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Effects of LED Lighting on Visual Comfort with Respect to the Reading Task

Ayşe Nihan Avcı, İpek Memikoğlu

***Abstract*—**Lighting systems in interior architecture need to be designed according to the function of the space, the type of task within the space, user comfort and needs. Desired and comfortable lighting levels increase task efficiency. When natural lighting is inadequate in a space, artificial lighting is additionally used to support the level of light. With the technological developments, the characteristics of light are being researched comprehensively and several business segments have focused on its qualitative and quantitative characteristics. These studies have increased awareness and usage of artificial lighting systems and researchers have investigated the effects of lighting on physical and psychological aspects of human in various ways. The aim of this study is to research the effects of illuminance levels of LED lighting on user visual comfort. Eighty participants from the Department of Interior Architecture of Çankaya University participated in three lighting scenarios consisting of 200 lux, 500 lux and 800 lux that are created with LED lighting. Each lighting scenario is evaluated according to six visual comfort criteria in which a reading task is performed. The results of the study indicated that LED lighting with three different illuminance levels affect visual comfort in different ways. The results are limited to the participants and questions that are attended and used in this study.

***Keywords*—**Illuminance levels, LED lighting, reading task, visual comfort criteria.

I. Introduction

LIGHT is the form of energy that supports user–environment interaction through natural and artificial lighting sources. It is designed to enable the user to perceive his/her environment and its elements in desired levels. Behind this technical information, there is a real meaning that light exists in every sphere of life and is a basic need for human beings. Human beings usually require light to continue and complete their daily tasks. They need their senses, but seeing is more important and effective than the other senses. With the visual system, light provides us to understand and get information for visual tasks and it affects how we experience our environment [1].

Light is an essential requirement for human beings, since it enables us to experience the external world, but it also affects our physical, physiological and psychological behaviors. In interior architecture, one of the main purposes of lighting is creating comfortable and functional spaces for users to do their daily activities easily [2]. An optimal indoor environment can increase performance, comfort, motivation, interpersonal communication, health and well-being in human beings [3]. Accordingly, studies have been conducted to analyze the effects of different lighting conditions on human beings to obtain good quality lighting. Since the 1990s, good quality lighting has been provided for users and its affects have been evaluated during tasks. In addition, the optimal level of lighting for visual performance has been investigated [4].

The quality of lighting is one of the essential elements of interior architecture. Light illuminates the space by three ways: naturally, artificially and in combination of natural and artificial. When natural lighting is not enough in a space, artificial lighting systems are preferred to obtain the desired levels of light. With the technological developments, the characteristics of light are being researched extensively and several studies have focused on its qualitative and quantitative properties [5]. One of the most important lighting characteristics is the illuminance level. Illuminance level, which is indicated as lux, is the quantity of light measured on a working surface where the most important tasks in the space are performed [6]. Results of various studies show that illuminance levels have a substantial effect on user's performance, speed and comfort [7]. Illuminance levels are usually adjusted according to user needs on a working surface. Several standards are used to obtain suitable illuminance levels for each space and each task, for instance, according to the Turkish standards, TS EN 12464-1, an optimal illuminance level for a reading task is 500 lux [8].

Together with the development of technology, in order to satisfy the needs, several lighting fixtures are produced such as spot halogen lamps, tungsten halogen lamps, fluorescent lamps, fiber optic cables, light stones and light-emitting diodes (LEDs). Fluorescent and other lighting fixtures are widely used, but newer technologies such as LED lightings have become more advantageous due to their low power consumption, flexibility in usage and long-life span than the other fixtures [9]. If LEDs were to replace the other light sources, about 270 million tons of CO_2 per year would be saved and this would represent a huge ecologic gain [10]. Light is a part of electro-magnetic spectrum that the human eye is sensitive, ranging from 400 nm to 760 nm [11]. In addition, the spectral power distribution (SPD), which is the optical radiation emitted from a light source, of the blue based LED has a high wavelength about 450 nm that is different from the SPD of fluorescent lamps. Blue light has a fundamental effect on the human circadian system that inhibits more melatonin secretion and promotes more cortisol secretion [12]. Thus, LED lamps are expected to have different effects on visual comfort task performance than other artificial lighting sources. Considerable amount of research

Ayşe Nihan Avcı and İpek Memikoğlu are with the Interior Architecture Department, Çankaya University, Ankara, CO 06530 (e-mail: nihanavci@cankaya.edu.tr, ipekmemikoglu@cankaya.edu.tr).

has been done related to the technical aspects of lighting fixtures; however, little research has been considered on how LED lightings affect user performance and visual comfort [12], [13]. The aim of this study is to analyze the effects of different illuminance levels of LED lighting on user visual comfort and task performance with respect to a reading task. Visual comfort criteria can be stated as visual distraction, visual clarity, visual fatigue, burning eye, focusing problem and glare.

