas there was no significant difference in value differentiation task between mentioned color temperatures.

In this study, the accuracy refers to the number of correct color chips arrangement. When someone misplaced first and second color chips, they had the same number of correct arrangement with who misplaced first and fourth color chips. Although the number of correct chips was the same, the magnitude of the errors was not. In order to assess the magnitude of error, each arrangement of the color chips was supposed as a vector. The errors in vectors are generally expressed in terms of norms and Euclidean norm is often known as the magnitude (Gentle, 2007). With the Euclidean norm, the distance between the wrongly arranged vector and correctly arranged vector was calculated which refers to the magnitude of error. It was calculated utilizing the MATLAB 13.0 software. When accuracy identified as the magnitude of errors, the effects of color temperatures on task performance results showed that red, green and yellow chroma differentiation performances and red-yellow, green-blue, blue-purple hue differentiation performances were better under 4000K compared to the 2700K color temperature. There was no significant difference in blue and purple chroma differentiation performances, green- yellow hue, and purple- red hue differentiation performances and value differentiation performance between the color temperatures (See Appendix C Table C8). The effects of color temperatures on color task performance results were similar in terms of the number of correct arrangement and magnitude of errors. Both of the results approved that color task performance is higher under 4000K compared to 2700K color temperature. Therefore, H1: “Color task performance is higher under 4000K compared to 2700K color temperature” is not rejected.

The color tasks investigated in the literature review were generally based on color discrimination performance which were analyzed by Farnsworth- Munsell 100- hue

test. The arranging set of colors in the FM 100 test have the same value and chroma levels and the test just assesses hue differentiation ability (Cranwell et al., 2015) and colors are perceived accurately depending on recognition of three attributes (Cooper, 1941; Nassau, 1997). For this reason, it was hypothesized that a new color task implementation was needed to be designed for measuring color task performance. The new color task implementation had the ability to assess color differentiation performance of three attributes of colors. Therefore, H2: “A new color task implementation model is needed to measure color task performance” is not rejected.

In this dissertation, the impact of color attributes (hue, chroma, and value) on color task performance was also examined. As stated by Melgosa et al., (2000) in the literature, the ability to distinguish color attributes are not the same. Among the color attributes, chroma is the most hardly differentiated one and the value is the most easily differentiated one independent of the difference's size. Hue is distinguished easily if the differences are in large scale. This study approved that, there are significant differences between hue, chroma and value tasks in terms of accuracy of task. Although in each type of color task, color chips differed from each other 5% hue, chroma or value step, the differentiation performances were not the same. The participants made significantly more accurate arrangement during value differentiation task. The sequence of color attributes performance was; value differentiation performance, hue differentiation performance, and chroma differentiation performance under both 4000K and 2700K color temperatures. Therefore, H3: “Among the color attributes value differentiation is effective on color task performance” is not rejected.

Also, in the literature, Melgosa et al. (2000) states that yellow color differences are recognized more difficult compared to other colors. However, in this study, purple color differentiation performance was found as the most difficult one under both color temperatures. Almost all participants complained about purple color.

Moreover, this study explored the effects of color temperatures on user's mood.

Under both color temperatures after the exposure of light and task performances, whereas PA scores of participants did not change significantly, NA scores decreased significantly. When each PANAS items were compared before and after the exposure of light and task performance, the results showed that under 4000K color temperature, there was significant decrease in distressed (NA), irritable (NA), ashamed (NA), nervous (NA), and afraid (NA) moods and significant increase in alert (PA), attentive (PA), and active (PA) moods. Under 2700K color temperature, there was significant decrease in distressed (NA), upset (NA), irritable (NA), nervous (NA), jittery (NA), and determined (PA) moods and significant increase in excited (PA) mood. Consequently, the change of positive mood under two color temperatures showed 4000K affected participants' mood in a positive way. In terms of effects of different color temperatures on mood, there are a number of studies in the literature. A study which was conducted by Knez and Enmarker (1998), investigated the effects of office lighting on subjects' mood, cognitive performance among the gender and found that preservation of positive mood and decrease in negative mood was observed under 3000K for male participants and under 4000K for female participants. Another study, conducted by Park et al., (2010) stated that under higher color temperature conditions; participants were more alive, concentrative, and tensioned and less sleepy, tedious, and undesirable compared to lower color

temperature conditions. Similarly, Shamsul et al. (2013) found that subjective alertness level was significantly decreased under 2700K. Gou et al., (2015) compared the effects of naturally lit and artificially lit (by 4000K light) environments on participants' mood and task performance. Results showed that although naturally lit environment gave a better first impression of space, after the application of task performance, 4000K artificial lighting generated higher Positive Affect (PA) and lower Negative Affect (NA) compared to natural lit environment. The studies in the literature review support the findings of this dissertation about the effects of color temperatures on mood of users. Therefore, H4: "There is a positive correlation between color task performance and mood" is not rejected.

As given in the results, although, both of the color temperatures have the same illuminance values and their brightness levels were not perceived as uncomfortably bright, 2700K was perceived as uncomfortably dim compared to 4000K color temperature. Participants were more satisfied with 4000K compared to the 2700K color temperature. Also, participants evaluated 4000K color temperature significantly more comfortable for work performance compared to 2700K color temperature. In terms of effects of lighting on satisfaction and comfort, there are a number of studies in the literature. It is found that there is a correlation between color temperature of lighting and brightness perception. In an early study conducted by Harrington (1954), it was stated that higher color temperature conditions generate the higher brightness perception in comparison of 3000K, 3500K and 4000K. The later studies, conducted by Ju et al. (2012) and Wei et al. (2014) support Harrington's study and found that higher color temperatures were perceived brighter than the lower ones. The results of another study showed that combination of 3000K and

more than 500 lux illumination levels causes visual discomfort by glare and brightness. A combination of 500 lux and 6500K color temperature, and 500-750 lux and 4000K color temperature were evaluated as better for visual satisfaction in workplaces (Lee et al., 2014). Besides, the study conducted by Manav (2007) showed that for the impression of spaciousness and comfort, 4000K was preferred, and for relaxation 2700K was preferred. According to Shamsul et al. (2013), 6200K color temperature was more comfortable color temperature compared to 4000K and 2700K, but 4000K was the most preferred one for office lighting. Similarly, Sivaji (2013) found that 4000K color temperature is the most comfortable and preferred color temperature for workplaces. The results of the studies in the literature and this study are compatible in terms of brightness perception and comfort.

