THE EFFECTS OF CORRELATED COLOR TEMPERATURE ON SUSTAINED ATTENTION AND MOOD OF UNIVERSITY STUDENTS IN LEARNING ENVIRONMENTS

A Master's Thesis

by

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Graduate School of Economics and Social Sciences

of

İhsan Doğramacı Bilkent University

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İHSAN DOĞRAMACI BİLKENT UNIVERSITY

ANKARA

July 2015

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.

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ABSTRACT

THE EFFECTS OF CORRELATED COLOR TEMPERATURE ON SUSTAINED ATTENTION AND MOOD OF UNIVERSITY STUDENTS IN LEARNING ENVIRONMENTS

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July 2015

The aim of this study is to understand the effects of correlated color temperature on sustained attention and mood of university students in learning environments and to compare different color temperatures. The experiment was conducted with two different sample groups in two different lighting settings; 4000 K and 6500 K in a single phase. The participants were ninety seven undergraduate students from Bilkent University. The participants were seated in a regular lecture room and tested by the researcher. They were asked to perform three paper- based tests; one of them about the sustained attention, d2 Test of Attention, and the other two about mood, (PANAS) Positive and Negative Affect Schedule. It was found that correlated color temperature has no significant effect on concentration performance, errors of omission, total numbers of items processed. A certain conclusion could not be derived about the effect of color temperature on mood. However, color temperature has a significant effect on errors of commission and number of errors. It was found that 4000 K significantly increases errors of commission and number of errors, thus 6500 K is more appropriate for university learning environments.

Keywords: Sustained Attention, Mood, Correlated Color Temperature, Lighting, University Learning Environment

ÖZET

IŞIĞIN RENK SICAKLIĞININ EĞİTİM ORTAMLARINDA ÜNİVERSİTE ÖĞRENCİLERİNİN DİKKAT VE DUYGU DURUMU ÜZERİNE ETKİSİ

Kocaoğlu, Rengin

İç Mimarlık ve Çevre Tasarımı Yüksek Lisans Programı

Danışman: Doç. Dr. Nilgün Olguntürk

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Bu çalışmanın amacı, ışığın renk sıcaklığının eğitim ortamlarında üniversite öğrencilerinin dikkati ve duygu durumu üzerine olan etkisini anlamak ve farklı seviyelerdeki renk sıcaklıklarını karşılaştırmaktır. Deney iki farklı deney grubu ile 4000 K ve 6500 K olmak üzere iki farklı renk sıcaklığı ile gerçekleştirilmiştir. Katılımcı grubu Bilkent Üniversitesi'nden toplam doksan yedi lisans öğrencisinden oluşmaktadır. Katılımcılar sıradan bir derslikte araştırmacının yönlendirmesi ile test edilmiş; dikkat ve duygu durumuyla ilgili üç adet test çözmüşlerdir. Işığın renk sıcaklığının konsantrasyon performansı, işaretlenmeden atlanılan karakter sayısı ve taranan toplam karakter sayısı üzerine bir etkisi olmadığı bulunmuştur. Renk sıcaklığının öğrencilerin duygu durumu üzerine kesin bir sonuca ulaşılamamıştır. Renk sıcaklığının yanlış işaretlenen karakter sayısı ve yapılan hata sayısı üzerinde bir etkisi bulunmuştur. 4000 K seviyesindeki ışığın yanlış işaretlenen karakter sayısını ve yapılan hata sayısını arttırdığı ve 6500 K seviyesindeki ışığın da üniversite eğitim ortamları için uygun bulunmuştur.

Anahtar Kelimeler: Dikkat, Duygu Durumu, Renk Sıcaklığı, Aydınlatma, Üniversite Eğitim Ortamları

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CHAPTER I

INTRODUCTION

Lighting quality is about creating lit environments to enhance occupants' performances, behaviors, psychology and health (Boyce, 2000). Various studies have been conducted to compare the effects of different lighting conditions to obtain lighting quality to enhance occupants' mental and emotional reactions such as health, productivity, well-being and alertness level in interior environments (Knez, 1995; Shamsul et. al., 2013). Lighting quality can be evaluated by the level of visual comfort and pleasantness during a performance of an activity. Besides the short-term effects of lighting quality, it has also long-term effects on occupants' health. According to Shamsul et. al. (2013) lighting quality is one of the main components of interior environment qualities. Lighting quality consists of illuminance level and uniformity, distributions of luminance and correlated color temperature (Veitch & Nesham, 1998; Barkmann et. al., 2012). Illuminance level (lux) is the quantity of light that reaches to surface (Egan & Olgyay, 2002). Another important characteristic of lighting quality and the main concern of this study is the correlated color

temperature (CCT) which is the temperature (Kelvin) of a light source that irradiates from the blackbody radiator (Egan & Olgyay, 2002). CCT of a light source in an interior environment plays an important role in affecting both psychological and physiological functions of the occupants. The correct application of CCT in an interior environment can be beneficial to occupants; it increases motivation, improves health and supports cognitive processes. In contrast, the use of incorrect application of CCT might has important negative results on human health, such as eye strain and headaches, or changing regular process of the circadian system and transform mood (van Bommel & van den Beld, 2004; Mills, Tomkins & Schlangen, 2007; Halonen, Tetri & Bhusal, 2010) and those unwanted results can cause loss of productivity (Shamsul et. al., 2013). As one of the determinants of the lighting quality, CCT is also affecting and enhancing the quality of learning in school environments (Sanaz, 2011; Shamsul et. al., 2013). There are several studies about the relationship between human perception and illuminance but there is lack of information exploring the relationship between CCT and sustained attention and mood.

Human spend most of their time in interior environments such as residences, offices schools, hospitals and they all perform some tasks. In an office, the employee is responsible for being successful in completing his/ her task; in a school, the student is responsible for learning new things, gaining knowledge and be successful. Cognition actually means *knowing* and it uses existing knowledge and generates new knowledge so for gaining knowledge cognition is needed (McLeod, 2007). The term ‘cognition’ means the mental processes to gain knowledge, which consists of “thinking, knowing, remembering, judging, problem solving, reasoning,

comprehension and production of language and attention". Sustained attention and mood are the basic components of cognition and learning. According to Russell & Snodgrass (1987) mood can be defined as a person's personal main feelings at a certain given moment and it affects learning. For learning, maintaining attention is necessary and it is the ability of human to direct and sustain attention on an information source purposefully (Huang et. al., 2014; McAvinue et. al., 2012).

The presence of comfortable visual environment enhances humans' sustained attention and mood, thus improving gaining knowledge and increases productivity levels. It is important to understand the effects of CCT of lighting on sustained attention and mood of university students in learning environments, because the effects of CCT of lighting on both sustained attention and mood are not explored yet. In addition, it is not certainly known whether CCT of lighting has an effect on these terms, thus, any contributions are important in this field. By exploring the effects of CCT of lighting, this study aims to fill in the uncovered area in the literature about sustained attention, mood and lighting research.

1.1.Aim of the Study

The main purpose of this study is to understand the effects of CCT of lighting on sustained attention and mood of university students in learning environments, also, to understand the relationships between CCT, sustained attention and mood. In the literature, there is not enough research exploring the relationship between CCT of lighting and sustained attention and mood and this study aims to fulfill the gap in the

literature. The findings of the study can be useful for interior architects, lighting designers and who are interested in sustained attention and mood.

1.2.Structure of the Thesis

The thesis consists of seven chapters. The first chapter is the introduction, the concepts of sustained attention and mood and how they can be affected by correlated color temperature of lighting are briefly indicated. In addition, the aim of the study and the structure of the thesis are stated in this chapter.

In order to understand the definitions of sustained attention and mood, the term *cognition* needs to be explored which is also included briefly in this chapter. Thus, the second chapter is about the definition and characteristics of cognition. The relationship between cognition and learning is explored firstly with the definition of learning, then the characteristics of learning, process of learning and the factors that affect learning.

The third chapter explores sustained attention and the criteria used for measuring sustained attention. Sustained attention performance criteria is measured with d2 Test of Attention. The evaluation criteria are; number of errors (E%) which is the sum of errors of omission (EO) and errors of commission (EC) over total number (TN) and concentration performance (CP) which is the total number of correctly marked items in the d2 Test of Attention. Those criteria are explained with literature review. Also, other studies using different aged sample groups and individual differences at

different interior environments are examined to understand if there is a relationship between different correlated color temperature levels and sustained attention.

In the fourth chapter the definition of mood is given. In addition to this, mood designation criteria, PANAS that is a self- reported current mood test is explained with literature review. The relationship between correlated color temperature and mood are also explained in this chapter.

The fifth chapter is about lighting and correlated color temperature, basic terms of lighting and CCT are described with literature review and studies using correlated color temperature of lighting. Also, the standards of lighting in learning environments are stated.

The experiment is described in the sixth chapter. Aim of the study, research questions and hypotheses are stated. The method of the study, sample group and the procedure of the experiment is explained with the setting of the experiment and sets of the experiment such as selecting the proper lighting equipment for the experiment. The results of the experiment are statistically analyzed and evaluated in this chapter. The results of the experiment are discussed and compared with the previous studies' results.

In the last chapter, conclusions about the study are stated. Moreover, for further research some suggestions are given.

CHAPTER II

COGNITION

2.1. The Definition of Cognition

"Cognition" comes from a Latin verb *cognosco* and can be translated into English as "I know, I perceive" which means "to conceptualize" or "to recognize" (Franchi & Bianchini, 2011). The term cognition refers to mental processes for gaining knowledge and understanding, which includes thinking, knowing, remembering, judging, problem solving, reasoning, comprehension and production of language and attention. Cognition actually means *knowing* and it uses existing knowledge to generate new knowledge (McLeod, 2007).

There are three branches of cognitive psychology; cognitive neuroscience, computer analogies information processing approach and human experimental psychology. For this study the third one, human experimental psychology is adopted. According to McLeod (2007), cognitive psychology focuses on how human process and treat the

information and how this treatment leads to responses (See Figure 1). Cognitive psychology is interested in the process, which are composed of stimuli and responses; those processes include perception, attention, language, memory and thinking, and problem solving (Atkinson & Shiffrin, 1968; Miller, 1956; Niesser, 1967; Tolman, 1948; Wiener, 1948).

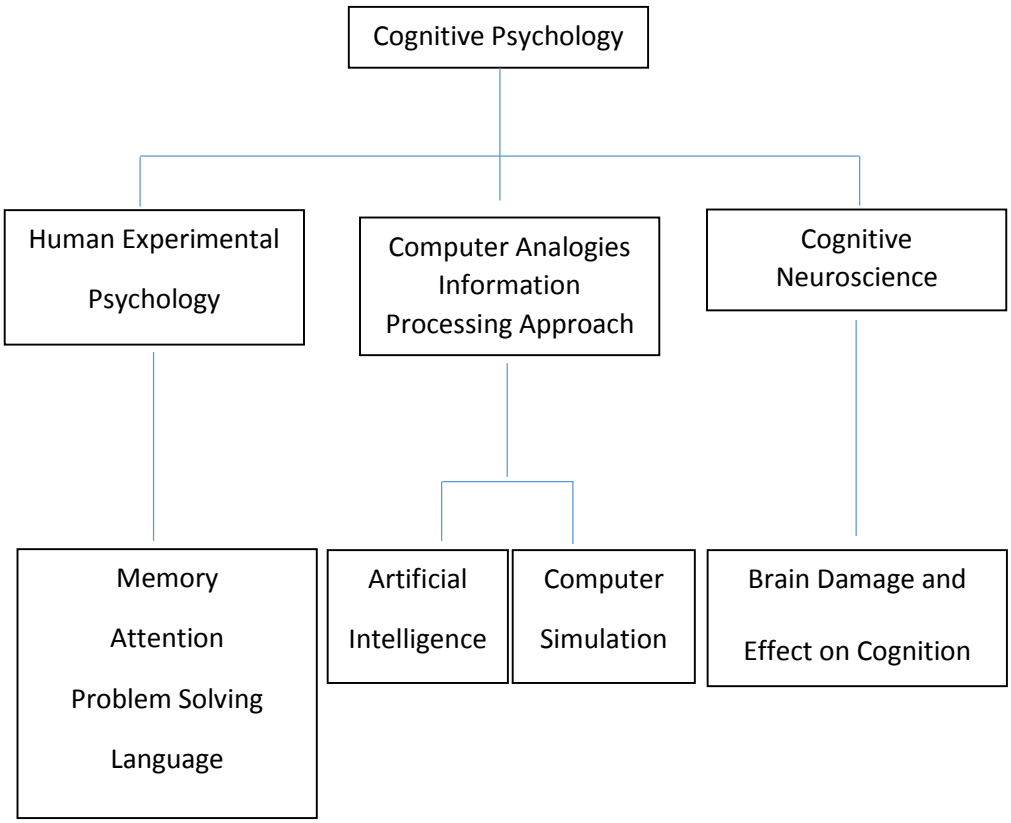

Figure 1: A Diagram showing cognitive psychology

(Source: http://www.simplypsychology.org/cognitive.html)

Learning process cannot occur without drawing attention on the incoming information source and attention is one of the basic components of cognitive psychology. Cognition and learning are the two similar terms need to be understood

well, also understanding the relationship between those terms are useful for this study.

2.2. Cognition and Learning

Cognition is the process involved in gaining knowledge, whereas learning is the process of acquiring knowledge. Learning is required for the process of cognition and at the same time cognition is required to apply and recall the previously learned knowledge to a future situation. So both cognition and learning is interrelated. For learning and cognition; recognizing and recalling are necessary therefore attention is a measure of learning (Nissen & Bullemer, 1987). It can be said that attention supports an individual to clear and select relevant things to deal effectively and ignore other thing while learning. It arouses interest in learners to learn a particular thing and it increases efficiency of the learner, making him/ her ready to learn (Driscoll & Driscoll, 2005). Also, it makes an individual being more alert for doing the task and to perceive the objects to learn in a clearer manner.

According to Allport (1993), attention has two major functions in individuals' daily lives; it is important in selecting and processing information which is relevant to current tasks and in processing novel, potentially relevant information. These two functions sometimes interfere with one another (Robinson, Watkins & Harmon-Jones, 2013).

2.2.1. The Definition of Learning

Learning is the change in a relatively permanent way in behavior due to experience and there are many different perspectives that define learning but, basically it can be viewed from two perspectives; learning refers to the development of overt, adaptive behavior and learning refers to acquired knowledge (Tarpy, 1997). For this study *learning as knowledge* is concerned.

Learning can be defined as an inferred change in the organism's mental state, which results from experience, and which influences in a relatively permanent fashion the organism's potential for ensuing adaptive behavior (Tarpy, 1997). Also, "learning is a process of acquiring modifications in existing knowledge, skills, habits, or tendencies through experience, practice, or exercise" (Skinner, 1938). According to Bigge (1982) learning can be considered as the changes in behavior, perception, insight and motivation or it can be the combinations of all these.

2.2.2. Characteristics of Learning

Learning is the adjustments of the individual's behavior that is continuous throughout his/ her life (Morgan & King, 1966). According to Yoakam & Simpson (1948), learning is the organization of experiences, both individually, socially, emotionally and intellectually, and it is purposefully the adjustments of the behaviors of an individual according to the changing environment. Learning can be considered as the improvement process which can be determined by practices and experiences, in addition to this it can be called as the reorganization of the past experiences of an

individual. Learning involves a permanent change in behavior of the individual. Also, learning and performance are always different from each other, learning cannot be directly observable; but it can be noticeable in an individual's activities (Tarpy, 1997). Learning depends on motivation; the individual learns things when he/ she is more motivated (Morgan & King, 1966).

As learning contains many features, it is important to understand the characteristics and the process of it in depth to enhance students' learning ability in school environments. One of the most important components of learning is attention and the other one is mood of students and in this study both of them are examined.

2.2.3. Process of Learning

There are three components of learning process which involves; the motivation, an attractive goal and an obstacle to the attainment of the goal. The motivation is like a force that strengthens behavior and induces the individual to act to learn. When an individual's motivation is strong, it forces him/ her to learn something new. The goal is necessary in learning for achievement. When a definite goal is set by an individual, learning becomes purposeful. The obstacle is as important as the goal in the process of learning and it is essential which keeps the individual away from attaining the goal and thus strengthens the motivation to act to learn (Gollwitzer & Bargh, 1996).