II. Methods

A. Participants

The sample group consisted of 2015-2016 academic year undergraduate students from the department of Interior Architecture at Çankaya University, Ankara, Turkey. Eighty undergraduate students were chosen randomly from the 2nd, 3rd and 4th years. They were familiar with natural and artificial lighting course. After contacting the volunteering participants, they were invited to and informed about the test cabin. There were 41 (51.3%) females and 39 (48.7%) males and their ages were in a narrow range from 19 to 30 years old in order to avoid the influences of age-related effects in vision. The mean age was 22.74, the median age was 22, and the standard deviation was 2.49. Twenty-three participants out of 80 either used eye glasses or contact lenses.

B. Description of the Setting

The test cabin, which was created in the office of two research assistants, is in Çankaya University / Balgat Campus in Ankara and the campus is located in the Çankaya District. The test cabin was placed away from the window. The dimensions of the cabin were 1.60 m x 2.60 m x 2.80 m. In order to eliminate the effect of color and prevent the penetration of light, white curtains were used around the cabin and jalousies were used to prevent daylight. Except the flooring, all the surfaces and furnishings in the cabin were white. A white table (1.20 m x 0.80 m x 0.80 m) and a stool were used in the cabin during the reading of the texts.

In order to understand the effects of different illuminance levels of LED lighting on user visual comfort, the illuminance levels were determined for each light source. Three illuminance levels were identified as 200 lux (below standards), 500 lux (as standards), 800 lux (above standards). After contacting with the suppliers about the properties of the products and analyzing their IES files, DIALux Evo 6.1, which is the lighting design software, was used in order to decide the number of LED lamps. Five LED lamps were used to obtain these three illuminance levels (200 – 500 – 800 lux). After that, the lighting setting was designed. The lighting setting consisted of a white frame that was installed to carry the suspended lamps, five LED lamps. The lighting setting was suspended from four points by chains and the height from the floor was 2.20 m. All artificial light sources were placed at the ceiling level, roughly over the center of the desk to avoid glare or reflections on the paper [14]. LED lamps were controlled by a dimmable switch. The properties of LED lamp are shown in Table I. Illuminance levels inside the cabin were measured with the TES 1332A Illuminance Meter (range of 0.01 to 200.000 lux).

TABLE I
THE PROPERTIES OF LED LAMP

Brand / Model	Dimension	Lumen	CCT	CRI	Product
Osram LED Star Classic A 60	11 cm x 6 cm	806 lm	2700 K	≥ 80	

C. Procedure

The experiment was conducted between 3rd of October and 21st of October 2016. Before each experiment, participants were informed about the setting and the procedure. The experiment was conducted in the morning due to the cortisol hormone (stress hormone) and melatonin hormone (sleep hormone) that play an important role on alertness and sleepiness. The level of cortisol increases in the morning to prepare the body for daily tasks [15]. It remains in a high level over in the morning hours. Several studies indicated that the being awake, hours of sleep, time spent outside, travelling across time zones, drinking coffee and smoking cigarettes are very important factors that affect performance [14], [16]. Before the experiment, all the participants declared that they had adequate sleep, did not travel across time zones and had not spent time outside, did not drink coffee and did not smoke cigarette.

The questionnaire had thirteen questions that were adopted from the “Office Lighting Survey” questions, which were generated by Eklund and Boyce in 1996 [17]. The questionnaire was divided into two parts. The first part consisted of four questions that aimed to get general information about the participants such as age, gender, usage of eye glasses and contact lenses and mood. The second part was divided into three sub-parts. All the sub-parts had the same questions, but the reading texts were different. In the sub-parts, familiarity with the books from which the reading texts were selected from, were indicated. The seven-point Likert scale was used to evaluate the visual comfort criteria while reading the selected texts. These criteria were indicated as visual distraction, visual clarity, visual fatigue, eye burning, focusing problem and glare. All the participants answered the questionnarie in the same order.