Additionally, the participants reported that the effect of 4000K was significantly higher on their performances. It was found that expected success and reported accuracy are better under 4000K compared to 2700K color temperature, and there was no significant difference in reported speed between the color temperatures. Similar results have also been obtained by Shamsul et al. (2013) that suggests subjects can work longer time under 4000K color temperature. In this study, no significant difference between 2700K and 4000K for the participants' reported speed was observed. There was a strong association between participants' performance and their expected success. As it was mentioned before, the color task performance results showed that accuracy of tasks were significantly higher compared to 2700K color temperature and there was no significant difference in speed of tasks between the color temperatures. The results of the perceived performance were correlated with the results of the task performance.

CHAPTER IV

CONCLUSION

The effects of color temperatures on user's performance and mood were investigated in full- scale experimental office environment. The experiment was conducted under 2700K and 4000K color temperatures. In order to measure the performance, a color task implementation method was used. The studies in the literature state that colors are perceived depending upon three attributes which are hue, chroma and value. The change in each attribute generates a new color. The ability to recognize the difference between the attributes of color may not be the same (Holtzschue, 2012). Therefore, in this study three types of color tasks (hue, chroma and value differentiation tasks) were used to explore the effects of lighting on color task performance. In the study, it was also explored that the impact of color temperatures on users' mood, self-satisfaction and perceived performances by questionnaires which consisted of Watson's PANAS mood measurement test, OLS and perceived performance test.

Most of the previous studies on effects of color temperatures on task performance were focused on computer or paper based reading and typing task. On the other hand, if a color task was performed, FM-100 hue differentiation test was used which explored only hue differentiation ability. Also, it was important that in the office spaces, performance was not the only parameter that should be considered. Task performance, mood, comfort and personal satisfaction are directly related with each other and have the same significance level. This study showed that colors should be assessed with their attributes and, effects of color temperatures on visual task performance should be taken into consideration not only from physiologically but also in psychologically point of view.

In terms of physiological view, the results of the study explored that color temperatures affect color task performance significantly in terms of accuracy of task. 4000K lighting enables users to differentiate hue and chroma attributes of color significantly better than 2700K color temperature. However, in the value differentiation performance, there was no significant difference found between the color temperatures. Additionally, apart from the color temperature, in terms of the effects of color attributes on task performance, it was found that chroma was the hardest differentiated color attribute whereas value was the easiest one. In terms of psychological view, it was found that 4000K generated more positive mood than 2700K color temperature. After exposure to 4000K participants became more alert, attentive and active. Also, participants evaluated 4000K color temperature as more comfortable than 2700K. 2700K lighting was evaluated uncomfortably dim so users preferred 4000K for working activities.

Although the study reached its aims, it has some limitations. First of all, the experiment was conducted in a full-scale office environment and had some differences from a real one and participants were not real office workers. Therefore, for future studies, the experiment can be conducted in a real office environment. In this study, just 2700K and 4000K color temperatures were tested. Also, since daylight is an unstable variable and change throughout the day, daylight penetration to the experiment room was prevented. In order to enrich the knowledge of the effects of color temperatures; broad color temperature levels with naturally lit color temperatures can be examined.

The color task performance was conducted on 40 degrees inclined setup to create an offending zone for reflections. Besides, the size of color chips was 2x4cm dimensions. Task performance can be affected by both setup and size of color chips. For future studies, the experiment can be conducted on different angled inclined setups or without setup with distinct size of color chips.

The experiment did not concentrate on demographics such as age, gender, and department. Since the participants were chosen among university students and their ages were in the same range effects of age could not be studied. Besides, since the number of available female and male students in the Interior Architecture and Environmental Design Department was not equal to each other, this study also could not consider gender effect. Further experiments can study the effects of color temperatures on task performance and mood between female and male users among different age groups.

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APPENDICES

Appendix A. Questionnaire

The PANAS

This scale consists of a number of words that describe different feelings and emotions. Read each item and then mark the appropriate answer in the space next to that word. Indicate to what extent [INSERT APPROPRIATE TIME INSTRUCTIONS HERE]. Use the following scale to record your answers.

1 very slightly or not at all	2 a little	3 moderately	4 quite a bit	5 extremely
	_____ interested (ilgili)		_____ irritable (tedirgin)	
	_____ distressed (sıkıntılı)		_____ alert (uyanık)	
	_____ excited (heyecanlı)		_____ ashamed (utanmış)	
	_____ upset (mutsuz)		_____ inspired (ilhamlı)	
	_____ strong (güçlü)		_____ nervous (sinirli)	
	_____ guilty (suçlu)		_____ determined (kararlı)	
	_____ scared (ürkümüş)		_____ attentive (dikkatli)	
	_____ hostile (düşmanca)		_____ jittery (asabi)	
	_____ enthusiastic (hevesli)		_____ active (aktif)	
	_____ proud (gurulu)		_____ afraid (korkmuş)	

We have used PANAS with the following time instructions:

Moment	(you feel this way right now, that is, at the present moment)
Today	(you have felt this way today)
Past few days	(you have felt this way during the past few days)
Week	(you have felt this way during the past week)
Past few weeks	(you have felt this way during the past few weeks)
Year	(you have felt this way during the past year)
General	(you generally feel this way, that is, how you feel on the average)

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Figure A1: Watson's PANAS Mood Test

(Source: Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: the PANAS scales. *Journal of personality and social psychology*, 54(6), 1063.