The process of learning contains several phases and all of those are interrelated with each other, however for this study motivation is the main concern. For a person to

learn something motivation is needed like maintaining attention to learn. The factors that are affecting learning are also important in understanding the relationship between motivation, mood and cognition.

2.2.4. The Factors Affecting Learning

Learning can be considered as the development of an individual's "skills, attitudes, knowledge and by which the concepts are acquired, understood, applied and extended. All individuals engage in the process of learning" (Driscoll & Driscoll, 2005). Individuals learn ideas mostly from teaching, instructions or experiences but at the same time learn through feelings is important also in the learning process. Feelings are part of individuals' lives and have impact on the things learned, how and why it is learned. "Learning has been considered both as a cognitive process and a social as an effective component. It is qualified as a cognitive process, since it involves the functions of attention, perception, and reasoning, analysis, drawing of conclusions, making interpretations and giving meaning to the observed phenomena. All of these are mental processes that are related to the intellectual functions of the individual" (Driscoll & Driscoll, 2005). The most important factor of learning is the environment in which human being occupies.

From birth, through the years of education and work, humans occupy in artificial settings varies from old people's homes/hospitals to schools, offices and houses (Knez, 1995). According to Knez (1995), human spend most of their time in man-made settings, think, act and react emotionally to every stimulus within those settings and are exposed to different physical indoor variables such as artificial lighting. The

artificial biotope is the setting that human sojourns. Biotope comes from two concatenated Latin words; *bios*, which means mode of life and topos, which means place. Biotope means a milieu of living and an environment that influences humans (Knez, 1995). According to Knez (1995), there is a relationship between the artificial biotope and the organism (human being) and this relationship is called by Knez as "the model of artificial biotope and organism" (p. 40). This model is focused on the causation of affect from the luminous milieu on cognitive processes via mood (Knez, 1995) (See Figure 2). As Knez (1995) argued that "the luminous milieu could act as a mood inducer that induces different mood valances in human and their cognitive processes can be affected via these moods". Artificial light is one physical variable within an artificial biotope which has an influence on the organism. Organism consists of mood and cognition which can be measured with sensitive instruments, also mood has an influence on cognition. Mood contains somatic component and cognitive component (Knez, 1995) and this study is concerning with the latter. Somatic component of mood means subjects do not indicate their mood verbally, their biological data is collected to understand mood whereas cognitive component means subjects indicate their mood verbally or written (Knez, 1995).

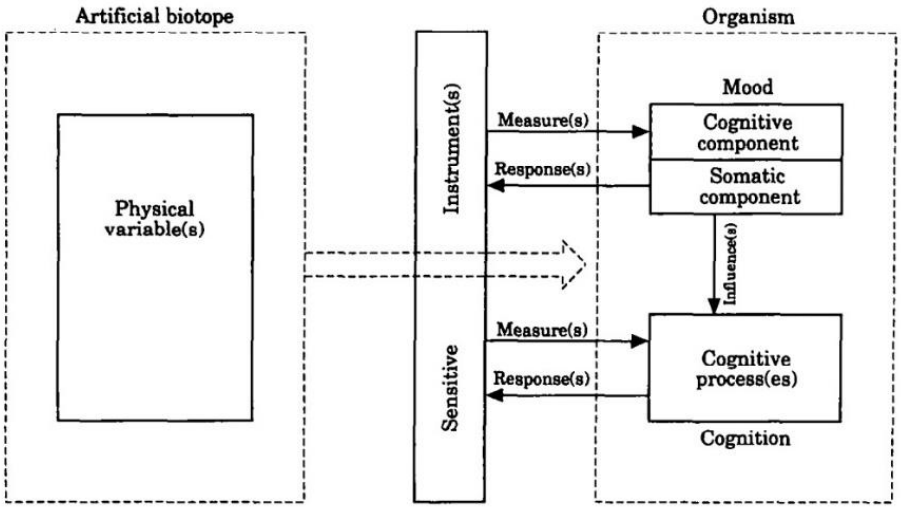

Figure 2: A diagram showing the model of artificial biotope and organism

(Source: Knez, I. (1995). Effects of indoor lighting on mood and cognition. *Journal of Environmental Psychology*, 15(1), 39-51.)

There is an interrelation between motivation, mood and cognition: they influence and interact with each other (Gray, 1990; Lazarus, 1991; Leventhal & Scherer, 1987; Showers & Cantor, 1985; Sorrentino & Higgins, 1986; Storbeck & Clore, 2007). Motivation is defined as an inspiration that propels someone into an action. Motivation is an internal condition that stimulates of an individual's emotional state, opinions and actions (Lahey, 2000). According to Lazarus (1984, p. 124) in the absence of cognition, mood cannot exist.

> "This is because for mood to exist there must be an appraisal of a situation that informs the individual whether there is the potential for something desirable or undesirable. In this view, mood and cognition are interdependent, in that mood can influence cognition, but cognition comes first. Motivation underlies

cognition (and therefore also mood), because motivation provides the meaning necessary for a cognitive appraisal of a situation."

Positive mood broadens attention and enhances cognitive processing as Isen (2001, p. 75) stated:

"...as long as the situation is one that is either interesting or important to the decision maker, positive affect facilitates systematic, careful, cognitive processing, tending to make it both more efficient and more detailed."

A conclusive diagram can be driven to describe the relationship between the terms; cognition, learning, mood and attention, which are the main concerns of this, study (See Figure 3).

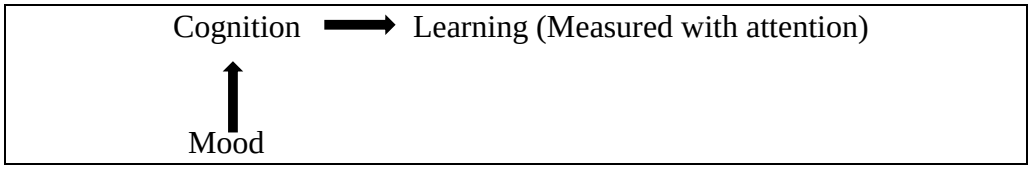

Figure 3: A diagram showing the model of artificial biotope and organism

For gaining knowledge, cognition is necessary and for learning things, knowledge is required. Those terms are interrelated with each other that are affected by mood and at the same time are affected by environmental conditions such as light, thus this study aims to examine the effects of light on mood and sustained attention.

CHAPTER III

SUSTAINED ATTENTION

3.1. The Definition of Sustained Attention

According to James (1890) "attention is the taking possession of the mind, in clear and vivid form, of one out of what may seem several instantaneously possible objects or trains of thoughts, which implies the withdrawal of some objects in order to deal effectively with others. Attention is the behavioral and cognitive process of selectively concentrating on one aspect of the environment while ignoring the other things. Attention has also been referred as the allocation of limited processing resources" (Anderson, 2004; Carrasco, 2011). Visual attention consists of two processes; in the first one attention uniformly distributed over the visual scene and at the same time the information that was detected is processed, the second process is which attention is focused to a visual scene especially to a specific area (Jonides, 1983).

Attention has been defined as the "set of processes that supports the preservation of goal- directed behavior during several competing distractions" (Parasuraman, 2000). Basic arousal, alertness, selection the relevant information source, being concentrated and sustaining attention for a time are the processes of attention (Barkley, 1988; Parasuraman & Davies, 1984; Mirsky et. al., 1991; Ballard, 1996). It is important to notice the relevant information source and to discard the irrelevant one during attention (Davies et. al., 1984; Parasuraman & Davies, 1984; Ballard, 1996). After a focus is achieved, sustained attention involves the continuous maintenance over time of alertness and openness for a specific set of stimuli or stimulus alterations (Davies et. al., 1984; Parasuraman & Davies, 1984; Parasuraman, 1984, Ballard, 1996). In brief, sustained attention is the mental ability in which individuals purposefully select important information sources to focus and maintain alertness and attention over time (Huang et. al., 2014; McAvinue et. al., 2012).

The ability to sustain attention is also known as "vigilance" behavior (Mackworth, 1970; Warm, 1984; Ballard, 1996). According to Mackworth (1957) vigilance is the term that is used for describing the ability to notice and react to the stimulus changes which happen rarely or at unequal recesses, so they are hardly noticeable. According to Ballard (1996), factors that affect sustained attention level has three categories; first one is parameters of the task, second one is the factors of environment or the situation, and last one is characteristics of subject and all those categories interact with each other also affect the performance. For this study, environmental factors such as lighting conditions that affect sustained attention are the main concerns.

3.2. Sustained Attention Performance Criteria: d2 Test of Attention

The d2 Test of attention is used as a test for measuring sustained attention and it was created by Brickenkamp in 1981 in Germany (Brickenkamp & Zillmer, 1998; Culbertson & Sari, 1997; Wassenberg et. al., 2008; Spreen & Straus, 1998). According to Brickenkamp & Zillmer (1998), the d2 Test of attention, a cancellation test that involves simultaneous presentation of stimuli (visually similar) is useful for measuring attention and concentration processes. The task in the d2 Test of attention is to cancel out all the target characters (a "d" with a total of two dashes placed above and or below), which are interspersed with non-target characters (a "d" with more or less than two dashes, and "p" characters with any number of dashes), in 14 successive timed trials (Brickenkamp, 1962). The d2 Test consists of 14 lines, each containing 47 characters (658 items total) (See Appendix A, Figure 15). For each line twenty seconds are allowed and participants are asked to complete the test without making mistakes. The d2 Test of attention can be administered individually or in group format (Wassenberg et. al, 2008).

According to Bates and Lemay (2003), the d2 Test of attention includes non-target distracters that are visually quite similar to targets (a "d" with varying spatial configurations of two dashes), thus reducing the competitive advantage of the targets and requiring more complex processing because competition for attention is high. The duration time of the d2 Test of attention is 5 minutes, and its difficulty allow the analysis of the participant's ability to achieve, shift, and maintain attention which are the elements of sustained attention. Also, the stimulus characteristics of the test are well suited to the basic study of attentional processes (Bates & Lemay, 2003). The

test is easily administered, it does not require too much instruction and its age range is large (Brickenkamp & Zillmer, 1998; Culbertson & Sari, 1997; Culbertson & Zillmer, 1998). Paper- pencil based d2 Test of attention is preferable than computer based tests; because it increases the accuracy of response timing and scoring. In addition, computerized tests might be inappropriate for the one who have a limited computer experience (Bates & Lemay, 2003).

The outcome measures of d2 Test of attention are; the total number of items processed, the number of misses (errors of omission: d's with two dashes that were not marked), the number of false alarms (errors of commission: marked d's with less or more than 2 dashes or p's) (Brickenkamp & Zillmer, 1998). For analyzing the d2 Test of attention, the participants' errors (number of the total incorrect answers) and concentration performance (the total number of correctly marked d2 symbols minus the number of errors; both errors of commission and errors of omission) are calculated (Bates & Lemay, 2003; Wassenberg et. al., 2008; Sleegers et. al., 2012).

3.3. Correlated Color Temperature and Sustained Attention

In the literature, there are several studies exploring the effects of correlated color temperature on sustained attention. The relationship between CCT and sustained attention was examined with numerous CCT levels with different sample groups under different experiment conditions.

Boray et. al. (1989) examined the effects of three lighting conditions; warm white, cool white and full- spectrum fluorescent light (3000 K, 4150 K, 5000 K at 500 lux) on visual tasks, cognitive performance, mood and found no significant differences in the effects of quantitative tasks.

Vrabel et. al. (1998) examined the effects of different correlated color temperatures on visual performance and clarity; 2700 K, 4100 K, 4200 K and 5000 K at 538 lux and found no significant differences on visual performance and visual clarity.

The effects of correlated color temperature on students' concentration was investigated by using three levels of correlated color temperature; 2900 K, 6500 K and 12000 K by Sleegers et. al. (2012). The experiment shows that 6500 K increases students' concentration compared to 2900 K and 12000 K.

Rautkyla et. al. (2010) studied the effects of 4000 K and 17000 K CCT and timing of light exposure on daytime alertness in lecture environments with undergraduate students. This study found that CCT and timing of the light exposure, played important roles in alertness in lecture environments. Another study by Shamsul et. al. (2013) examined the impacts of 3000 K, 4000 K and 6500 K CCT on alertness and visual comfort level of undergraduate students.

Most of the studies are dealing with children, younger adults or adults and their cognitive performances under different correlated color temperature conditions.

There are studies focusing on elderly people and their visual performance with different correlated color temperatures as well: according to Navvab (2001) high correlated color temperature, 6500 K, was preferred rather than 3500 K by the elderly. Also, Boyce et. al. (2000) found similarly to Navvab (2001), for older people correlated color temperature of 6500 K was preferred when compared with lower 3000 K in visual tasks.

Another study found that for older people 8200 K is a better lighting condition whereas under 5000 K, younger people perform better in tests than 2500 K or 8200 K CCT of lighting (Yamagishi et. al., 2008). Huang et. al. (2014) indicated that attention is significantly better when correlated color temperature was at 4300 K rather than at 2700 K and 6500 K. In contrast to Yamagishi et. al. (2008) and Huang et. al. (2014), it was found that correlated color temperature at 6500 K led to faster reaction times in tasks associated with sustained attention than 2700 K (Chellappa et. al., 2011).

Through the literature review about sustained attention, for the current study it is possible to indicate that sustained attention is affected by CCT of light. With the results of the previous studies, the range of CCT level for this study is set. It can be refined from the literature review that CCT as high as 6500 K or as low as 2700 K will be less appropriate for younger people (Huang et. al., 2013). So for this study, 4000 K and 6500 K CCT of light will be used during the experiments. In addition, the subject group and the measurements of sustained attention are decided with the help of literature review. The subject group for this study is the university students

whose ages range from 18 to 25. Also, the main concerns of this study are the concentration performance and number of errors, which are the outcomes of d2 Test of attention.

CHAPTER IV

MOOD

4.1. The Definition of Mood

According to Knez (2001) the physical factors of light affect mood and mood has an effect on cognitive processes (Clark & Fiske, 1982; Isen, 1984; Russell & Snodgrass, 1987). As Knez (2001) suggested like Belcher & Kluzny (1987) and Baron and Rea (1991) there is a connection between cognitive performance and luminous environment and this relationship can be affected by mood. Individual's memory, thinking, and imagination is affected by mood (Izard, 1977). Izard (1977) suggested, "frightened person has difficulty considering the whole field and examining various alternatives; the person in anger is inclined to have only 'angry thoughts'; the person in a high state of interest or excitement, the individual is curious, desirous of learning and exploring".

A clear distinction between mood and emotion cannot be drawn easily, because both mood and emotion belong to the same conceptual framework (Watson & Clark, 1997). Russell & Snodgrass (1987) defined mood as the core feelings of a person's subjective state at any given moment. According to McCloughan et. al. (1999) mood can be differentiated from emotion; they may have identifiable causes and is more variable, less intense and less transient also it contains more than one emotion. They are different from emotions in terms of their period; mood continues longer than emotion, which can last for hours even for days (Ekman, 1994). Emotions contain actions and movements, which usually appear in "facial expression, posture, gesture, specific behaviors, and conversation" at the same time they have their own facial expressions whereas moods do not have unique facial expression (Ekman, 1994). According to Ekman (1994, p. 57), "one infers an irritable mood by seeing many facial expressions of anger, but there is no distinctive facial expression of irritability itself".

Mood can be briefly classified into two; positive (enthusiastic, active, alert, interested, excited and attentive) or negative (distressed, upset, disgust, fear, guilt and nervousness) (Barone et al., 2000; Lee & Sternthal, 1999; Meloy, 2000; Rusting, 1998; Rusting & DeHart, 2000; Thayer, Newman, & McClain, 1994; Sedikides, 1995) and it can be affected by a particular stimulus such as lighting conditions since mood lasts longer than emotion which relates directly to the experiences of an individual rather than the situation itself (Ekman, 1994).