Reading/writing on paper are more transportable and comfortable than reading/writing on screen-keyboard for users. Moreover, this method is useful for speed reading [18]. Thus, participants read three reading texts on white A4 pages that were the abstracts of the books: “Little Prince”, “My Left Foot” and “Pomegranate Tree”. The word count of the reading texts was between 375 to 383. There were three lighting scenarios in the experiment that consisted of different illuminance levels (LED 200-500-800 lux) and reading texts. Lighting scenarios were carried out in random order to avoid the adaption of the eye. When the participants started to read the first reading text, their reading speeds were timed. After the reading, the participants answered the questions related to each scenario and got out of the test cabin. In between each lighting scenario, participants had a rest time of about five minutes and they continued with the next scenario in the same way. The duration time for a person was approximately forty minutes.

The three lighting scenarios can be seen in Table II. Some studies have been concluded that font character effects the visual performance and 12-point Times New Roman font style is comfortable [5], [12]. Thus, the questionnaire and reading texts were printed in black ink on white A4 pages with 12-point Times New Roman font style.

TABLE II
DETAILS OF LIGHTING SCENARIOS

Lighting Scenario	Illuminance Level	Light Source	Reading Text	Word Count
1	200 lux	LED	Little Prince	383
2	800 lux	LED	Pomegranate Tree	375
3	500 lux	LED	My Left Foot	378

D. Results and Discussion

Statistical Package for the Social Sciences (IBM Corp. SPSS) 20.0 program was used to analyze the data. In the analysis of the data, one-way analysis of variance (ANOVA) was conducted.

The participants rated their current physical condition on a seven-point Likert scale as being “little tired” (33.8%) and “normal” (28.8%) (M = 4.21, SD = 1.61). They were familiar with the first reading text more than the other texts, but they read it slower than the others. Details of the second part of the questionnaire are represented in Table III.

TABLE III
DETAILS OF THE SECOND PART OF THE QUESTIONNAIRE

Reading Text	Familiarity	Light Source	Illuminance Level	Mean Reading Speed
Little Prince	71 (88.8%)	LED	200 lux	1.90 (SD = 0.56)
Pomegranate Tree	9 (11.3%)	LED	800 lux	1.83 (SD = 0.50)
My Left Foot	38 (47.5%)	LED	500 lux	1.61 (SD = 0.42)

Visual Distraction: According to ANOVA, the mean of the visual distraction levels of participants for LED 500 lux (M = 5.75, SD = 1.71) was higher than that of the LED 200 lux (M = 4.91, SD = 1.87) and 800 lux (M = 4.70, SD = 1.97). There was statistically no significant difference between 200 lux and 800 lux on users’ visual comfort in this criteria (Wilks’ Λ = 0.77, F(3,80) = 11.44, p = 0.395 > 0.05). However, there was a statistically significant difference between 200 lux and 500 lux in this criteria (p = 0.000 < 0.05). Results of differences between the illuminance levels of LED lighting with respect to the visual distraction are shown in Table IV.

Visual Clarity: The mean of the visual clarity levels of participants for LED 500 lux (M = 5.80, SD = 1.66) was higher than that of the LED 200 lux (M = 5.40, SD = 1.80) and 800 lux (M = 5.09, SD = 1.96). There was statistically no significant difference between 200 lux and 800 lux on users’ visual comfort in these criteria (Wilks’ Λ = 0.89, F (3,80) = 4.91, p = 0.248 > 0.05). However, there was a statistically significant difference between 500 lux and 800 lux in these criteria (p = 0.003 < 0.05). Results of differences between the illuminance levels of LED lighting with respect to the visual clarity are shown in Table V.

TABLE IV
DIFFERENCES WITH RESPECT TO THE VISUAL DISTRACTION

	200 lux – 800 lux	200 lux – 500 lux
No Sig. Dif.	p=0.40	
Sig. Dif.		p=0.00

TABLE V
DIFFERENCES WITH RESPECT TO THE VISUAL CLARITY

	200 lux – 800 lux	500 lux – 800 lux
No Sig. Dif.	p=0.25	
Sig. Dif.		p=0.00

Visual Fatigue: The mean of the visual fatigue levels of participants for LED 500 lux (M = 5.16, SD = 1.82) was higher than that of the LED 200 lux (M = 5.04, SD = 1.86) and 800 lux (M = 4.23, SD = 1.89). There was statistically no significant difference between 200 lux and 500 lux on users’ visual comfort in this criteria (Wilks’ Λ = 0.80, F(3,80) = 10.05, p = 0.633> 0.05). However, there was a statistically significant difference between 200 lux and 800 lux point of visual fatigue (p = 0.001 < 0.05). Results of differences between the illuminance levels of LED lighting with respect to the visual fatigue are shown in Table VI.

