ITU A|Z • Vol 18 No 2 • July 2021 • 397-411

Evaluating effectiveness of LED and OLED lights on user visual comfort and reading performance

Ayşe Nihan AVCI[1], İpek MEMİKOĞLU[2]
[1] nihanavci@cankaya.edu.tr • Department of Interior Architecture, Faculty of Architecture, Çankaya University, Ankara, Turkey
[2] ipek.memikoglu@atilim.edu.tr • Department of Interior Architecture and Environmental Design, School of Fine Arts, Design and Architecture, Atılım University, Ankara, Turkey

Received: January 2020 • Final Acceptance: September 2020

Abstract

In interior architecture, one of the main purposes of light is to create comfortable and functional spaces according to user needs. Light provides individuals to understand, get information for visual tasks and it affects how they experience and behave in the environment. Desired illuminance levels are required for visual comfort and task efficiency. This study analyzes the effects of different illuminance levels of light emitting diode (LED) and organic light emitting diodie (OLED) lights on user visual comfort and reading performance. An experiment was conducted with eighty interior architecture students at Çankaya University. Six lighting scenarios were created with LED and OLED lighting sources that assessed six visual comfort criteria. The experimental setting consisted of three different illuminance levels, as 200, 500 and 800 lx. The results revealed that different illuminance levels were found more comfortable for different visual comfort criteria, but the illuminance level of 500 lx was visually more comfortable than the other illuminance levels. The illuminance level of LED 200 lx was visually more comfortable than LED 800 lx. OLED light was found visually more comfortable than LED light. In addition, participants read slower under the illuminance level of LED 200 lx. It was concluded that illuminance levels of light effect user's visual comfort and reading performance. This study provides a basis to recommend the preferred illuminance level for LED and OLED light during a reading performance.

Keywords
Illuminance level, LED, OLED, Reading performance, Visual comfort.

doi: 10.5505/itujfa.2021.22438

1. Introduction

Light is the application and energy that supports user – environment interaction through natural and artificial light sources. It is an essential requirement for users that affect their motivation of work-related tasks, health and well-being. In interior spaces, one of the main purposes of light is to create comfortable and functional spaces for users to do their daily activities. Optimal levels of light increase the performance, comfort, motivation and interpersonal communication of users (Borisuit, Linhart, Scartezzini & Münch, 2015).

Since 1990s, a good qualified lighting has been a fundamental criterion for interior spaces; it has been provided for users and evaluated during tasks as naturally and/or artificially. Optimal levels of light for visual performance have been investigated (Bellia, Bisegna & Spada, 2011). When natural light is insufficient in a space, artificial light systems are additionally used in order to obtain the comfortable levels. With the technological developments, light has been researched with respect to its qualitative and quantitative characteristics (Shen, Shieh, Chao & Lee, 2009). These studies have increased the realization and the usage of artificial light systems. By changing the colour temperature, colour rendering, luminous flux of light, or lamp type, various light fixtures have been manifactured that offer diversity to satisfy user needs. However, some researches have considered the effects of illuminances on visual comfort and user performance. Boyce et al. (2006a) found no effects and Veitch and Gifford (1996) found that giving personal control over lighting conditions led to slower working and lower productivity. Aries (2005) found that higher illuminance, especially a high vertical illuminance (at the eye), have a positive effect on these aspects and are associated with less fatigue. In the work of Smolders, de Kort and Cluitmans (2012), higher illuminance at eye level can induce vitality and improve performance on a task.

According to European standards (TS EN 12464-1), a convenient illuminance for a reading task is 500 lx; however, illuminance can be adjusted according to user needs (European Standards, 2002). Several studies showed that illuminance have an effect on user's performance, speed and comfort (Avcı & Memikoğlu, 2016; Boyce et al., 2006b; Dubois et al., 2016). Various studies indicated that users generally prefer illuminance that is lower than recommended by the standards (Boyce et al., 2006b; Newsham, Mancini & Marchand, 2008). According to Smolders et al. (2012), one of the most important quantitative features of light is the illuminance that effects visual comfort and performance of users.

With the development of light technology, several lighting fixtures have been produced. While fluorescent and other lamp types are widely used, newer technologies such as LED lamps and OLED panels have become more advantageous. In comparison to LED, OLED has a flexible shape, low power consumption, flexibility in usage and long-life span (Hawes et al., 2012). OLED, as the next step of the Solid State Light (SSL) technology that is environmentally friendly lighting technology, has mainly been used in digital cameras, aircraft instruments, automobiles, mobile phones and television industry. Only very recently has the market began to offer OLEDs useful for lighting and not as systems for screens in electronic applications. It is important to investigate their performance in this kind of application. It is necessary to remember that the visual comfort of a lighting system consisting of artificial light sources that is linked to the luminance distribution, illuminance, directionality of light, variability of light, colour rendering and colour temperature, glare, and flicker in the work environment (BSI Standards, 2015).