4.2. Mood Designation Criteria: PANAS

According to Watson, Clark & Tellegen (1988) PANAS, (Positive and Negative Affect Schedule) is a self- reported test to understand the participants' current mood. There are two mood factors that are opposite to one another in PANAS; positive and negative affect that are strongly negatively correlated with each other. "Positive Affect (PA) reflects the extent to which a person feels enthusiastic, active, and alert. High PA is a state of high energy, full concentration, and pleasurable engagement, whereas low PA is characterized by sadness and lethargy. In contrast, Negative Affect (NA) is a general dimension of subjective distress and unpleasable engagement that subsumes a variety of aversive mood states, including anger, contempt, disgust, guilt, fear, and nervousness, with low NA being a state of calmness and serenity" (Watson et. al, 1988). PANAS measures participants' moods with 10 adjectives on a 5-point scale: "very slightly or not at all", "a little", "moderately", "quite a bit" and "extremely" (Knez, 2001). For a person to be completely concentrated and calm, getting the highest points from positive affect and getting the lowest points from negative affect is needed. The duration time of the test is 5 minutes (See Appendix B Figure 16).

This study aims to fill the knowledge gap in sustained attention level, mood and lighting research by exploring whether there are any effects of CCT on sustained attention and mood of students in learning environments.

4.3. Correlated Color Temperature (CCT) and Mood

According to the ‘model of artificial biotope and the organism’ explored by Knez (1995), the physical variables affect the organism which means it influences individuals’ mood and cognition. In addition, it is stated by Knez (1995) in his model that mood has a direct impact on cognition, which can be tested via attention. The physical variables of the environment includes many aspects such as the setting of the environment, its temperature, color, lighting and so on. As one of the aspects of lighting, CCT might have an effect on individuals’ mood and cognition. Several researchers investigate the relationship between CCT and mood. Most of those studies are about the level of working performances related with mood in working environments. One of the studies in literature, by Veitch and Gifford (1996), investigated the theories about the possible effects of lighting on human health and mood. This study is reflecting the users’ beliefs about the effects of lighting on the following issues.

Küller et. al. (2006) studied the impact of light and color on psychological mood in working environments. This study was about illuminance levels of lighting instead of CCT of lighting. The participants’ mood started to decline when the lighting level was too low or too bright so it is difficult to say that light has an impact on participants’ mood. On the other hand, it is stated that color design might be helpful in enhancing positive mood of the participants.

Another study examined the office workers' daily exposure to light and its influence on sleep quality and mood (Hubalek et. al., 2010). This study focused on the amount

of light and illuminance instead of CCT of lighting and found that there is no a relationship between the amount of light and mood.

Veitch (1997) examined the performance and mood effects of information about lighting and fluorescent lamp type (full spectrum and cool- white fluorescent lighting). It was found that there were no effects of lamp type on performance on reading comprehension or mood (pleasure, arousal and dominance).

By Boyce et. al. (2000) the relationship between illuminance, task performance and mood was investigated. The study found that individual lighting control systems are not useful in enhancement individuals' mood.

Lighting is undeniably an important atmospheric tool, which influences individuals' mood and behavior. There are several studies examining the effects of lighting on individuals' mood however, a certain result could not be derived. Therefore, this study aims to explore the relationship between mood and CCT to prove that an ideal CCT level enhances individuals' mood hence, their sustained attention increases. This enhancement can be important and useful in learning environments to improve students' sustained attention during learning processes.

CHAPTER V

LIGHTING AND CCT

5.1. Lighting and CCT

Humans receive a variety of influences from light and light is indispensable for everyday life. Light has a broad range of effects on its' users and changes their experiences in an environment (Katsuura, 2000). Without the existence of light, the physical qualities of an environment cannot be well perceived, so light can be called as the central concept of architecture and visual experience as achieved by seeing and interpreting elements within that environment (Egan & Olgyay, 2002). Light is an architectural element that should be designed well to provide better interior spaces; because lighting of an environment does not only affect its' users physiologically, but also affects them psychologically (Kumoğlu, 2013). Both visual effects of light and non-visual effects of light can be effective on humans' cognition and behavior. Lighting has visual and non- visual biological effects which are related with individuals' visual performance, health and well- being and there is an

interrelationship between visual, non- visual and emotion that determine individuals' visual performance (Van Bommel, 2006) (See Figure 4).

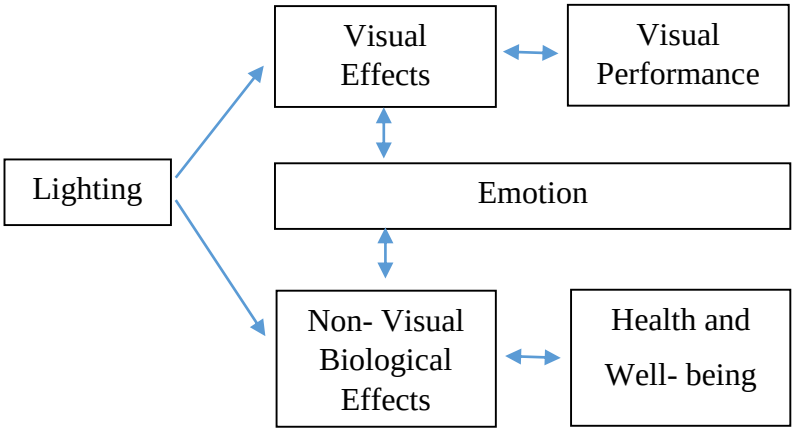

Figure 4: A diagram showing the relationship between lighting and its effects (Source: Van Bommel, W. J. (2006). Non-visual biological effect of lighting and the practical meaning for lighting for work. *Applied ergonomics, 37*(4), 461-466)

In order to discuss the effects of CCT on sustained attention and mood of university students in learning environments, first understanding the main elements of lighting is important.

According to American National Standards (1987), one of the fundamental aspects of lighting is the quality of lighting and Correlated Color Temperature is one of the most important components of quality of light about human perception, which provides comfortable and effective visual environments (Veitch & Newsham, 1998; Katsuura, 2000; Samani, 2011). The other aspect is the quantity of light, which is measured mostly through illuminance or luminance.

There are two basic properties of light; illuminance and luminance. Illuminance is density of luminous flux incident on a surface and it is measured in lumens per square meter, lux. Lux can be measured with an illuminance meter (Egan & Olgyay, 2002). Luminance is the measured brightness and is a directional quantity. Luminance is defined as the intensity of visible brightness of a source or surface in the direction of the observer, divided by the area of the source or surface seen, cd/m^2. Luminance can be measured with a luminance meter (Egan & Olgyay, 2002). Both illuminance and luminance are significant terms in understanding the characteristics of light and helps to discuss the effects of CCT, for this study CCT is focused in a more detailed way.

CIE Chromaticity chart (See Figure 5) shows a light source's color temperature, which chromaticity coordinates fall on the Planckian locus, and it is equal to the blackbody temperature of the Planckian radiator (McCamy, 1992). "Blackbody characteristics at different temperatures are defined by Planck's radiation law. The perceived colors of blackbody radiators at different temperatures depend on the state of adaptation of the observer as the temperature rises, the color changes from red to orange to yellow to white to blue" (Rea, 2000).

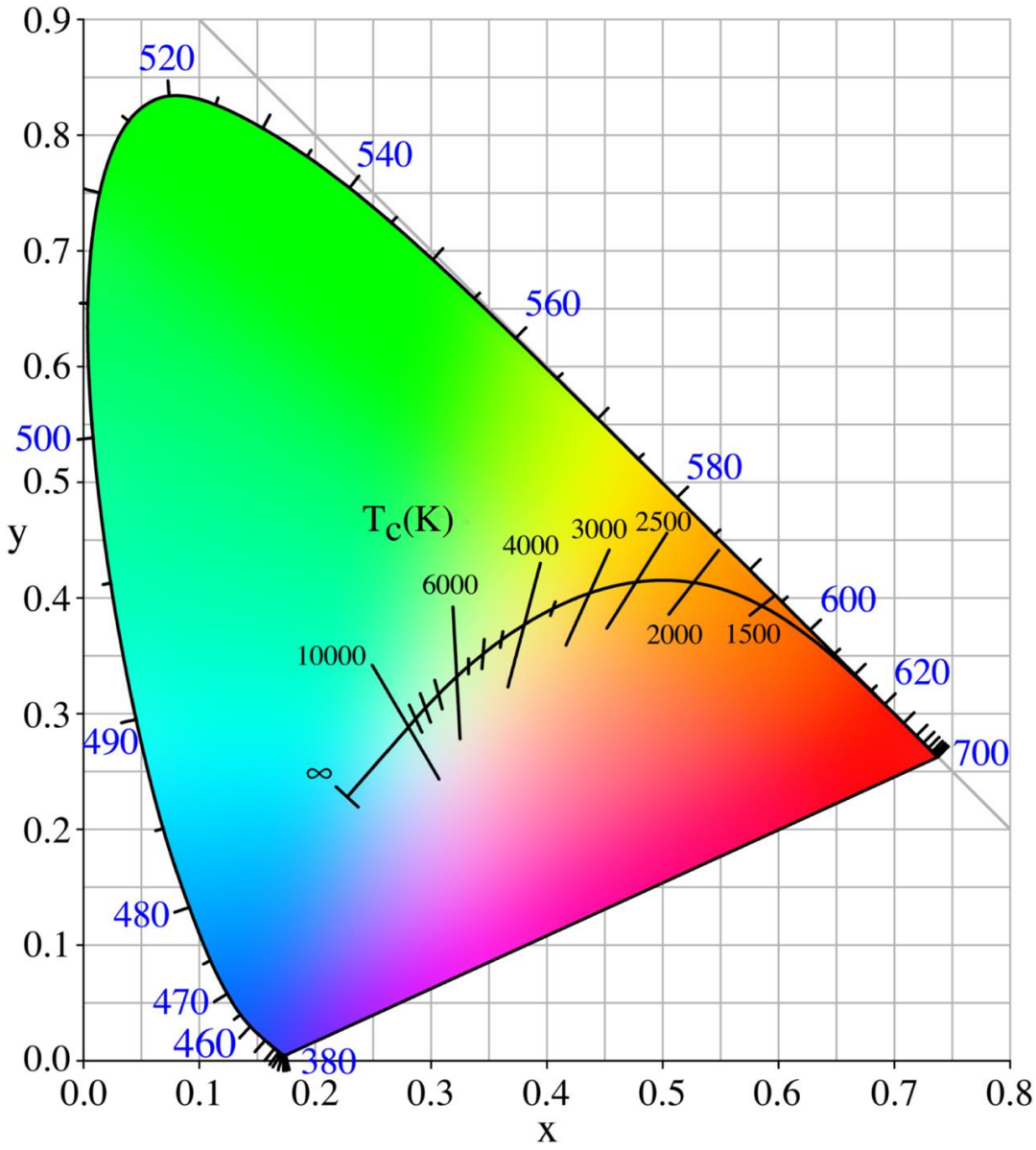

Figure 5: Black body locus on CIE chromaticity diagram

(Source: http://en.wikipedia.org/wiki/Planckian_locus)

The locus of blackbody chromaticities on the x, y diagram known as the planckian locus. Any chromaticity represented by a point on this locus can be specified by color temperature. Correlated color temperature should be used to specify a chromaticity that does not lie on the Planckian locus (Rea, 2000). Correlated color

temperature is the temperature of color that matches on the radiator locus, where adjacent point signifies the chromaticity of the lighting measured on a uniform-chromaticity- scale diagram (Coaton & Cayless & Marsden, 1997).

The Correlated Color Temperature of light is defined as the absolute temperature (Kelvin; K) of the perfect black body that irradiates the light equivalent to the color of the light source. Correlated Color Temperature expresses light source's warmth or coolness like yellowish white, bluish white, or neutral in appearance, not the spectral energy distribution or the physical temperature (Egan & Olgyay, 2002). The tincture of blue increases at a higher color temperature, while the tincture of red increases at a lower color temperature (See Figure 6) (Katsuura, 2000). For this study, 4000 K and 6500 K is used because 4000 K is at the mid- range and 6500 K is between cool white and daylight range. According to several studies without deriving any certain results, 4000 K and 6500 K are the lower and upper limits for both increasing sustained attention and mood.

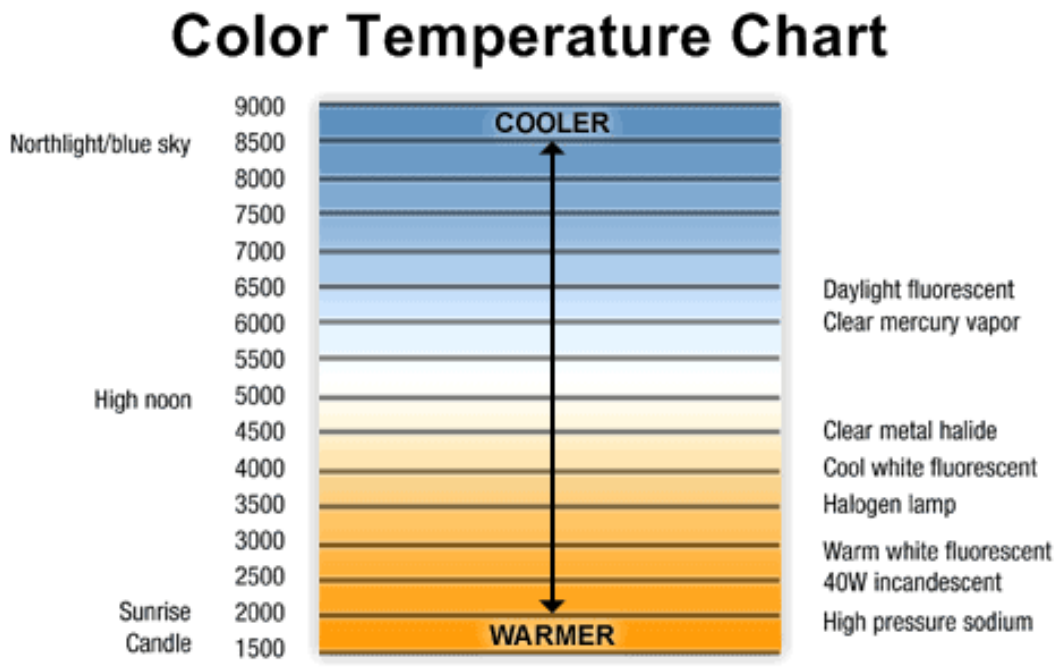

Figure 6: A chart showing the color temperature and artificial light sources

(Source: http://www.bulborama.com/lightingreferenceglossary-13.html)

The Color Rendering Index (CRI) is defined by Egan & Olgyay (2002) as the measure of how well the light source renders color. It can be called as the effect of the light source on the color appearance of objects (Rea, 2000). As CRI gets higher, the lighting source show the colors become more natural. CRI is measured on a scale from 0–100 where 100 is the best. For example, a lighting with CRI of 100 appears more natural (Philips A to Z Product Knowledge, May 15, 2015). The CRI is an indication of how similar the color of an object is rendered by a light source relative to a specific Kelvin temperature on the black body line (Kumoğlu, 2013). While comparing lighting sources, it is important to have the same color rendering indices.

Kruithof Curve is explaining the relationship between the color temperature and the illuminance level. There is an area within that curve called as the ‘pleasing area’ that states the possible combinations of CCT and illuminance levels for obtaining

pleasing lit environments (See Figure 7). The upper area of that curve appears reddish and the lower area appears bluish (Rea, 2000).