For the Turkish Version: Gençöz, T. (2000). Positive and Negative Affect Schedule: A study of validity and reliability. *Türk Psikoloji Dergisi*, 46(15), 19-26.)

*In this dissertation the questions of 10, 14, 17, 24, 25, 26, 29 in OLS survey were not included.

Office Lighting Survey

What is the address of your building? _____

What floor of this building are you on? _____

All of the statements below refer to your work area. Please put a check in the box to the right of each statement (labeled with the corresponding number) if you **agree** with the statement for questions 1 through 9. If you disagree, leave the box blank.

1) Overall, the lighting is comfortable.	1
2) The lighting is uncomfortably bright for the tasks that I perform.	2
3) The lighting is uncomfortably dim for the tasks that I perform.	3
4) The lighting is poorly distributed here.	4
5) The lighting causes deep shadows.	5
6) Reflections from the light fixtures hinder my work.	6
7) The light fixtures are too bright.	7
8) My skin is an unnatural tone under the lighting.	8
9) The lights flicker throughout the day.	9

For question 10 put a check in the box below corresponding to your answer.

10) How does the lighting compare to similar workplaces in other buildings.

10. Worse.	10. About the same.	10. Better.
------------	---------------------	-------------

Please rate the following attributes of your particular desk location in this building by circling the appropriate number between 1 and 5 that best summarizes your experience of working here.

11. Electrical Lighting	1 BAD	2	3	4	5 GOOD
12. How bright lights are	1 TOO MUCH LIGHT	2	3	4	5 DOES NOT GET TOO BRIGHT
13. Glare from lights	1 HIGH GLARE	2	3	4	5 NO GLARE

Figure A2: First page of OLS

14. For each task performed, please rate the lighting available to you by checking the appropriate column:

	excellent	pretty good	neutral	not very good	poor	not applicable
Reading.....	___	___	___	___	___	___
Writing (by hand)....	___	___	___	___	___	___
Using a typewriter...	___	___	___	___	___	___
Using a computer.....	___	___	___	___	___	___
Drafting/Drawing.....	___	___	___	___	___	___
Filing.....	___	___	___	___	___	___

15. Overall, how satisfied are you with the lighting at your office or work space?

- very satisfied
- fairly satisfied
- neither satisfied nor dissatisfied
- not very satisfied
- not at all satisfied

16. How would you describe the amount of light available to you now?

- much too bright
- a bit too bright
- just about right
- a bit too dim
- much too dim

17. Please indicate how bothersome each of the following is to you by checking the appropriate column:

	not at all bothersome	not very bothersome	fairly bothersome	not bothersome
reflected glare from work surface....	___	___	___	___
glare from ceiling lights.....	___	___	___	___
glare from task lights/ desk lamps...	___	___	___	___
bright lights in workspace.....	___	___	___	___
(skip if you do not have a computer) glare reflected in computer screen...	___	___	___	___

18. Would you say that the amount of light for the work that you do is...

- excellent
- good
- fair
- poor

Figure A3: Second page of OLS

The following information is needed only for statistical purposes:

19. Are you
a) male
b) female
20. How old are you?
a) under 25
b) 25-34
c) 35-44
d) 45-54
e) 55-64
f) 65-74
g) 75 or older
21. Do you wear glasses or contact lenses?
a) no
b) yes
If yes, please describe why
a) difficulty seeing things close up (such as reading books)
b) difficulty seeing things far away (such as road signs)
c) both a and b
d) astigmatism
e) other (please specify) _____
22. Do you have difficulty distinguishing between colors?
a) no
b) yes
23. Have you have any medical problems with your eyes (e.g., cataract, glaucoma, injury, etc.)?
a) no
b) yes...please describe _____
24. Which of the following tasks describe the work that you do?
(circle all that apply)
a) typing
b) filing papers
c) analysis of materials
d) drafting or drawing
e) writing manuscripts
f) accounting or working with ledgers
g) using a computer
h) reading
i) installing or fixing equipment
j) interviewing or talking to clients in person
k) talking on the phone
25. Of the above activities, which one do you do most of the time?
(circle only one)
a b c d e f g h i j k
26. Which of the following best describes your job?
a) manager/administrator/supervisor
b) engineer
c) programmer
d) secretarial/clerical
e) researcher
f) technician
g) operator services
h) business office representative
i) other...please specify _____
27. How many days each week are you usually at your desk or workspace?
28. On average, how many hours do you spend per day at your desk or workspace? _____

Figure A4: Third page of OLS

29. Do you have a task light or desk lamp at your workspace or desk?
a) no
b) yes
30. If you have any opinions or comments about the lighting at your desk or workspace that you would like have recorded, please write them in the space below (your comments will be kept confidential).

Thank you for your consideration in filling out our survey!

If you have any questions or comments regarding this research, please feel free to contact:

Neil Eklund
Research Associate
Lighting Research Center
Rensselaer Polytechnic Institute
Troy, New York 12180
(518) 276-4802

Declan MacManus
Real Estate Operations Product Manager - Energy Management
Company A
Pony Street
Brooklyn, New York 11201
(666) 555-4444

Figure A5: Forth page of OLS

(Source: Eklund, N. H., & Boyce, P. R. (1996). The development of a reliable, valid, and simple office lighting survey. *Journal of the Illuminating Engineering Society*, 25(2), 25-40.)