TABLE VI
DIFFERENCES WITH RESPECT TO THE VISUAL FATIGUE

	200 lux – 500 lux	200 lux – 800 lux
No Sig. Dif.	p=0.63	
Sig. Dif.		p=0.00

Burning Eye: The mean of the burning eye levels of participants for LED 200 lux (M = 5.81, SD = 1.44) was higher than that of the LED 500 lux (M = 5.75, SD = 1.72) and 800 lux (M = 4.81, SD = 1.90). There was statistically no significant difference between 200 lux and 500 lux on users’ visual comfort in this criteria (Wilks’ Λ = 0.75, F(3,80) = 13.03, p = 0.754 > 0.05). However, there was a statistically significant difference between 200 lux and 800 lux on users’ visual comfort in this criteria (p = 0.000 < 0.05). Results of differences between the illuminance levels of LED lighting with respect to the burning eye are shown in Table VII.

TABLE VII
DIFFERENCES WITH RESPECT TO THE BURNING EYE

	200 lux – 500 lux	200 lux – 800 lux
No Sig. Dif.	p=0.75	
Sig. Dif.		p=0.00

Focusing Problem: The mean of the focusing problem levels of participants for LED 500 lux (M = 5.59, SD = 1.83) was higher than that of the LED 200 lux (M = 5.05, SD = 2.04) and 800 lux (M = 4.74, SD = 2.01). There was a statistically significant difference between 500 lux and 800 lux on users’ visual comfort in this criteria (Wilks’ Λ = 0.88, F(3,80) = 5.18, p = 0.002 < 0.05). Results of differences between the illuminance levels of LED lighting with respect to the focusing problem are shown in Table VIII.

TABLE VIII
DIFFERENCES WITH RESPECT TO THE FOCUSING PROBLEM

	500 lux – 800 lux
Sig. Dif.	p=0.002

Glare: The mean of the glare levels of participants for LED 500 lux (M = 5.68, SD = 1.70) was almost the same with LED 200 lux (M = 5.63, SD = 1.75) and higher than 800 lux (M = 4.65, SD = 2.15). There was statistically no significant difference between 200 lux and 500 lux on users' visual comfort in this criteria (Wilks' $\Lambda = 0.82$, $F(3,80) = 8.60$, $p = 0.817 > 0.05$). However, there was a statistically significant difference between 200 lux and 800 lux in this criterion ($p = 0.000 < 0.05$). Results of differences between the illuminance levels of LED lighting are shown in Table IX.

TABLE IX
DIFFERENCES WITH RESPECT TO THE GLARE

	200 lux – 500 lux	200 lux – 800 lux
No Sig. Dif.	p=0.82	
Sig. Dif.		p=0.00

The results indicated that the illuminance level of 500 lux was slightly found visually more comfortable than the other illuminance levels according to visual distraction, visual clarity, visual fatigue, focusing problem and glare. On the contrary, the illuminance level of 200 lux was slightly found more comfortable than other illuminance levels according to burning eye. The results were not in line with one of the research and it was proposed that light sources did not have any significant effect on visual comfort and visual fatigue [5]. According to TS EN 12464-1 of the Turkish Standards, the optimal illuminance level for a reading task was determined as 500 lux [8].

There were statistically no correlations between the illuminance levels and reading speeds. There was a statistically negative correlation that as the illuminance level increased, reading speed decreased. It can be stated that illuminance levels of the light source have an effect on visual comfort and reading performance. The results are not in line with many studies [19], [20]. It was indicated that reading speeds increased as the illuminance levels increased from 300, 700 to 1500 lux [18]. Another research proposed that illuminance levels of 1000 and 1500 lux supported faster reading than did those of 200 and 500 lux [20].

III. CONCLUSION

This study aimed to analyze the effects of different illuminance levels of LED lighting on users' visual comfort and reading performance. Three illuminance levels were identified, 200 lux, 500 lux and 800 lux. According to the TS EN 12464-1 of the Turkish Standards, 500 lux is considered optimal for a reading task. The illuminance level of LED 500 lux was generally found visually more comfortable; on the other hand, the illuminance level of LED 200 lux was found visually more comfortable than the other illuminance levels with respect to the criteria of burning eye. The result of this study revealed that illuminance levels have a significant effect on users' visual comfort and the illuminance levels of LED lighting do not affect all visual comfort criteria in the same way. For further studies, the effects of illuminance levels of LED lighting on gender and age can be compared. The effects of them on different task performances other than reading performance can be researched and be compared within each task. The relationship of color and texture with LED lighting can be researched.

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