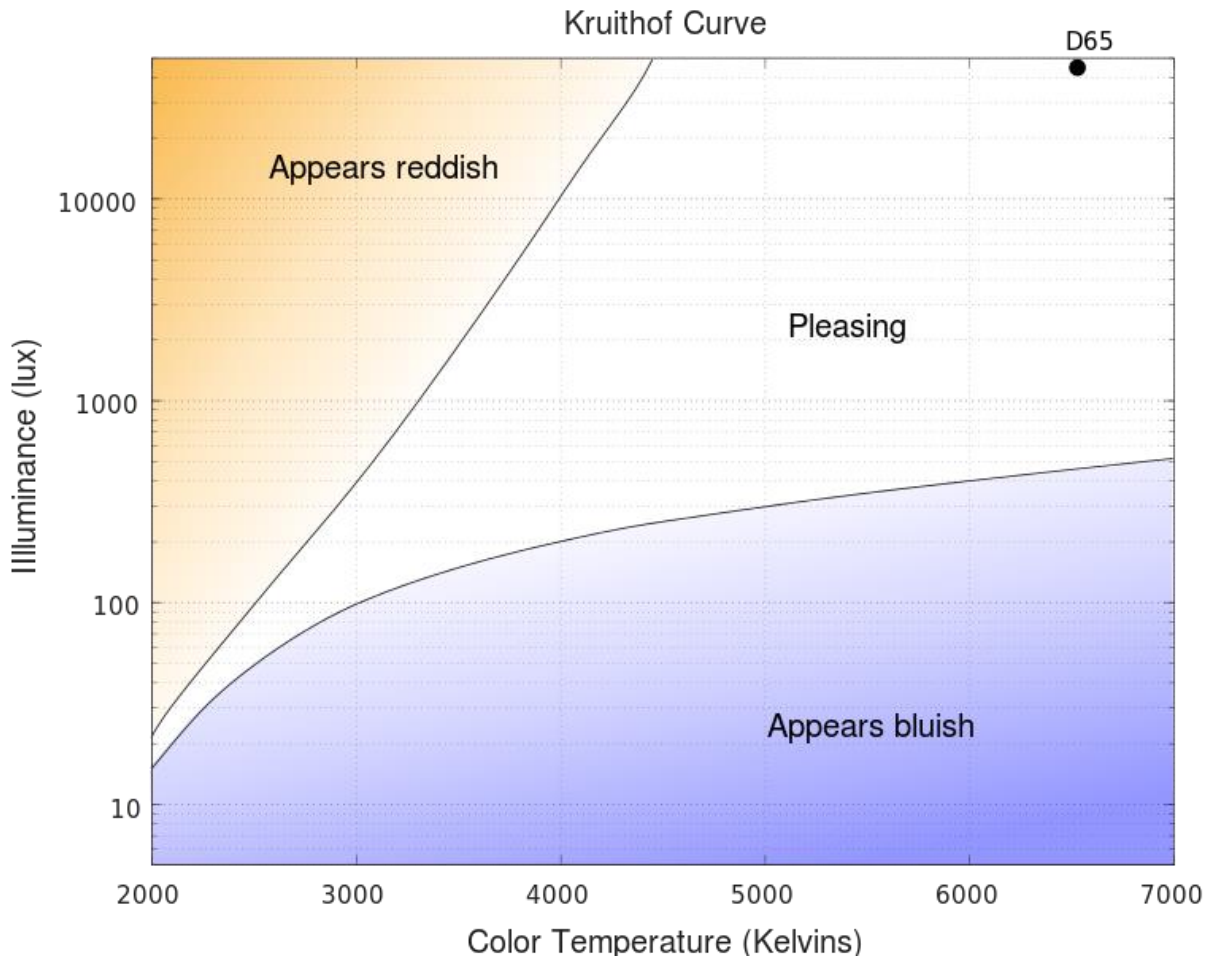

Figure 7: A diagram showing the Kruithof Curve

(Source: http://en.wikipedia.org/wiki/File:Kruithof_curve_2.svg)

In order to explore the effects of correlated color temperature on sustained attention and mood, it is essential to distinguish the properties of different lighting sources such as incandescent lamps, halogen lamps, fluorescent lamps, High Intensity Discharge lamps (HID) and Light Emitting Diode (LED). Thus, several lighting sources are explored briefly.

Incandescent lamps produce light when an electric current heats the tungsten filament of lamp up until it glows (Rea, 2000). According to American National Standard (1987) incandescent lamps have high color rendering ability and low initial cost. The life span of a standard incandescent lamp is 750 hours to 1250 hours and CCT varies from 2400 K to 2900 K (Philips A to Z Product Knowledge, May 15, 2015).

Halogen lamps are technically incandescent lamps with some differences caused by altered technical features; it contains small amount of halogen gas. They are whiter, brighter and have longer life span and CCT varies from 2800 K to 3200 K and have a CRI of 95- 100 (Karlen et. al., 2012; Philips A to Z Product Knowledge, May 15, 2015).

Fluorescent lamps are low energy cost lamps than incandescent and halogen lamps their life span are longer, they can operate up to 20000 hours. The operation of fluorescent lamp is different from incandescent and halogen lamps; when fluorescent lamp is started the electrodes at the end of opposite corners of the lamp release electrons. In the tube, during the travel of the electrons, they collide and start a chemical reaction with the mercury atoms and with this collision mercury molecules releases invisible ultraviolet energy. With the hits of the mercury molecules to the inner coat of the fluorescent tube, the phosphor turns the ultraviolet energy into visible light (Philips A to Z Product Knowledge, May 15, 2015). CCT of fluorescent lamps vary from 2700 K to 12000 K, which cover wide range than other lamps. Fluorescent lamps have a CRI of 80- 90 (Karlen et. al., 2012).

High Intensity Discharge lamps (HID) contain metal halide, mercury vapor and high-pressure sodium. An electric current that passes through a high-pressure vapor in HID lamps, which produces light. This produced light has longer life and it is very effective (Philips A to Z Product Knowledge, May 15, 2015). HID lamps' CRI varies from 20 to 95 and its CCT ranges from 2000 K to 6700 K. Its life span is up to 24000 hours, which is longer than other lamp types. One disadvantage of HID lamps is, it need a warm- up period which can last from 3 to 10 minutes depending on its type and wattage before it gives full light output (Philips A to Z Product Knowledge, May 15, 2015). According to Rea (2000), HID lamps are used outside such as streets, bridges, stadiums, tunnels and building facades because they have poor color, high brightness it can operate under different weather conditions and temperatures.

Light Emitting Diode (LED) is an electronic light source, which is a semiconductor that emits visible light of a certain color (Kumoğlu, 2013). Unlike other light sources, light-emitting diodes has many advantages such as longer life spans, lower energy consumptions, faster reaction times and it is more environmental friendly because there is no toxic lead, mercury or gas. It does not have a fragile lamp bulb that may cause damages (Huang et. al., 2013; Kumoğlu, 2013). In terms of operation and technical properties, LEDs are different from incandescent, halogen and fluorescent lamps. LEDs have become a new lighting device increasingly adopted in working, living and public environments (Huang et. al., 2013).

"There is both a theoretical and a practical value in knowing how the physical parameters of the indoor environment may combine or interact in producing effects on affect and cognition" (Knez, 2001). Interior lighting aims to generate comfortable

and efficient environments, visually and psychologically. The existence of visual and psychological comfort circumstances, which are both covered by the quality and quantity of light, confirms user being well and increases their motivation that will enhance them to perform and produce better (Manav, 2007). Lighting conditions influence performance through the intervening variable of positive affect (Baron et al., 1992). Education, skill, previous experiences and knowledge affect the performance and definitely lighting has an influence on the attention and performance level, to accomplish a task, that have been disregarded for most of the time; it is the least expensive and most important factor which effects user's performance in an environment (Katzev, 1992).

A good visual environment allows users to focus on the information of interest without the distraction of competing non-relevant information (Egan & Olgyay, 2002). According to Fotios (2011, p. 114):

> "The purpose of lighting is to give information: to enable the people in a space to perceive the nature of the space they are in, what other people are doing and what they have to accomplish in a task. Interior spaces require light so that they may be used safely, so that the occupants have a comfortable visual environment and to enhance the performance of visual tasks. Artificial lighting is provided for situations where daylight is insufficient to meet these needs. In offices, as with other workplaces, lighting is needed so that the occupants can see to carry out their work tasks quickly, accurately and easily. There are three routes whereby the visual environment, and thus lighting, can influence task performance: by changing the visibility of the task (the visual system), by

changing the mood of workers and hence their motivation to do the task (the perceptual system) and by stimulating greater alertness (the circadian system). Consideration of all three aspects is needed to ensure a visual environment that maximizes productivity."

Light is needed in interior spaces in order to provide comfortable environments for users to carry on their visual tasks (Fotios, 2011; Manav & Yener, 1999; Shamsul et. al., 2013). When there is not enough visual comfort in an environment to differentiate the signal and the background, occupants become uncomfortable and tend to make more mistakes (Egan & Olgyay, 2002). The accuracy and the speed of a person while doing a task is related with the objects' level of recognition and lighting level should be sufficient to provide adequate working environments (Van Bommel, 2006).

With the usage of proper artificial lighting, visual comfort, well- being and health can be achieved; according to Van Bommel (2006) by following the human rhythm with artificial dynamic lightings, a comfortable environment could be attained. Van Bommel (2006) studied the non- visual effects of lighting in working environments and he suggested that with right combinations of lighting level and color temperature, natural activation and relaxation can be obtained so fewer errors, fewer accidents and better work performance also be gained.

According to American National Standard (1987), accomplishing a task and mood setting can be enhanced by the improved qualities of lighting. Light determines how a user perceive the space that they are in and light should produce an atmosphere and

correspondingly produce a mood in that space (Cullen, 1986; Flagge, 1994). It is pointed out by American National Standard (1987) that "impressions or moods are often fundamental in satisfying some experience and activity requirements in a designed space. Light atmospheres can give rise to a happy or contented state of being, but it can also make man suffer. It is stated that light is a kind of vehicle for influencing users' selective attention or altering the informational content of the visual field". Also in learning environments, CCT is an indispensable aspect because it supports and enhances the impact of lighting on users (Samani, 2011; Shamsul et. al., 2013).

It is important to understand the relationship between sustained attention levels and mood of students in lecture environments and correlated color temperature. Several important aspects of educational research has been made such as the contents of learning materials, time frames of the courses and how teachers' should give education whereas about learning environments it is not possible to find sufficient research. The research about the effects of physical characteristics of the learning environments on students, like lighting, is limited (Dunn et. al, 1985; Sleegers et. al., 2012). The effects of correlated color temperature on sustained attention level and on mood is explored independently mostly in working environments with adults (Fotios, 2011; Knez, 1995; Knez, 2001; Küller, 2006; Manav, 2007; McCloughan et. al., 1999; Rautkyla et. al., 2010; Shamsul et. al., 2013; Sleegers et. al., 2012; Taniguchi et. al., 2011; Veitch, 1997; Veitch &Newsham, 1998) and according to Sleegers et. al. (2012) those studies do not unequivocally verify or falsify the effects of lighting. The studies about school environments are limited, and still there is lack of research

in literature exploring the effects of correlated color temperature on both sustained attention level and mood of students in learning environments.

5.2. Lighting in Learning Environments

Natural lighting during daylight hours should always be the major source in learning environments (Building Bulletin 90, 2008). When natural lighting cannot be sufficient in some cases like during an overcast day, artificial lighting should be used to support natural lighting. While using artificial lighting in learning environments, it is important to reduce or eliminate direct glare for gaining a comfortable environment and it is important to provide ceiling and upper wall surface to be illuminated (Benya, 2007) (See Figure 8). With proper lighting equipment, it is possible to provide comfortable learning environments, which support learning.

Figure 8: A view from an example of artificial lighting in learning environment

(Source: Benya, J. R. (2007). *LEED and Lighting for Schools*)

It is the main concern to provide a comfortable visual milieu in learning environments for enhancing students' learning processes. With the help of improved lighting qualities, when the visual task can be seen quickly and accurately, better learning process can be achieved (Rea, 2000). The required illuminance level in learning environments are proven by many studies, its standard is stated in literature. The required illumination level in learning environments is given as the minimum of 300 lux (Building Bulletin 90, UK 2008; Turkish Standards TS 9518, 2000; Yener, 2011). However, there is lack of information in literature about the recommended correlated color temperatures in learning environments.

In learning environments, the psychology and the emotional needs of the learners should be reinforced by physical aspects such as lighting. Enhancing the feeling of spaciousness, supporting and motivating the behaviors of the learners to learn and at the same time transforming the learning environment into a more pleasant and attractive place can be achieved by the lighting conditions (Rea, 2000). According to The Chartered Institution of Building Services (CIBSE) "the illumination system in learning environments should be sufficient to perform activities like reading and writing on the horizontal desk plane (paperwork) and vertical chalkboard, whiteboard or charts, projector screens and other displays on the walls". Visual tasks in educational facilities vary in size, contrast, viewing direction, and distance. The primary critical tasks are reading and writing, commonly requiring prolonged and close attention (Rea, 2000). According to PIER (*Public Interest Energy- Efficiency Research Program* of the California Energy Commission); teachers prefer and employ multiple scene classroom lighting systems and teaching with board lights contribute to student attention and retention (PIER, 2002).

"It is necessary to light the space so that it appears 'bright' and 'interesting'. Light surfaces, particularly the walls and perhaps the ceiling too, contribute to this impression. It is also desirable to achieve a degree of non-uniformity in the light pattern, as spaces, which have areas of, light and shade are generally liked, but it is important for this variation in brightness not to be too great, otherwise poor visibility or even visual discomfort may result" (Building Bulletin 90, 2008). Glare should be avoided and a uniform distribution of light is required in the classrooms (Yener, 2011).

The most commonly used lighting source in learning environments is the linear fluorescents also used in this study. Fluorescent lamps can give good color performance, color rendering and appearance, can provide a relatively even pattern of light and at the same time have good efficacy, which states how good a light source can produce visible light (Building Bulletin 90, 2008). Even though fluorescent lamps are the most common light sources in learning environments, with the developing technology some studies are examining the usage of LEDs in school interiors. Those studies show that usage of LED increases the performances of students. In a field study and a following laboratory testing, they showed consistently that increasing the color temperature and illumination levels with LEDs in the morning hours led to a higher performance in alertness tests and school related tasks (Liu & Wojtysiak, 2013).

It is important to provide comfortable learning environments but at the same time it is also important to ensure students' health. Some researches (Wilkins & Clark, 1990; CIBSE, 2011) has shown that "approximately 14% of the population are

susceptible to eyestrain and headaches caused by 50Hz fluorescent lighting and that this reduces to about 7% with high frequency fluorescent lighting. Epilepsy is sometimes triggered by low frequency flashes of light by which can occur with strobe lights, with some compact fluorescent lamps at ignition, or more generally with discharge lamps at the end of their life. Flicker at less than 4 flashes per second is unlikely to be a problem. Other studies have shown that people prefer lighting, which creates a 'light' interior with a non-uniform light pattern (Lui & Wojtysiak, 2013). There is currently no evidence that this form of lighting improves health, but if people prefer it, the feeling of 'wellbeing' which is created can only be beneficial" (Building Bulletin 90, 2008).

CHAPTER VI

THE EXPERIMENT

6.1. Aim of the Study

This study compares the effects of different correlated color temperatures on university students' sustained attention and mood in learning environments. The aim of the study is to understand the effects of CCT on sustained attention and mood of university students in learning environments.

6.1.1. Research Questions

1. Is there a significant effect of correlated color temperature of lighting on sustained attention levels of university students' in terms of the concentration performance (CP) in d2 Test of Attention?

2. Is there a significant effect of correlated color temperature of lighting on sustained attention levels of university students' in terms of the number of errors in d2 Test of Attention?

3. Is there a significant effect of correlated color temperature of lighting on university students' mood?

6.1.2. Hypotheses

1. Students' Concentration Performance (CP) in d2 Test of Attention will be increased at 6500 K than 4000 K.

2. Students' number of errors in d2 Test of Attention will be decreased at 6500 K than 4000 K.

3. Students' Positive Affect (PA) in PANAS will be increased at 6500 K than 4000 K.

6.2. Method of the Study

6.2.1. Sample Group

The sample group of the study consisted of undergraduate students from Interior Architecture and Environmental Design Department at Bilkent University. The students of IAED 244 Lighting Design 2014- 2015 Spring Semester course and IAED 342 Sustainable Design for Interiors 2014- 2015 Spring Semester course were chosen; because the two courses had similar scientific area content and same lecture hours. The total number of the sample group were ninety seven students; thirty two

students were from the IAED 244 Lighting Design 2014- 2015 Spring Semester course and sixty five students were from IAED 342 Sustainable Design for Interiors 2014- 2015 Spring Semester course. The students' age range were from 18 to 25. There was a student with learning disability; dyslexia who was excluded from the sample group. The experiment was performed with two different sample groups for the two different experiment sets having identical characteristics except different correlated color temperatures.