Appendix B. Photographs of the Experiment Setup and Color Tasks

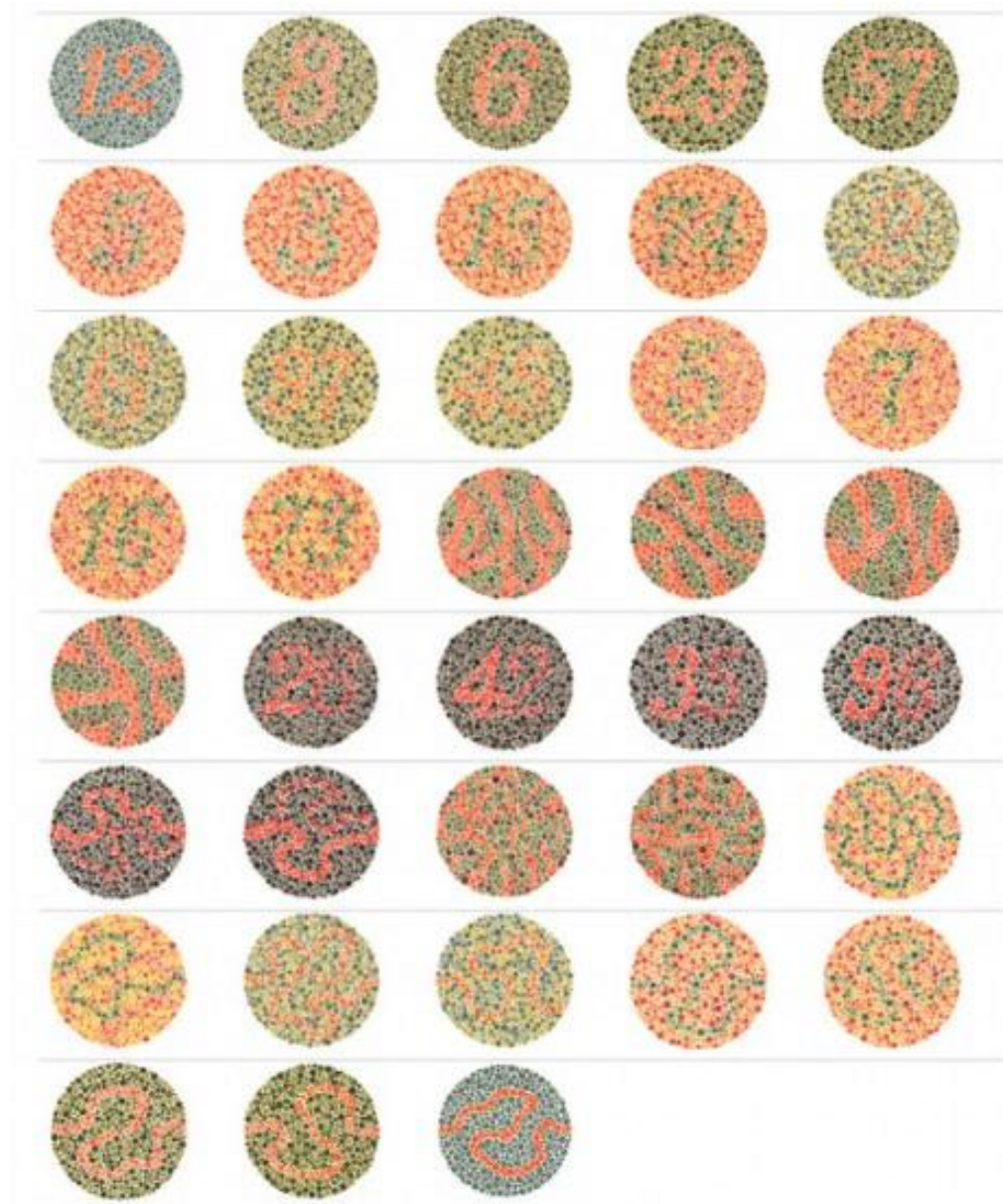


Figure B1: Ishihara Color Blindness Test

(Source: <http://www.color-blindness.com/ishiharas-test-for-colour-deficiency-38-plates-edition/>)