6.2.2. Procedure

6.2.2.1. Setting of the Experiment

The settings of the experiment were two 5.50 m x 10.94 m x 3.65 m classrooms at Bilkent University FF Building, FF 102 and FF 202 (See Figure 9). The ceiling and walls of the classroom are white, and flooring is dark grey granite tile (See Appendix C Table 7, 8). The classroom is a regular lecture room and daylight penetration was totally blocked with dark blue curtains and black paperboards. The existing lighting equipment was replaced with Philips Master TL-D Super 80 36W/840 1SL for 4000 K and Philips Master TL-D Super 80 36W/865 1SL for 6500 K (See Figure 10). The classroom was illuminated before the start of the session for adaptation and was kept open until the end of the session.

Figure 9: A view showing the setting of the experiment

Figure 10: A view showing the setting of the experiment

6.2.2.2. Sets of the Experiment

It is important to have different correlated color temperature lighting sets to understand its effects on sustained attention level and mood of university students in learning environments. There were two identical experiment settings with two different lighting equipment in terms of having different correlated color temperatures. One lighting equipment was set to 4000 K (Cool White) and the other was set to 6500 K (Cool Daylight). There were eight luminaires fixed at ceiling in the selected classrooms and each luminaire contains two fluorescent tubes. Only the fluorescent tubes were changed in order to have different correlated color temperatures. The lighting equipment had the same luminance flux; 500 lux, had the same color rendering indices; 85 Ra8 and same luminous flux; 3250 Lm and 3350 Lm (See Appendix). Illuminance level was measured in the experiment setting with Konica Minolta T-1 Illuminance Meter (range of 0.01 to 99,900 lux). The average recorded illuminance values in the experiment setting for 6500 K was 412 lux and for 4000 K was 401 lux at the standard working level of 0.7 meters above the floor level.

6.2.2.3. The Experiment

The experiments were conducted in two weekdays; March 4th, 2015 Wednesday and March 6th, 2015 Friday. IAED 244 Lighting Design 2014- 2015 Spring Semester course and IAED 342 Sustainable Design for Interiors 2014- 2015 Spring Semester courses were chosen. Both courses had the same class slots, classes started at 10:40 and ended at 12:30 and were at identical classrooms, FF 102 and FF 202 (See Figure 11).

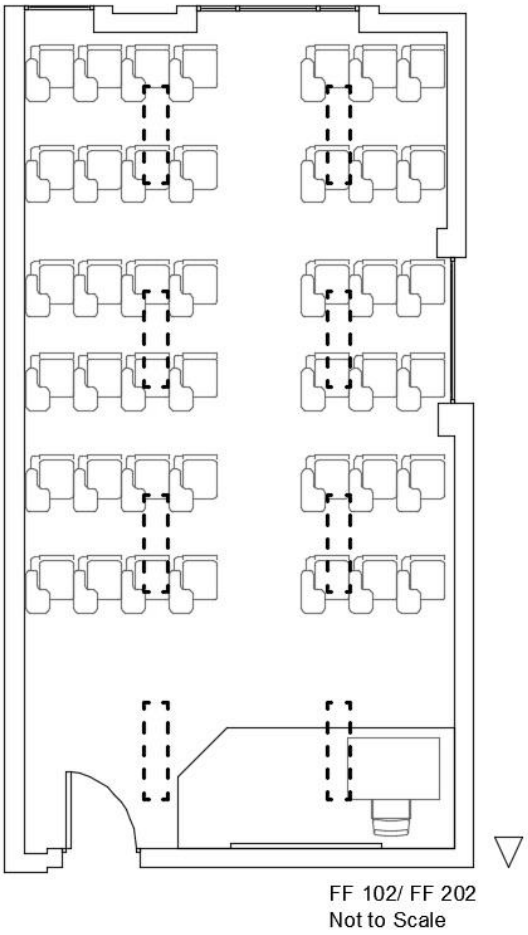

Figure 11: Plan of the setting of the experiment

Philips Master TL-D Super 80 36W/865 1SL for 6500 K were installed at FF 102 and Philips Master TL-D Super 80 36W/840 1SL for 4000 K were installed at FF 202 for the experiments on March 4th, 2015 Wednesday (See Table 1).

Table 1: A table showing the number of participants, location, time and distribution of the CCTs

	Male	**Female**	**Total**	**Total**	**CCT**	**Time**	**Location**
IAED 244-03	3	15	18	53	6500 K	March 4th 2015 Wednesday	FF 102
IAED 342-02	6	29	35		6500 K	March 6th 2015 Friday	FF 202
IAED 244-04	4	10	14	44	4000 K	March 6th 2015 Friday	FF 102
IAED 342-01	4	26	30		4000 K	March 4th 2015 Wednesday	FF 202
Total	17	80	97				

The experiments were conducted in a single phase and all the participants were tested in-group format by the researcher (See Figure 12). The participants were seated at regular school desks and they participated their regular lectures for at least one class hour. All the participants were asked to perform three paper- based tests; one of them about the sustained attention, d2 Test of Attention, and the other two about mood, PANAS (Positive and Negative Affect Schedule) (See Figure 13). Before the experiment sessions, participants were informed briefly about the procedures of the tests. Before the lecture started, participants were asked to take the test; PANAS. After completing PANAS, the regular lecture started. At the end of the lecture, participants were asked to take the PANAS test again for rating their mood after the lighting exposure for at least one class hour. For the PANAS there is no time limitation for participants to complete the self- reported mood-rating test. Then d2 Test of Attention were distributed to the participants to understand the effects of CCT on their sustained attention (See Figure 14). For the d2 Test of Attention; the given time is limited. There are 14 lines and 47 items at each line; for each line, the participants are given 20 seconds. For the total of the d2 Test of Attention approximately 5 minutes are given.

Each experiment session lasted for 10-15 minutes and was repeated on March 6th, 2015 Friday with Philips Master TL-D Super 80 36W/865 1SL for 6500 K installed at FF 202 and Philips Master TL-D Super 80 36W/840 1SL for 4000 K installed at FF 102 for the second phase of the experiments.

Figure 12: A view showing one session of the experiment

Adı Soyadı:

Yaş:

Tarih:

The Positive and Negative Affect Schedule (PANAS; Watson et al., 1988) PANAS Questionnaire (Pozitif ve Negatif Duygu Olçeği)

This scale consists of a number of words that describe different feelings and emotions. Read each item and then list the number from the scale below next to each word. Indicate to what extent you feel this way right now, that is, at the present moment. (Aşağıdaki maddelerde çeşitli duygu ve hisleri tanımlayan sözcükler yer almaktadır. Her bir maddeyi okuyunuz ve her bir sözcük için 1'den 5'e kadar numaralandırma yapınız. Içinde bulunduğunuz şu an için bu duyguları hangi sıklıkla yaşadığınızı belirtiniz.)

1	2	3	4	5
Very Slightly or Not at All (Çok Az veya Hiç)	A Little (Biraz)	Moderately (Kısmen)	Quite a Bit (Sık Sık)	Extremely (Çok Fazla)

_____1.Interested (Ilgili)
_____2.Distressed (Sıkıntılı)
_____3.Excited (Heyecanlı)
_____4.Upset (Mutsuz)
_____5.Strong (Güçlü)
_____6.Guilty (Suçlu)
_____7.Scared (Urkmüş)
_____8.Hostile (Düşmanca)
_____9.Enthusiastic (Hevesli)
_____10.Proud (Gururlu)
_____ 11. Irritable (Tedirgin)
_____ 12. Alert (Uyanık)
_____ 13. Ashamed (Utanmış)
_____ 14. Inspired (Ilhamlı)
_____ 15. Nervous (Sinirli)
_____ 16. Determined (Kararlı)
_____ 17. Attentive (Dikkatli)
_____ 18. Jittery (Asabi)
_____ 19. Active (Aktif)
_____ 20. Afraid (Korkmuş)

Figure 13: 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.)

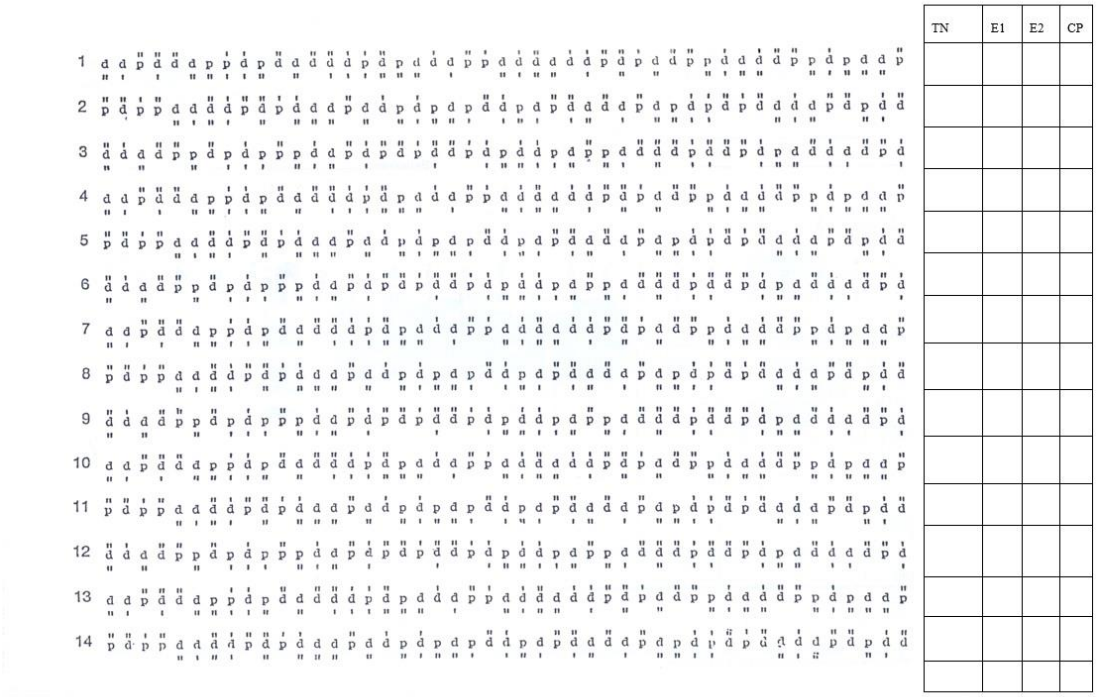

Figure 14: d2 Test of Attention

(Source: Bates, M. E., & Lemay, E. P. (2004). The d2 test of attention: construct validity and extensions in scoring techniques. *Journal of the International Neuropsychological Society*, 10(03), 392-400.)

6.3. Findings

Statistical Package for the Social Sciences (IBM Corp. SPSS) 20.0 was used to analyze the data. In the analysis of the data, Mann Whitney- U test, Wilcoxon Sign Test and Spearman's Rank Order Correlation test were used.

Findings from the statistical analysis are given in respect of the stated research questions (See sec. 6.1.1.).

For the study there were 78 female subjects (80.4%) and 19 male subjects (19.6%) at total (See Table 2).

Table 2: A table showing gender distribution numbers and percentages of subjects

		4000 K (14 Subjects)		**4000 K (30 Subjects)**		**6500 K (18 Subjects)**		**6500 K (35 Subjects)**		**Total**	
		n	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Gender	**Female**	10	71.4	26	86.7	15	83.3	27	77.1	78	80.4
	Male	4	28.6	4	13.3	3	16.7	8	22.9	19	19.6
	Total	14	100.0	30	100.0	18	100.0	35	100.0	97	100.0

The sample group of the study was university students, so their ages varied from 19 to 27. The mean age was 22.1 (See Table 3).

Table 3: A table showing the subjects' distribution of ages

	n	Mean	Median	Minimum	Maximum	S.D.
4000 K (14 Subjects)	14	21.2	21.0	19.0	24.0	1.6
4000 K (30 Subjects)	30	22.0	22.0	20.0	27.0	1.6
6500 K (18 Subjects)	18	21.9	22.0	19.0	27.0	2.1
6500 K (35 Subjects)	35	22.6	22.0	20.0	26.0	1.6
Total	97	22.1	22.0	19.0	27.0	1.7

Four sections of (two sections for each of the courses) were used for the study. For combining four sections to have two main sample groups for each correlated color temperature level, a statistical test, Mann-Whitney U Test was used to understand if there is a difference between those independent groups.

There were 14 and 30 subjects at two different sections at the experiment Set 1 (4000 K CCT). The PANAS (Before PA, After PA, Before NA and After NA) values were compared with Mann- Whitney U Test. According to Mann- Whitney U Test, there were no significant difference between groups at 99.5% Confidence Interval (Before PA; U (n_1= 14, n_2= 30)= 196, two- tailed, p= 0.723, After PA; U (n_1= 14, n_2= 30)= 177.5, two- tailed, p= 0.411, Before NA; U (n_1= 14, n_2= 30)= 201, two- tailed, p= 0.819, After NA; U (n_1= 14, n_2= 30)= 166.5, two- tailed, p= 0.271) (See Appendix C,

Table 9). So, two different sections with 14 and 30 subjects could be combined and one sample group of 44 subjects was obtained at experiment Set 1 (4000 K CCT).

There were 18 and 35 subjects at two different sections at the experiment Set 2 (6500 K CCT). The PANAS (Before PA, After PA, Before NA and After NA) values were compared with Mann- Whitney U Test. According to Mann- Whitney U Test, there was no significant difference between groups at 99.5% Confidence Interval (Before PA; U (n_1= 18, n_2= 35) = 267.5, two- tailed, p= 0.371, After PA; U (n_1= 18, n_2= 35) = 292, two- tailed, p= 0.665, Before NA; U (n_1= 18, n_2= 35)= 299.5, two- tailed, p= 0.711, After NA; U (n_1= 18, n_2= 35)= 292.5, two- tailed, p= 0.669) (See Appendix C, Table 10). So, two different sections with 18 and 35 subjects could be combined and one sample group of 53 subjects was obtained at experiment Set 2 (6500 K CCT).

6.3.1. The Effects of CCT on Sustained Attention

The effects of correlated color temperature on sustained attention were evaluated and analyzed with the outcomes of d2 Test of Attention;

- Total Number of Items Processed
- Errors of Omission
- Errors of Commission
- Error Percentage
- Concentration Performance

The outcome measures of d2 Test of attention are; the total number of items processed (TN), the number of errors (errors of omission (EO); d's with two dashes that were not marked), the number of false alarms (errors of commission (EC); marked d's with less or more than 2 dashes or p's) (Brickenkamp & Zillmer, 1998). The evaluation criteria are; number of errors (E%) which is the sum of errors of omission (EO) and errors of commission (EC) over total number (TN) and concentration performance (CP) which is the total number of correctly marked items (Bates & Lemay, 2003; Wassenberg et. al., 2008; Sleegers et. al., 2012).

To understand the effects of correlated color temperature on sustained attention of university students, the outcomes of d2 Test of Attention of the experiment Set 1 (4000 K CCT) and experiment Set 2 (6500 K CCT) were compared with Mann-Whitney U Test. Total number of items processed, errors of omission, errors of commission, error percentage and concentration performance values were compared separately for experiment Set 1 and experiment Set 2 (See Table 1).

Mann- Whitney U Test indicated that, the effect of CCT on the total number of items processed was not to be significant ($U (n_1= 44, n_2= 53) = 1050$, two- tailed, $p= 0.402$) (See Appendix C, Table 11). Therefore, CCT does not have an effect on a student's ability to visually scan the total number of items in d2 Test of attention.

Mann- Whitney U Test indicated that the effect of CCT on the errors of omission was not to be significant ($U (n_1= 44, n_2= 53) = 921$, two- tailed, $p= 0.075$) (See

Appendix C, Table 11). CCT does not have an effect on the number of the correct items, which omitted without marked.

Mann- Whitney U Test indicated that the effect of CCT on errors of commission was significant (U (n_1= 44, n_2= 53) = 723, two- tailed, p= 0.001) (See Appendix C, Table 11). Errors of commission of 4000 K CCT was significantly higher than 6500 K CCT. Thus, CCT have an effect on the number of incorrectly marked items; 6500 K CCT decreases the number of errors of commission. Therefore, 6500 K enhances students' sustained attention than 4000 K and helps them to become more attentive for not to make mistakes.

Mann- Whitney U Test indicated that the effect of CCT on the error percentage was significant (U (n_1= 44, n_2= 53) = 697, two- tailed p= 0.0001) (See Appendix C, Table 11). Error percentage of 4000 K CCT was significantly higher than 6500 K CCT. Therefore, CCT have an effect on the error percentage (total numbers of errors of omission and errors of commission over the total items processed) a student makes, 6500 K CCT decreases the error percentage. So, 6500 K enhances students' sustained attention than 4000 K.

Mann- Whitney U Test indicated that the effect of CCT on the concentration performance was not to be significant (U (n_1= 44, n_2= 53) = 1022, two- tailed p= 0.296) (See Appendix C, Table 11). CCT does not have an effect on the concentration performance of a student.

Table 4: A table showing mean values and the outcomes of Mann- Whitney U Test of 4000 K and 6500 K CCT

4000 K/ 6500 K		n	Mean	Mann- Whitney U Test		
				Rank Sum	U	P
TN	**4000 K**	44	504.2	51.6	1050	0.402
	6500 K	53	486.1	46.8		
EO	**4000 K**	44	56.5	54.6	921	0.075
	6500 K	53	42.7	44.4		
EC	**4000 K**	44	22.6	59.1	723	0.001
	6500 K	53	7.4	40.6		
E%	**4000 K**	44	15.3	59.7	697	0.0001
	6500 K	53	10.1	40.2		
CP	**4000 K**	44	160.3	45.7	1022	0.296
	6500 K	53	169.0	51.7		

6.3.2. The Effects of CCT on Mood

The effects of correlated color temperature on mood of university students were evaluated and analyzed with the below outcomes of PANAS;

- Positive Affect
- Negative Affect

Both positive affect and negative affect should be evaluated together.

One of the outcomes of PANAS is positive affect (PA). Getting 50 points at most from PA states high energy, full concentration and pleasurable engagement. The other outcome of PANAS is negative affect (NA). Getting 10 points at least from NA states calmness and serenity. Getting 50 points from PA and 10 points from NA is the most desired condition for an individual to be fully concentrated and calm (Watson & Clark, 1997).

To understand the effects of CCT on university students' mood during the lighting exposure, their before PA- after PA values and before NA- after NA values were compared for 4000 K with Wilcoxon Sign Test (See Table 5).

Wilcoxon Sign Test indicated that there were no significant difference between before PA and after PA values (Z (n= 44) = -1.4, two- tailed, p= 0.161) (See Appendix C, Table 12). Wilcoxon Sign Test indicated that there were no significant difference between before NA and after NA values (Z (n= 44) = -0.6, two- tailed, p= 0.547) (See Appendix C, Table 12).

According to the findings, both positive and negative mood of students decreased after the lighting exposure of 4000 K CCT. Having NA value decreased after the lighting exposure is a desired condition to be fully concentrated however having PA value decreased is not (See Table 5).

Table 5: A table showing mean values and the outcomes of Wilcoxon Sign Test of 4000 K

4000 K	Wilcoxon Sign Test					
	n	Mean	Negative Rank	Positive Rank	z	p
Before PA	44	26.2	24.5	16.1	-1.4	0.161
After PA	44	24.3				
Before NA	44	16.3	20.8	22.4	-0.6	0.547
After NA	44	15.9				

To understand the effects of CCT on university students' mood during the lighting exposure, their before PA- after PA values and before NA- after NA values were compared for 6500 K with Wilcoxon Sign Test (See Table 6).

Wilcoxon Sign Test indicated that there was a significant difference between before PA and after PA values (Z (n= 53) = -2.1, two- tailed, p= 0.034) (See Appendix C, Table 13). Wilcoxon Sign Test indicated that there was a significant difference between before NA and after NA values (Z (n= 53) = -2.9, two- tailed, p= 0.003) (See Appendix C, Table 13). According to Wilcoxon Sign Test, after PA values are significantly lower than Before PA values and after NA values are significantly lower than before NA values at 6500 K.

According to the findings, both positive and negative mood of students decreased after the lighting exposure of 6500 K CCT. Having NA value decreased after the

lighting exposure is a desired condition to be fully concentrated however having PA value decreased is not (See Table 6).

Table 6: A table showing mean values and the outcomes of Wilcoxon Sign Test of 6500 K

6500 K	Wilcoxon Sign Test					
	n	**Mean**	**Negative Rank**	**Positive Rank**	**z**	**p**
Before PA	53	29.2	30.4	21.1	-2.1	0.034
After PA	53	27.2				
Before NA	53	17.1	24.7	22.1	-2.9	0.003
After NA	53	15.4				

6.3.3. Other Findings

Correlations between PANAS values and d2 Test of Attention values: According to the results of Spearman's Correlation test, there was no significant relationship between PANAS values and d2 Test of Attention values of 4000 K and 6500 K at 0.05 significance level (See Appendix C, Table 14, 15). The model of artificial biotope and organism states that there is a relationship between mood and sustained attention (See sec. II) (Knez, 1995) however the findings of this study did not find any significant relationship between them.

6.4. Discussion

In this thesis, the effects of correlated color temperature on sustained attention and mood of university students in learning environments was studied. It was hypothesized that there are differences between the effects of different correlated color temperatures on university students' sustained attention and mood. The participants' sustained attention and mood performances were compared under two different color temperatures; 4000 K and 6500 K, focusing on the related outcomes; concentration performance, number of errors, positive affect and negative affect.

In this study, it was found that there is a significant difference between 4000 K or 6500 K CCT on sustained attention of university students, 4000 K significantly increases errors of commission (EC, number of incorrectly marked items) (p= 0,001) (See Appendix C, Table 11) and number of errors (E%, total numbers of errors of omission and errors of commission over the total items processed) (p= 0,0001) (See Appendix C, Table 11). Higher errors of commission (EC) and number of errors (E%) are unwanted since they indicate lower level of maintaining concentration on continuous tasks or information sources. It was found that there is no effect of 4000 K or 6500 K CCT on concentration performance (p= 0,296) (See Appendix C, Table 11), errors of omission (p= 0,075) (See Appendix C, Table 11) or the total number of items processed (p= 0,402) (See Appendix C, Table 11) in terms of sustained attention of university students.

The findings of this study indicated that 6500 K supports students' ability to maintain their attention, under 6500 K lit environment students tend to make less mistakes

than 4000 K. For stating that 6500 K increases concentration of students, making less mistakes is not sufficient. According to the results of Sleegers et. al. (2012), 6500 K increased the concentration performances of students and at the same time they tend to make less mistakes however in this study the concentration performances or the total number of items processed did not affected by different levels of correlated color temperature.

A certain conclusion could not be derived about the effects of correlated color temperature on mood of university students. According to the results of this study, there was no significant difference between before PA and after PA values (Z (n= 44) = -1.4, two- tailed, p= 0.161) (See Appendix C, Table 12), also there were no significantly difference between before NA and after NA values (Z (n= 44) = -0.6, two- tailed, p= 0.547) (See Appendix C, Table 12) at 4000 K. The results indicated that after PA values are significantly lower than Before PA values (Z (n= 53) = -2.1, two- tailed, p= 0.034) (See Appendix C, Table 13) and after NA values are significantly lower than before NA values (Z (n= 53) = -2.9, two- tailed, p= 0.003) (See Appendix C, Table 13) at 6500 K. Having lower After NA value is the desired condition to be calm and concentrated which was the acquired result in 6500 K; as well for 6500 K, the expected results were having higher After PA values however according to results After PA values decreased. This result could be caused by several reasons such as the inequal numbers of male and female subjects participated in the experiment because genders might reacted differently to CCT of light. While comparing the results of this study with the previous studies in literature, it was found that there were some differences and similarities about sustained attention and mood were affected by CCT of light (Boray et. al., 1989; Boyce et. al., 2000; Huang

et. al., 2013; Navvab, 2001; Rautkyla et. al., 2010; Sleegers et. al., 2012; Shamsul et. al., 2013; Vrabel et. al., 1998; Yamagishi et. al., 2008).

According to the previous studies stated below, there are some different results in sustained attention outcomes in terms of; total numbers of items processed, errors of omission, errors of commission, error percentage and concentration performances. Most of the previous studies did not measure the effects of CCT of lighting on university students' sustained attention in learning environment (Boray et. al., 1989; Rautkyla et. al., 2010; Shamsul et. al., 2013; Vrabel et. al., 1998) and some of them examined attention in a different way with different sample groups in a different environment (Boyce et. al., 2000; Huang et. al., 2013; Navvab, 2001; Sleegers et. al., 2012; Yamagishi et. al., 2008).

Sleegers et. al. (2012) conducted an experimental study using students from Dutch schools. The effects of correlated color temperature on students' concentration was investigated by using different levels correlated color temperatures; 2900 K, 6500 K and 12000 K. The experiment shows that 6500 K increases students' concentration. Even though the sample group, who were primary school students, was different from the sample group of this study, the findings of Sleegers et. al. (2012) support the findings of this study about the effects of correlated color temperature on concentration performances.

The effects of correlated color temperature on focused and sustained attention was investigated by using three different correlated color temperature levels of white

LED desk lighting; 2700 K, 4300 K and 6500 K by Huang et. al. (2013). The sample group was undergraduate students and the experiment shows that 4300 K increases focused and sustained attention rather than 2700 K and 6500 K. The results of Huang et. al. (2013) contradicts with the results of this study. This contradiction could be caused by the type of the lighting equipment used in the study; LED desk lighting was used instead of using general lighting.

Shamsul et. al. (2013) explored the effects of correlated color temperature on visual comfort level, task performances and alertness among undergraduate students was investigated by using 3000 K, 4000 K and 6500 K CCTs. The experiment showed that 4000 K and 6500 K are beneficial for alertness level and academically activities. This study did not give any certain CCT level that are beneficial for alertness level and academic activities.

Cognitive performance and mood was investigated with different CCT levels of light; warm white, cool white and full-spectrum fluorescent lighting were used by Boray et. al. (1989). The effects of three lighting conditions on visual tasks, attractiveness and friendliness of others, estimated room size and self- reported pleasure and arousal were studied with 3000 K, 4150 K, 5000 K at 500 lux and found no significant differences in the effects of quantitative tasks. The results of this study could be caused by the usage of close levels of CCT (See sec. V Figure 6), the differences between those CCT levels are difficult to be recognized by the user.

Another study examined the visual performances and visual clarity under electric light sources with different correlated color temperatures; 2700 K, 4100 K, 4200 K and 5000 K at illumination level of 538 lux and found no significant differences on visual performances (Vrabel et. al., 1998). The results of this study was similar to the results of Boray et. al. (1989) and the reasons could be caused by the usage of close levels of CCT (See sec. 5 Figure 6), the differences between those CCT levels are difficult to be recognized by the user.

There are studies focused on elderly people and their visual performance with different correlated color temperatures; a comparison of visual performance under high and low color temperature fluorescent lamps was investigated and according to Navvab (2001) high correlated color temperature, 6500 K, was preferred rather than 3500 K. Also, Boyce et. al. (2000) found a similar result with Navvab (2001), for older people correlated color temperature of 6500 K was preferred when compared with lower correlated color temperature of 3000 K in visual tasks. Likewise in this study for young people to maintain their attention 6500 K was preferred to 4000 K.

A study about the effects of LED lighting characteristics on visual performance of elderly people found that for older people 8200 K is a better lighting condition but for younger people, the 5000 K condition produces better test performance than 2500 K and 8200 K (Yamagishi et. al., 2008). In contrast to Yamagishi et. al. (2008) and Huang et. al. (2014) found that correlated color temperature at 6500 K led to faster reaction times in tasks associated with sustained attention than 2700 K for younger

people. Also the findings of this study found similar results with Yamagishi et. al. (2008) and Huang et. al. (2014).

Effects of CCT and timing of light exposure on daytime alertness in lecture environments was studied by Rautkyla et. al. (2010) in Finland with 4000 K and 17000 K. The experiments were repeated at different seasons and the sample group was undergraduate students. This study found that CCT and timing of the light exposure, played important roles in alertness in lecture environments. Although the work of Rautkyla et. al. (2010) is not directly related with this study however being alert is related with mood, attention and learning (Driscoll & Driscoll, 2005).

According to the previous studies, there are some different results in mood designation criteria in terms of; positive affect and negative affect. Most of the studies did not measured the effects of CCT of lighting on university students' mood in learning environment and some of them examined mood in a different way with different sample groups in a different environment.

The effects of indoor lighting on cognitive performance via mood was investigated by comparing two correlated color temperature levels; 3000 K and 4000 K by Knez (1995). The results of the experiment showed that there was a difference between the mood of males and females according to different correlated color temperatures. Females' negative mood decreased in 4000 K whereas males' negative mood increased also females performed better in problem solving but the opposite situation was valid for males. The sample group of this study aged from 18 to 55 which

covered a wide range and the differences between those wide ranged age groups could cause some effect on measured variables such as cognitive performances could show some differences. In contrast to the findings of Knez (1995) a certain conclusion could not be derived about mood of the university students in the current study.

Another study conducted by Knez (2001) investigated the "influence of color of light; 'warm', 'cool', and artificial 'daylight' white lighting on subjects' self-reported mood, cognitive performance and room light estimation. No direct effect on positive and negative mood was indicated; main effects of color of light on short-term memory and problem solving showed that subjects performed better in the 'warm' than in the 'cool' and artificial 'daylight' white lighting". Knez used high school students as sample group of this study, which is similar to the sample group of this study. The results of Knez's study is similar with this study in terms of the effects of correlated color temperature of lighting on mood which might show that there is no relationship between correlated color temperature and mood.

This study could be used for future research about lighting practices to rearrange lit environments according to human needs. To have comfortable lit environments it is important to examine the visual and non- visual biological effects of lighting and this study aims to fulfill the gap in the literature, which focuses on learning, mood and sustained attention in learning environments.

CHAPTER VII

CONCLUSION

The impact of CCT on sustained attention of students' were explored in learning environments by concentration performance, errors of omission, errors of commission, error percentage and the total number of items processed. Also, their mood was explored from positive affect and negative affect aspects.

There are visual and biological effects of light that affect individuals, besides the biological effects of CCT, lighting must be responsive to the psychological and emotional needs (Rea, 2000). Lighting can make an environment pleasant, spacious and attractive. Also for a learning environment proper lighting, with right illuminance level and CCT level, can make that space comfortable, stimulate learning and improve behavior (Rea, 2000). Learning environments are one of the most important spaces and there are some challenges for lighting designers as new technologies develop day by day; many existing learning environments need to be

improved to have visual comfort to support learning and at the same time reduce energy usage (Rea, 2000). Still, there are limited studies in literature exploring the effects of CCT on students' sustained attention and mood in learning environments. Most of the studies are about the effects of illuminance and/ or CCT on health, well-being, alertness, productivity and comfort levels mostly in working environments. Several studies focusing on learning environments are dealing with the biological effects of lighting on students'. There is not any research exploring the relationship between CCT of light and sustained attention and mood of university students in learning environments. Generally, the effects of CCT of light on sustained attention and mood are separately studied; however, it is important to examine those issues together in order to understand the whole effects in a more realistic manner. The general structure and the statistical results of this thesis are important in fulfilling the gap in the literature about the effects of CCT of light on university students' sustained attention and mood in learning environments.

It was found that there is no effect of CCT on concentration performance, errors of omission or the total number of items processed in terms of sustained attention of university students. In this study, it was found that there is a significant difference between 4000 K and 6500 K on sustained attention of university students, 4000 K significantly increases errors of commission (EC) and number of errors (E%). Higher errors of commission (EC) and number of errors (E %) are unwanted outcomes of sustained attention that indicate lower level of maintaining sustained attention. Errors of commission and error percentage of students' in the set of 4000 K CCT was significantly higher than 6500 K CCT. The results show that 6500 K is better at increasing sustained attention in the learning environments.