Figure B2: Experiment setup

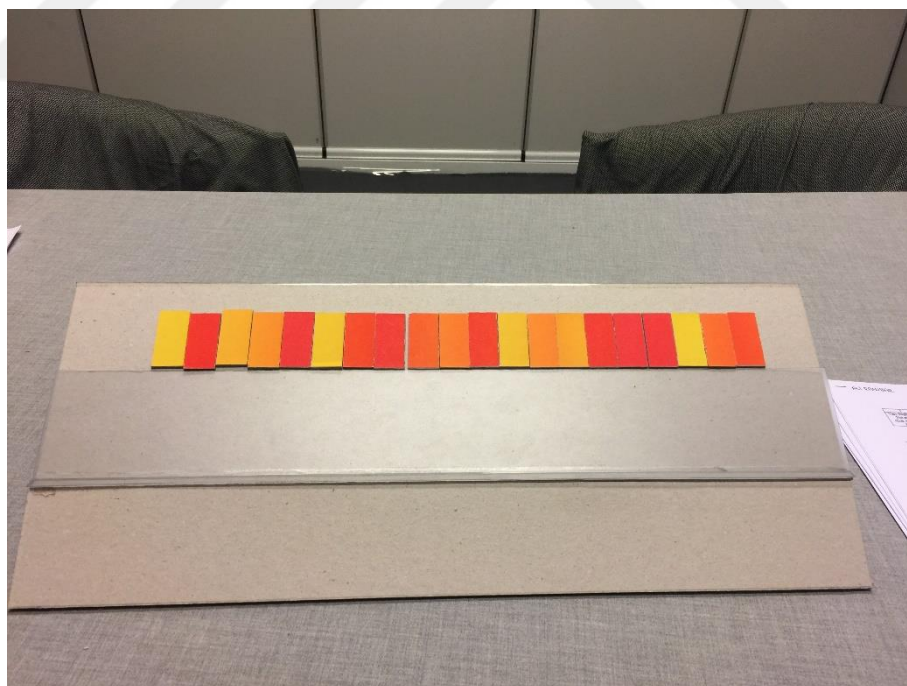


Figure B3: Red-Yellow Hue Differentiation Task

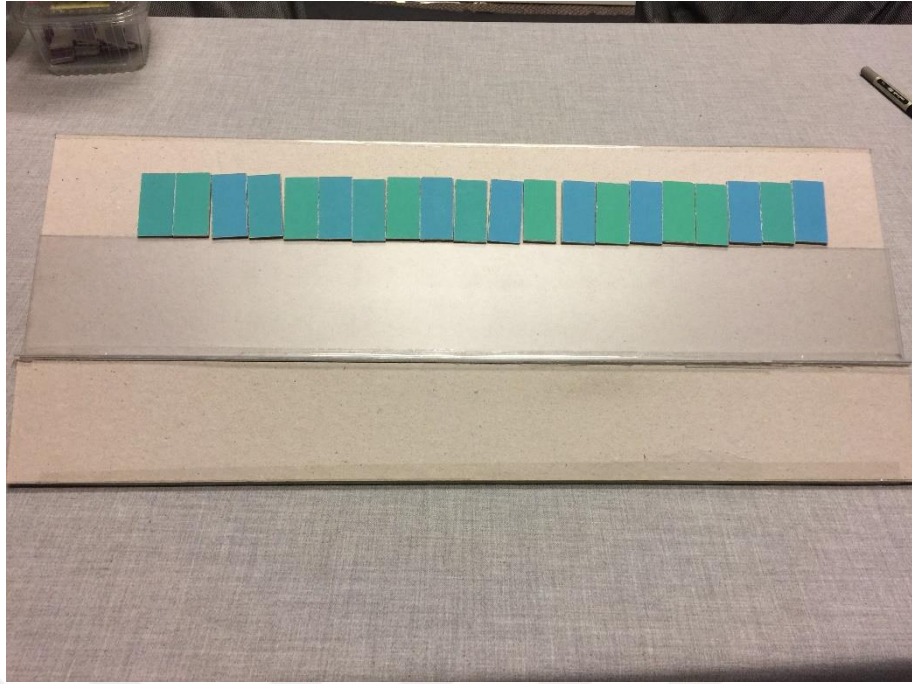


Figure B4: Blue-Green Hue Differentiation Task



Figure B5: Blue-Purple Hue Differentiation Task

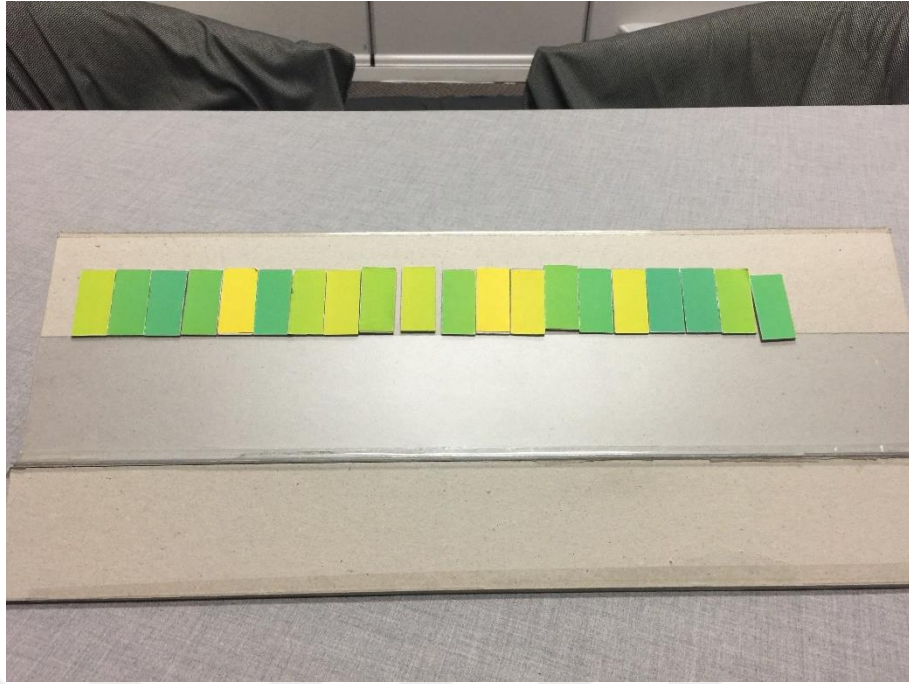


Figure B6: Yellow-Green Hue Differentiation Task



Figure B7: Red-Purple Hue Differentiation Task

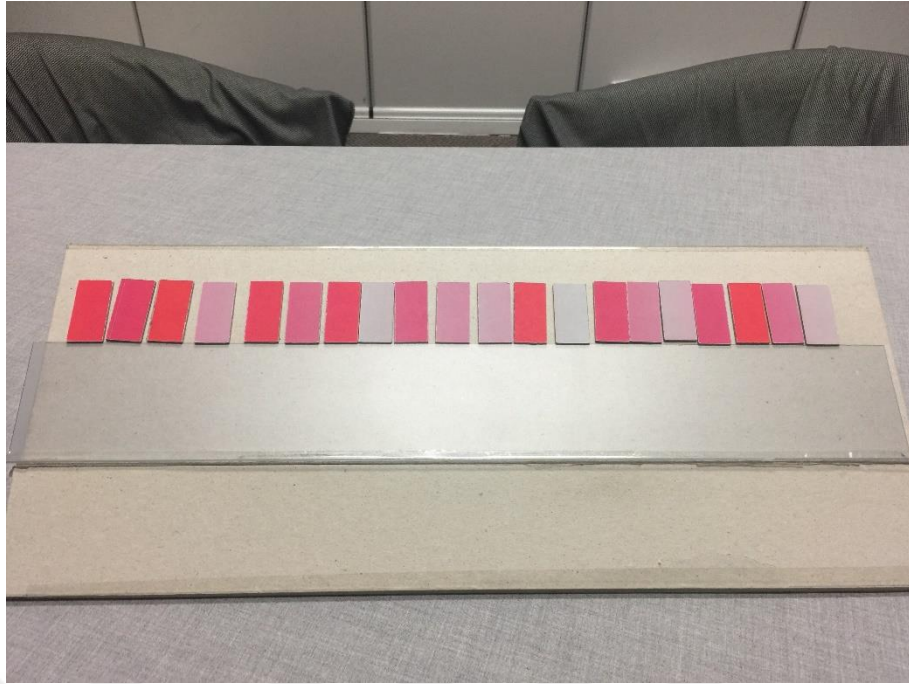


Figure B8: Red Chroma Differentiation Task

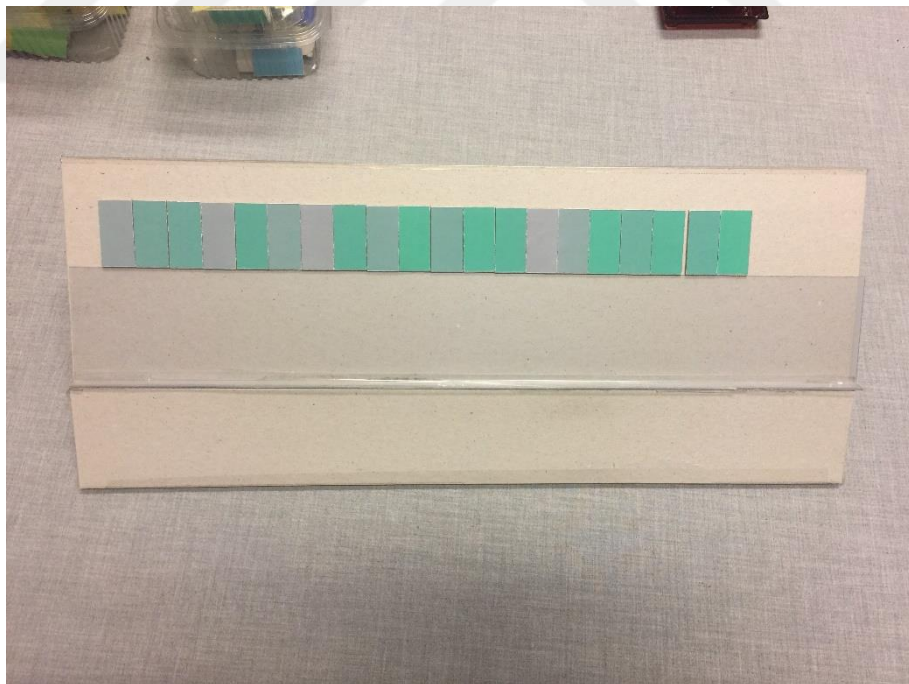


Figure B9: Green Chroma Differentiation Task

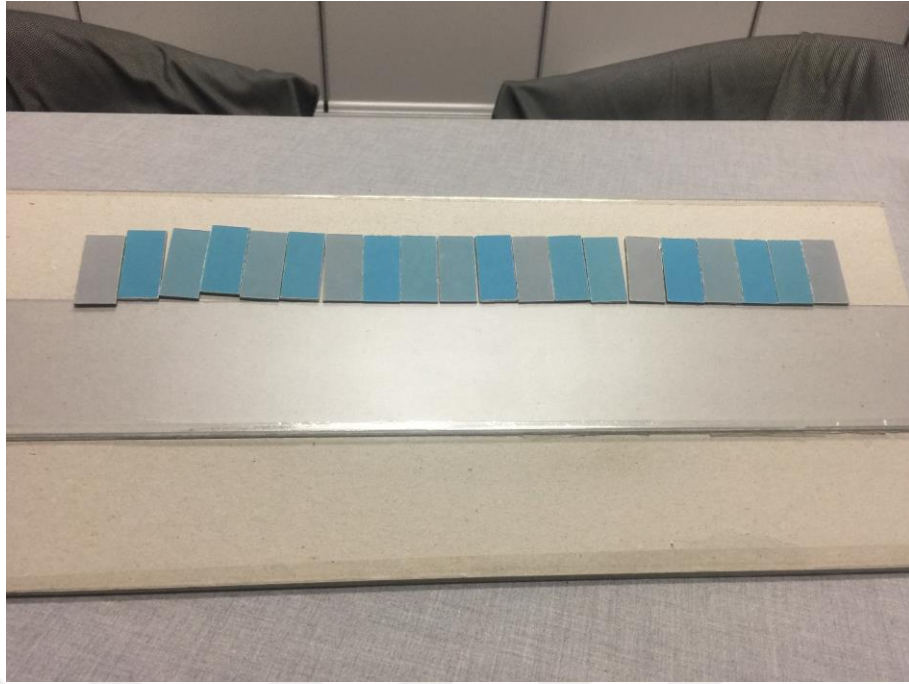


Figure B10: Blue Chroma Differentiation Task

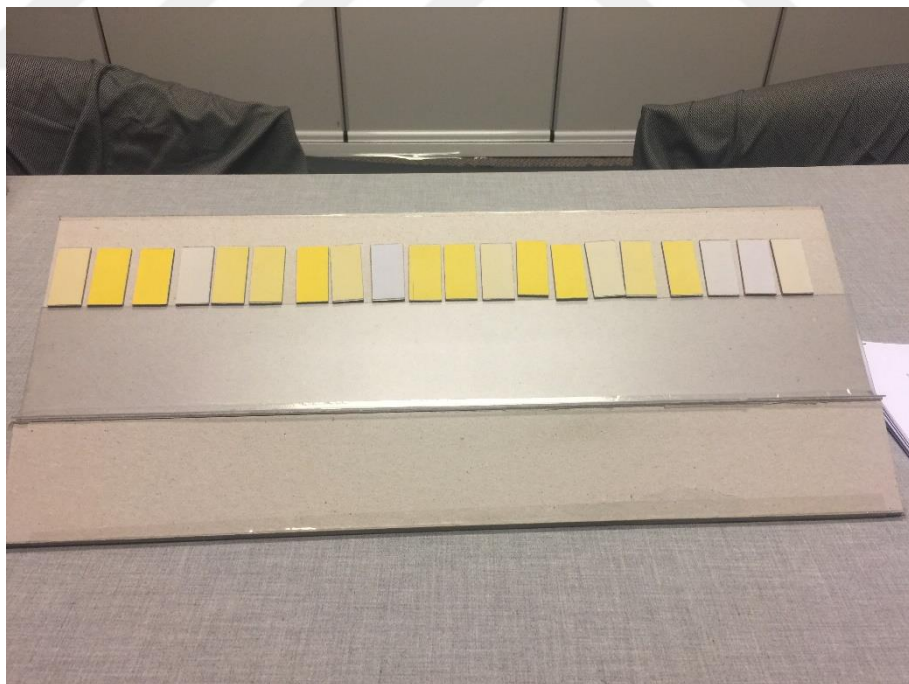


Figure B11: Yellow Chroma Differentiation Task

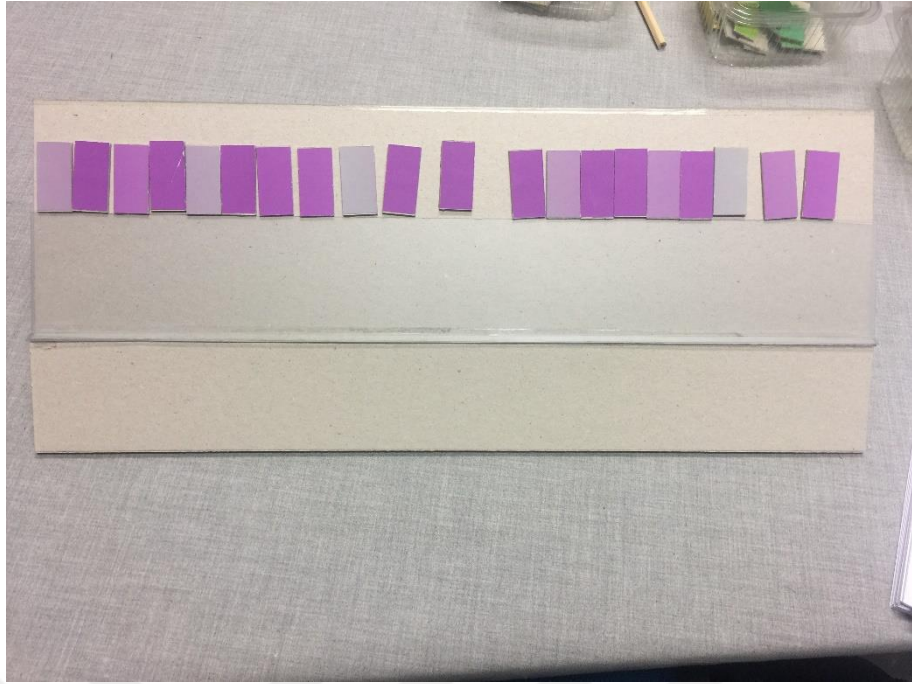


Figure B12: Purple Chroma Differentiation Task

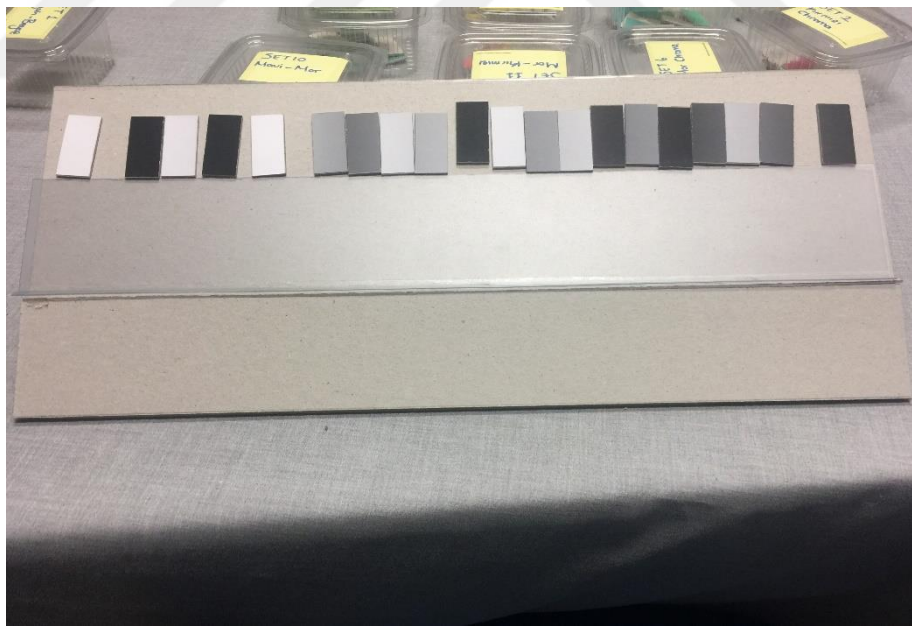


Figure B13: Value Differentiation Task