A certain conclusion could not be derived about the effects of CCT on mood of university students. The results indicated that there were no significant difference between before PA and after PA values also there were no significant difference between before NA and after NA values at 4000 K. After PA values are significantly lower than before PA values and after NA values are significantly lower than before NA values at 6500 K. It is not possible to say that CCT has an effect on mood of university students' in learning environments.

There are no limitations in this study, since the experiments were conducted in real learning environments with daylight control. The only limitation for this study is the gender of the subjects. There were inequal numbers of male and female students in Interior Architecture and Environmental Design Department at Bilkent University. Knez (1995) stated that, genders' mood varied from each other according to different lighting conditions so, for future studies, gender can be taken into account. Additionally, different aged sample groups can be used. Broader correlated color temperature levels can be examined in future studies to enrich the knowledge in this research area. Different types of lighting equipment can be used in future experiments like LED lighting in order to make further contributions both for technology and for the research about mood and sustained attention. In addition to these, longer experiment sessions can be tried out to obtain subjects' mood in a more stable condition that might enhance the measured mood however, longer sessions might deteriorate subjects' sustained attention.

According to the results of this study, in order to enhance students' sustained attention, the usage of CCT of 6500 K is recommended in learning environments. Depending on the literature review and the results of this study, the usage of fluorescent lighting and/ or LED lighting of 6500 K CCT is recommended for learning environments. These findings of this study have suggestion for lighting practices and might be helpful for future research about lit environments and human needs. The findings are useful for not only interior architects, but also for environmental psychologists or educationists who may be interested in school environments, learning, mood and sustained attention.

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APPENDICES

APPENDIX A

Adı Soyadı : **Tarih :**

Cinsiyet : Erkek ☐ Kız ☐

Kullandığı el: Sağ el ☐ Sol el ☐ **Yaş:** :

Örnek: d d d

Uygulama: d p d d d d p d d p d d d d p p d d p d d p d d d p d d p d d

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22

	Ham Puan	Yüzdelik	Yüzde Oran	
TN (Toplam Puan)				
E1 (Omissions)				
E2 (Commissions)				
E (Errors)				
TN-E (total errors)				
CP (concentration)				

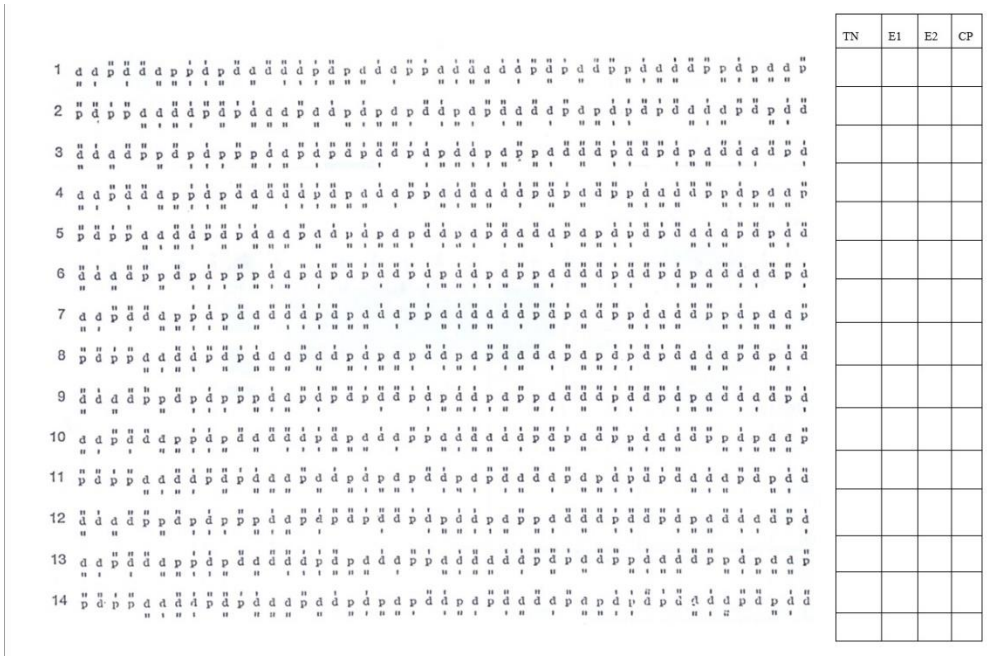

Figure 15: d2 Test of Attention

APPENDIX B

Adı Soyadı:

Yaş:

Tarih:

The Positive and Negative Affect Schedule (PANAS; Watson et al., 1988) PANAS Questionnaire (Pozitif ve Negatif Duygu Ölçeği)
This scale consists of a number of words that describe different feelings and emotions. Read each item and then list the number from the scale below next to each word. Indicate to what extent you feel this way right now, that is, at the present moment. (Aşağıdaki maddelerde çeşitli duygu ve hisleri tanımlayan sözcükler yer almaktadır. Her bir maddeyi okuyunuz ve her bir sözcük için 1'den 5'e kadar numaralandırma yapınız. İçinde bulunduğunuz şu an için bu duyguları hangi sıklıkla yaşadığınızı belirtiniz.)

1	2	3	4	5
Very Slightly or Not at All (Çok Az veya Hiç)	A Little (Biraz)	Moderately (Kısmen)	Quite a Bit (Sık Sık)	Extremely (Çok Fazla)

_____1.Interested (İlgili)
_____2.Distressed (Sıkıntılı)
_____3.Excited (Heyecanlı)
_____4.Upset (Mutsuz)
_____5.Strong (Güçlü)
_____6.Guilty (Suçlu)
_____7.Scared (Ürkmüş)
_____8.Hostile (Düşmanca)
_____9.Enthusiastic (Hevesli)
_____10.Proud (Gururlu)
_____11.Irritable (Tedirgin)
_____12.Alert (Uyanık)
_____13.Ashamed (Utanmış)
_____14.Inspired (İlhamlı)
_____15.Nervous (Sinirli)
_____16.Determined (Kararlı)
_____17.Attentive (Dikkatli)
_____18.Jittery (Asabi)
_____19.Active (Aktif)
_____20.Afraid (Korkmuş)

Figure 16: PANAS Mood Test

APPENDIX C

Table 7: NCS codes of FF 102 under 4000 K CCT

FF 102- 4000K	Color	NCS Code	Blackness	Chromaticness
Upper Wall (Paint)		S 0500-N	05	00
Lower Wall (Paint)		S 0502-Y	05	02
Ceiling (Paint)		S 0502-Y	05	02
Floor (Tile)		S 4502-G	45	02
Door		S 3502-B	35	02
Whiteboard		S 0500-N	05	00
Desk and Chair		S 2500-N	25	00
Carpet		S 5502- B	55	02
Curtain		S 5040- B	50	40

Table 8: NCS codes of FF 202 under 6500 K CCT

FF 202- 6500K	Color	NCS Code	Blackness	Chromaticness
Upper Wall (Paint)		S 0502-Y	05	02
Lower Wall (Paint)		S 0502-G	05	02
Ceiling (Paint)		S 0502-Y	05	02
Floor (Tile)		S 2502- G	25	02
Door		S 4502-B	45	02
Whiteboard		S 0502-Y	05	02
Desk and Chair		S 1502-B	15	02
Carpet		S 5502-G	55	02
Curtain		S 8502-Y	85	02

Table 9: Table showing the comparison between Before PA/ After PA values and Before NA/ After NA values of 4000 K with Mann- Whitney U Test

99.5% C.I		n	Mean	Median	Minimum	Maximum	S.D	Mann-Whitney U Test		
								Rank Sum	U	p
BEFORE PA	4000k(14 Subjects)	14	27.1	29.0	15.0	45.0	8.6	23.5	196	0.723
	4000k(30 Subjects)	30	25.8	25.0	12.0	40.0	6.9	22.0		
AFTER PA	4000k(14 Subjects)	14	23.2	24.0	10.0	35.0	7.8	20.2	177.5	0.411
	4000k(30 Subjects)	30	24.7	25.0	10.0	39.0	6.4	23.6		
BEFORE NA	4000k(14 Subjects)	14	16.5	15.5	10.0	26.0	5.0	23.1	201	0.819
	4000k(30 Subjects)	30	16.1	15.0	10.0	26.0	4.7	22.2		
AFTER NA	4000k(14 Subjects)	14	14.9	13.0	10.0	24.0	5.1	19.4	166.5	0.271
	4000k(30 Subjects)	30	16.3	14.5	10.0	30.0	5.4	24.0		

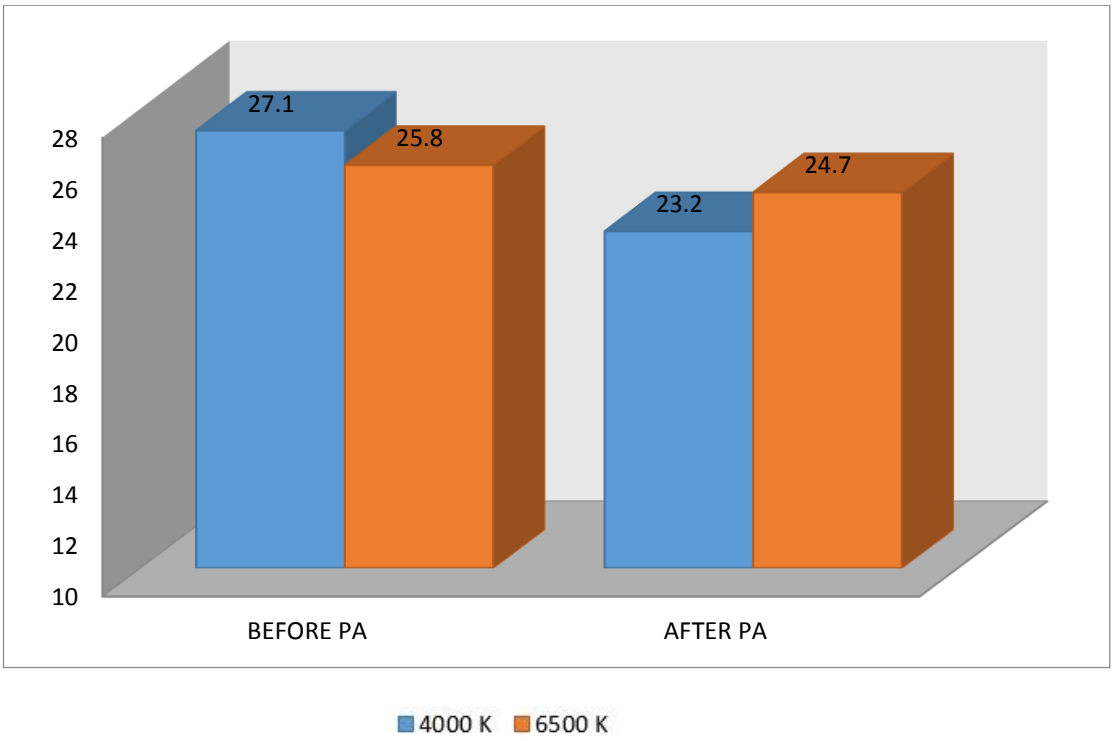

Figure 17: A graph showing the distribution of Before PA and After PA values of group of 14 subjects and group of 30 subjects

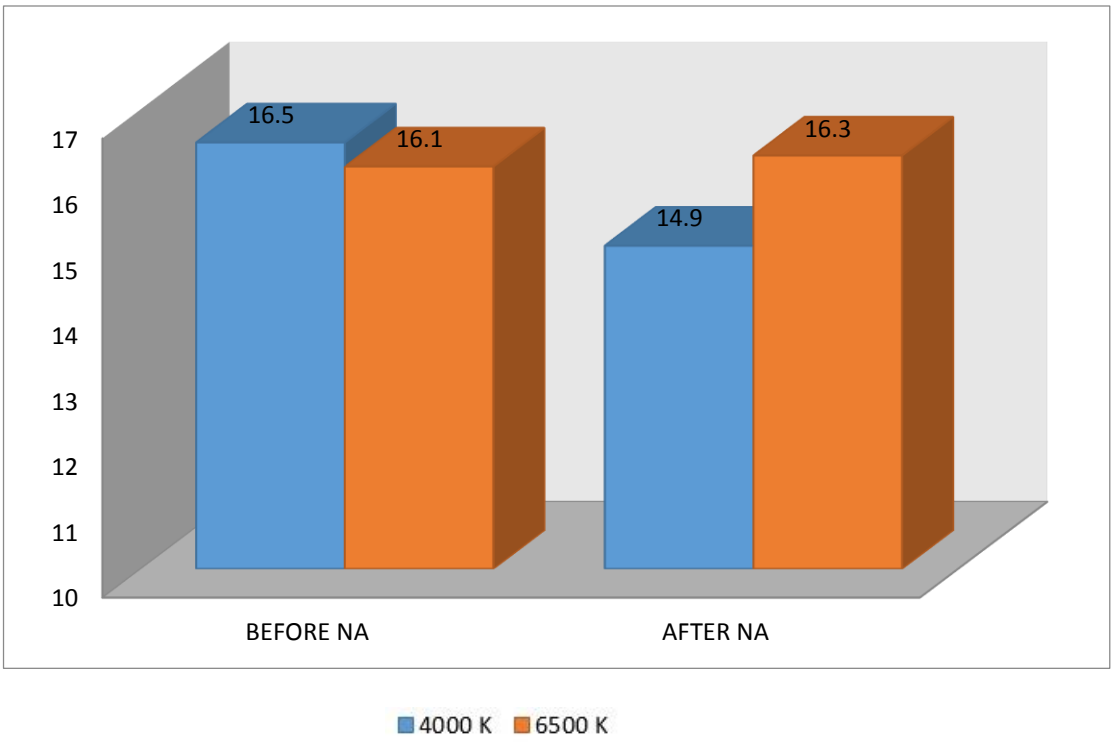

Figure 18: A graph showing the distribution of Before NA and After NA values of group of 14 subjects and group of 30 subjects

Table 10: Table showing the comparison between Before PA/ After PA values and Before NA/ After NA values of 6500 K with Mann- Whitney U Test

99.5% C.I		n	Mean	Median	Minimum	Maximum	S.D	Mann-Whitney U Test		
								Rank Sum	U	p
BEFORE PA	6500k(18 Subjects)	18	27.7	28.0	16.0	42.0	8.4	24.4	267.5	0.371
	6500k(35 Subjects)	35	30.0	32.0	11.0	48.0	9.1	28.4		
AFTER PA	6500k(18 Subjects)	18	26.4	27.5	13.0	46.0	10.2	25.7	292	0.665
	6500k(35 Subjects)	35	27.7	28.0	12.0	47.0	8.7	27.7		
BEFORE NA	6500k(18 Subjects)	18	16.4	15.0	10.0	26.0	5.3	26.1	299.5	0.771
	6500k(35 Subjects)	35	17.5	17.0	10.0	37.0	6.6	27.4		
AFTER NA	6500k(18 Subjects)	18	14.9	14.0	10.0	27.0	4.6	25.8	292.5	0.669
	6500k(35 Subjects)	35	15.6	16.0	10.0	30.0	5.3	27.6		

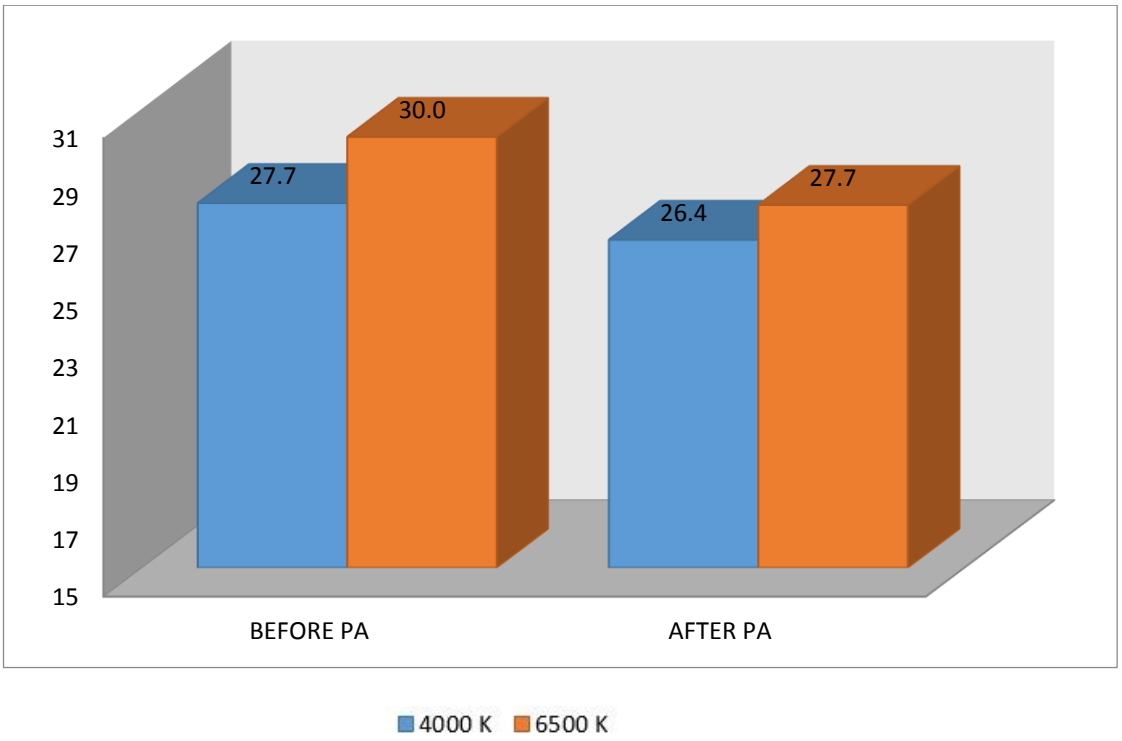

Figure 19: A graph showing the distribution of Before PA and After PA values of group of 18 subjects and group of 35 subjects

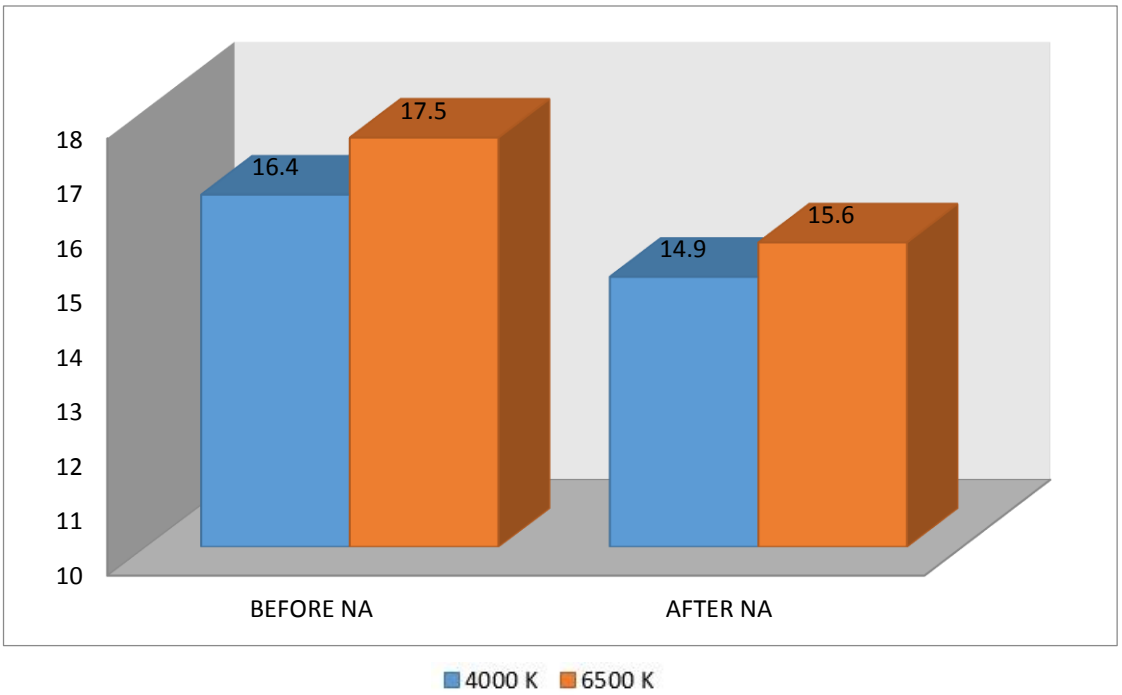

Figure 20: A graph showing the distribution of Before NA and After NA values of group of 18 subjects and group of 35 subjects

Table 11: Table showing mean values and the outcomes of Mann- Whitney U Test of 4000 K (44 subjects) and 6500 K (53 subjects) CCT

99.5% C.I		n	Mean	Median	Minimum	Maximum	S.D	Mann-Whitney U Test		
								Rank Sum	U	p
TN	**44 Subjects**	44	504.2	506.5	311.0	658.0	85.5	51.6	1050	0.402
	53 Subjects	53	486.1	490.0	267.0	646.0	100.3	46.8		
EO	**44 Subjects**	44	56.5	51.5	0.0	135.0	38.5	54.6	921	0.075
	53 Subjects	53	42.7	36.0	0.0	145.0	28.9	44.4		
EC	**44 Subjects**	44	22.6	6.0	0.0	122.0	37.0	59.1	723	0.001
	53 Subjects	53	7.4	2.0	0.0	120.0	18.8	40.6		
E%	**44 Subjects**	44	15.3	14.1	1.4	28.7	7.8	59.7	697	0.0001
	53 Subjects	53	10.1	8.5	2.7	24.7	5.1	40.2		
CP	**44 Subjects**	44	160.3	150.0	88.0	297.0	46.8	45.7	1022	0.296
	53 Subjects	53	169.0	153.0	74.0	290.0	46.9	51.7		

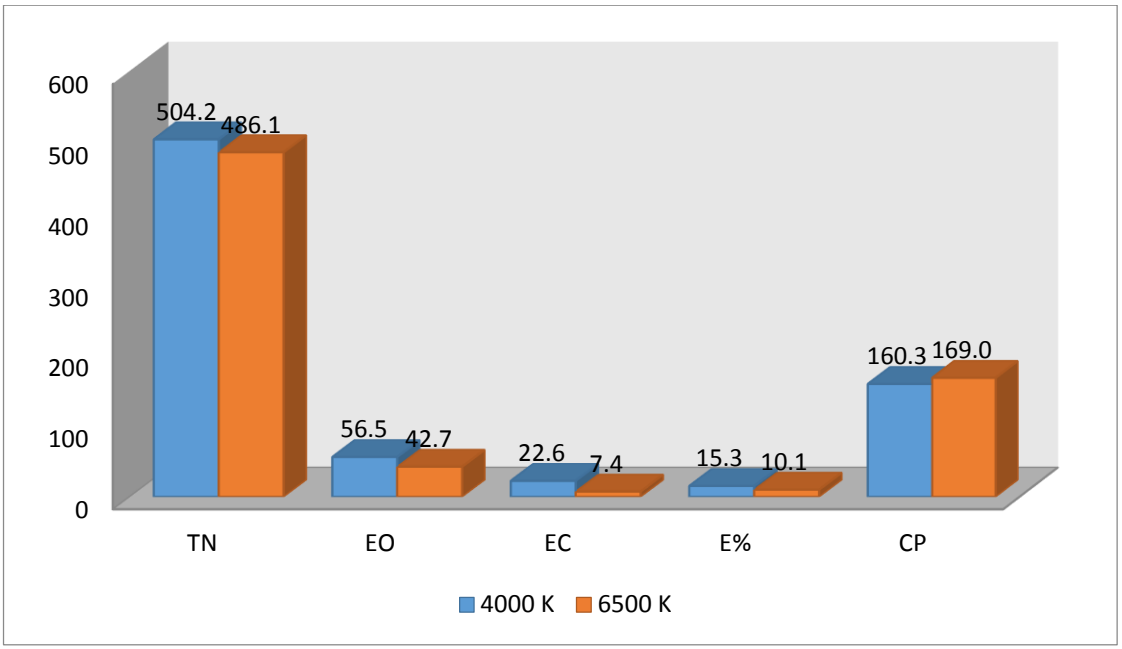

Figure 21: A graph showing the outcomes of d2 Test of Attention of 4000 K and 6500 K CCT

Table 12: Table showing mean values and the outcomes of Wilcoxon Sign Test of 4000 K CCT (44 subjects)

99.5% C.I	44 Subjects						Wilcoxon Sign Test			
	n	Mean	Median	Minimum	Maximum	S.D	Negative Rank	Positive Rank	z	p
Before PA	44	26.2	25.0	12.0	45.0	7.4	24.5	16.1	-1.4	0.161
After PA	44	24.3	25.0	10.0	39.0	6.8				
Before NA	44	16.3	15.0	10.0	26.0	4.7	20.8	22.4	-0.6	0.547
After NA	44	15.9	14.0	10.0	30.0	5.3				

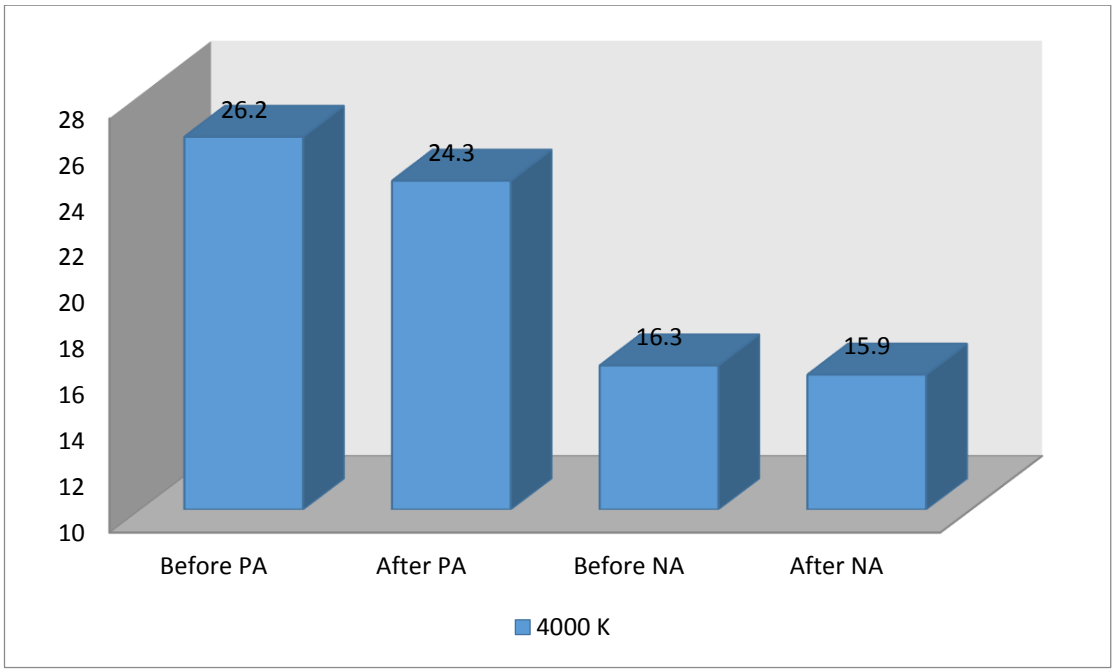

Figure 22: A graph showing the Before PA/ After PA and Before NA/ After NA values of 4000 K CCT (44 subjects)

Table 13: Table showing mean values and the outcomes of Wilcoxon Sign Test of 6500 K CCT (53 subjects)

99.5% C.I.	53 Subjects						Wilcoxon Sign Test			
	n	Mean	Median	Minimum	Maximum	S.D	Negative Rank	Positive Rank	z	p
Before PA	53	29.2	29.0	11.0	48.0	8.9	30.4	21.1	-2.1	0.034
After PA	53	27.2	28.0	12.0	47.0	9.1				
Before NA	53	17.1	15.0	10.0	37.0	6.2	24.7	22.2	-2.9	0.003
After NA	53	15.4	15.0	10.0	30.0	5.0				

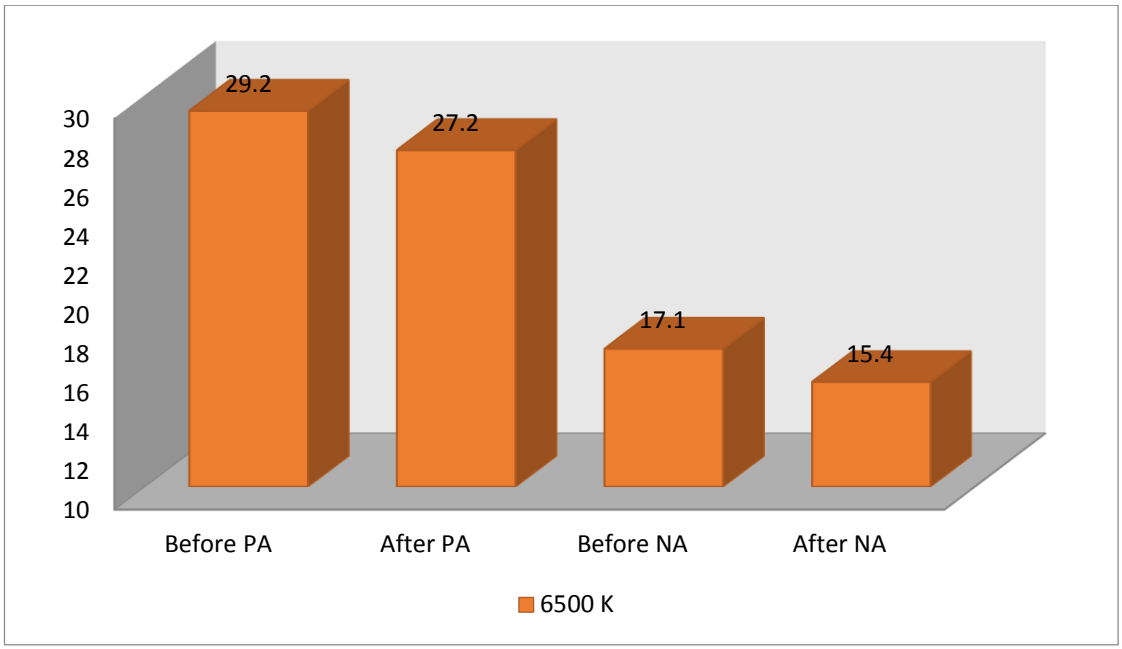

Figure 23: A graph showing the Before PA/ After PA and Before NA/ After NA values of 6500 K CCT (53 subjects)

Table 14: Table showing correlation between PANAS values and the outcomes of d2 Test of Attention of 4000 K with Spearman's Correlation Test

99.5% C.I			Delta PA	Delta NA
44 Subjects (4000 K)	d2-TN	r	-0.040	0.047
		p	0.794	0.760
		N	44	44
	d2-EO	r	-0.291	0.109
		p	0.055	0.480
		N	44	44
	d2-EC	r	0.105	-0.236
		p	0.497	0.123
		N	44	44
	d2-E%	r	-0.177	-0.150
		p	0.251	0.330
		N	44	44
	d2-CP	r	0.233	-0.038
		p	0.129	0.804
		N	44	44

Table 15: Table showing correlation between PANAS values and the outcomes of d2 Test of Attention of 6500 K with Spearman's Correlation Test

99.5% C.I			Delta PA	Delta NA
53 Subjects (6500 K)	d2-TN	r	0.047	-0.074
		p	0.737	0.600
		N	53	53
	d2-EO	r	-0.099	-0.001
		p	0.483	0.992
		N	53	53
	d2-EC	r	-0.227	0.038
		p	0.102	0.785
		N	53	53
	d2-E%	r	-0.269	0.082
		p	0.051	0.562
		N	53	53
	d2-CP	r	0.085	-0.085
		p	0.543	0,547
		N	53	53