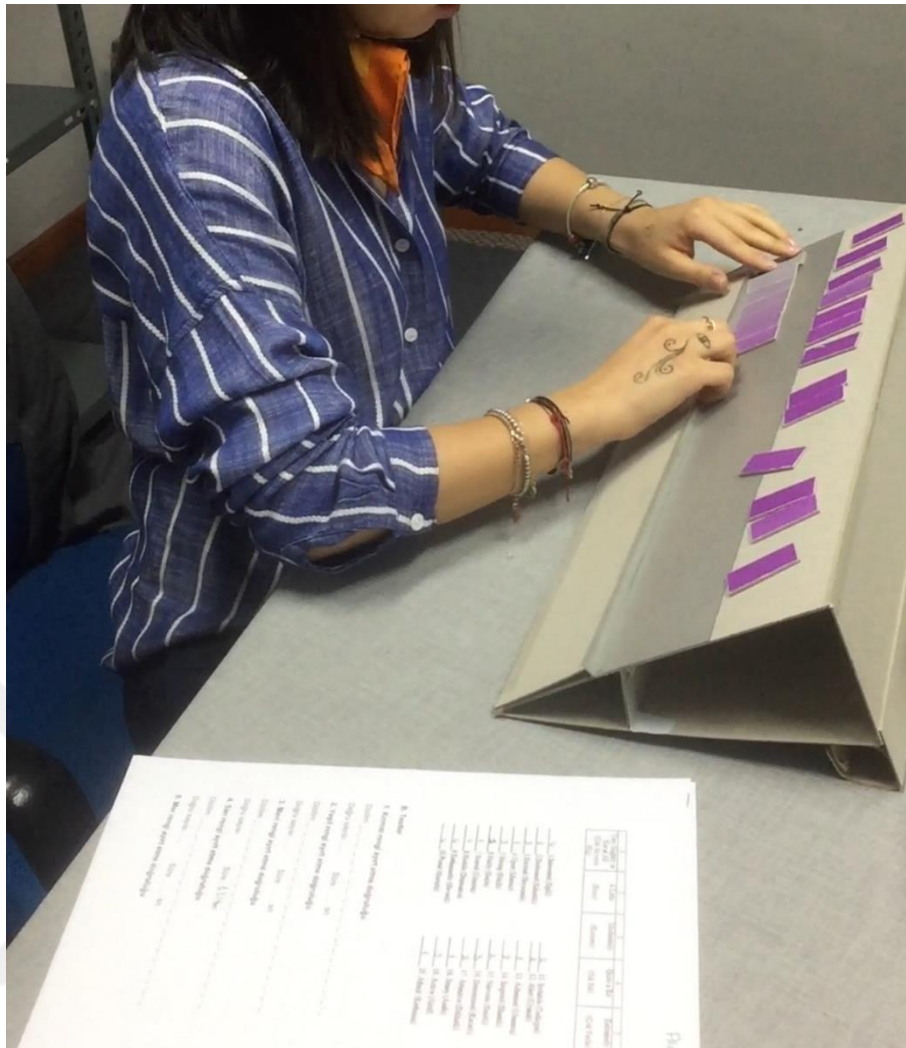


Figure B14: A View from Color Task Model Implementation

Appendix C. Statistical Results

Table C1. Lighting Satisfaction Results

Overall lighting is comfortable		2700	
	4000	YES	NO
	YES	51	33
	NO	14	2
The lighting is uncomfortably bright		2700	
	4000	YES	NO
	YES	4	24
	NO	12	60
The lighting is uncomfortably dim		2700	
	4000	YES	NO
	YES	1	2
	NO	19	78
The lighting is poorly distributed		2700	
	4000	YES	NO
	YES	3	8
	NO	19	70
The lighting causes deep shadows		2700	
	4000	YES	NO
	YES	0	5
	NO	12	83
Reflection hinder my work		2700	
	4000	YES	NO
	YES	12	9
	NO	13	66
Unnatural skin tone		2700	
	4000	YES	NO
	YES	5	6
	NO	60	29
Color distinguishing problem		2700K	
	4000K	NO	YES
	NO	29	50
	YES	8	13

Table C2. Electrical Lighting

		2700K Frequency	4000K Frequency
Valid	Bad	6	,0
	2	17	12
	3	38	21
	4	33	56
	Good	6	11
	Total	100	100

Table C3. Glare from Lights

		2700K Frequency	4000K Frequency
Valid	high glare	8	0
	2	16	10
	3	7	13
	4	18	23
	no glare	51	54
	Total	100	100

Table C4. Overall, how satisfied are you with the lighting at your office

		2700K Frequency	4000K Frequency
Valid	not at all satisfied	15	3
	not very satisfied	32	17
	neither satisfied nor dissatisfied	15	17
	fairly satisfied	33	41
	very satisfied	5	22
	Total	100	100

Table C5. How would you describe the amount of light available to you now?

		2700K Frequency	4000K Frequency
Valid	much too dim	0	1
	a bit too dim	28	3
	just about right	40	56
	a bit too bright	28	37
	much too bright	4	3
	Total	100	100

Table C6. Would you say that the amount of light for the work that you do is...

		2700K Frequency	4000K Frequency
Valid	poor	5	8
	fair	19	37
	good	61	52
	excellent	15	3
	Total	100	100

Table C7. Perceived performance frequency table

		Expected Success 2700K	Self- Speed 2700K	Self- Accuracy 2700K	Expected Success 4000K	Self- Speed 4000K	Self- Accuracy 4000K
Valid	poor	0	0	0	0	1	0
	fair	8	11	8	4	11	1
	good	37	41	37	34	23	42
	very good	53	38	53	52	52	45
	excellent	2	10	2	10	13	12
	Total	100	100	100	100	100	100

Table C8. Task Performance in terms of Magnitude of Errors

	4000K		2700K		WILCOXON	
	Mean	SD	Mean	SD	<i>z</i>	<i>p</i>
Red Chroma	,652	,861	,969	1,091	-2,336 ^a	,020
Green Chroma	2,230	1,408	3,461	2,957	-4,069 ^a	,000
Blue Chroma	2,620	1,581	3,181	2,557	-1,815 ^a	,070
Yellow Chroma	1,914	1,252	2,575	1,584	-3,425 ^a	,001
Purple Chroma	7,246	2,565	7,504	2,598	-,484 ^a	,629
Red-Yellow Hue	1,535	1,371	2,800	2,489	-5,070 ^a	,000
Yellow-Green Hue	,742	1,029	,875	1,152	-1,032 ^a	,302
Green-Blue Hue	1,701	1,616	2,465	1,746	-3,675 ^a	,000
Blue-Purple Hue	,716	,913	1,265	2,126	-2,255 ^a	,024
Purple-Red Hue	1,116	1,151	1,278	1,444	-,556 ^a	,578
Value	1,042	,939	,840	1,031	-1,380 ^b	,168

^a based on negative ranks

^b based on positive ranks