Emphasis is given to SSL sources especially LED and OLED as the new research area of artificial light sources. This study considers OLED as an element in an interior environment affecting user visual comfort and task performance and compares it with LED. It aims to analyze the effects of different illuminances of LED and OLED lights on user visual comfort and reading performance. It also targets to research whether LED light or OLED light is comfortable, since there is insufficient research on the relationship between illuminances, user visual comfort and reading performance. In addition, there is insufficient research on the correlation of illuminances of LED and OLED lights. Thus, this study intends to analyze these research topics.

Visual comfort plays an important role in the quality of users in an environment (Xu et al., 2017). In order to guarantee an appropriate visual comfort in an environment, discomfort glare should be avoided, the position of the light source should be considered and a convenient illuminance should be provided. Avcı & Memikoğlu (2016) analyzed the effects of different illuminances on visual comfort. LED and halogen lamps with illuminances of 150, 300 and 450 lx were used in the experiment. They found that 150 lx was generally uncomfortable for both LED and halogen lamps; however, 300 and 450 lx were visually comfortable for both types of artificial light sources. Studies have been conducted to analyze the productivity and performance of users in working environments (de Korte et al., 2015; Chang, Chou, & Shieh, 2013). Evaluation of the working environment is directly related to job satisfaction. As a result, visual comfort and task performance are fundamental criteria in working environments. Lighting conditions in reading environments promote a diversity of effects related to visual comfort, work satisfaction, reading performance and productivity (Borisuit et al., 2015). The light quality in reading environments is not only determined by the light on the visual task, but also the amount of light entering the eye that makes users feel healthy, causes sufficient work performance, fewer absenteeism and fewer accidents (van Bommel & van den Beld, 2004).

In reading environments, satisfaction of lighting is related to work plane illuminance, ratio of horizontal and vertical illumination, and direct glare (Borisuit et al., 2015). Visual comfort parameters are identified by the standards, but they are reluctant to change with respect to user requirements and their environments. Interpersonal preferences of illuminances have been researched and it has been reported that no more than 50% of users feel comfortable within 100 lx of illuminance on a reading plane (Newsham & Veitch, 2001). Fotios and Cheal (2010) found that preferred illuminances are close to the mean of available illuminance ranges that affects the overall illuminances preferred by users.

2. Methodology

2.1. Research questions

1. Is there a statistically significant difference between illuminances on users' visual comfort?
2. Is there a statistically significant difference between the illuminances of LED and OLED lights on users' visual comfort?
3. Is there a statistically significant correlation between illuminances on reading performance?

2.2. Hypotheses

1. The difference between the illuminances is statistically significant. For both types of light sources, 200 lx is more comfortable than 500 lx and 800 lx.
2. There is a statistically significant difference between LED and OLED lights. OLED light is more comfortable than LED light for all illuminances.
3. There is a statistically significant correlation between the effects of different illuminances on reading performance. The participants read under the illuminance of 200 lx faster than other illuminances for both types of artificial light.

2.3. Participants

The sample group consisted of the senior students of the Department of Interior Architecture at Çankaya University. Eighty students were chosen randomly among all students. As senior students they were familiar with physical and psychological properties of natural and artificial lights due to the course "INAR 209 Natural and Artificial Lighting" that they took during the second year of their education. The participants had normal or corrected to normal vision with glasses or contact lenses. There were 40 females and 40 males that were aged between 19 to 30 years (mean age was 22.74) in order to avoid the influences of age-related effects.

2.4. Experimental setting

The experiment was conducted in an office located on the first floor of block B building that faced North. The test cabin was located on the left corner of the office (see Figure 1) and measured 1.60 m x 2.60 m x 2.80 m. White curtain was used around the cabin to eliminate the effects of coloured light in the room. Except for the flooring, all the surfaces and furnishings (dimensions of white table: 1.20 m x 0.80 m x 0.80 m) in the cabin were white. A white table and a stool were used in the cabin during the test. The test cabin is shown in Figure 2.

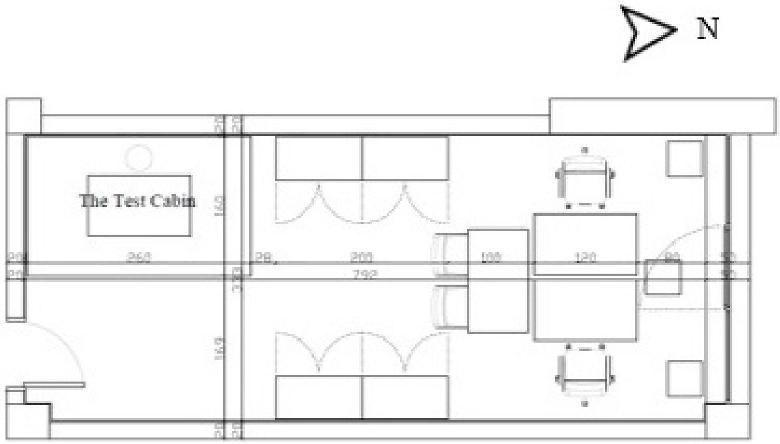

Figure 1. *Plan of the office.*

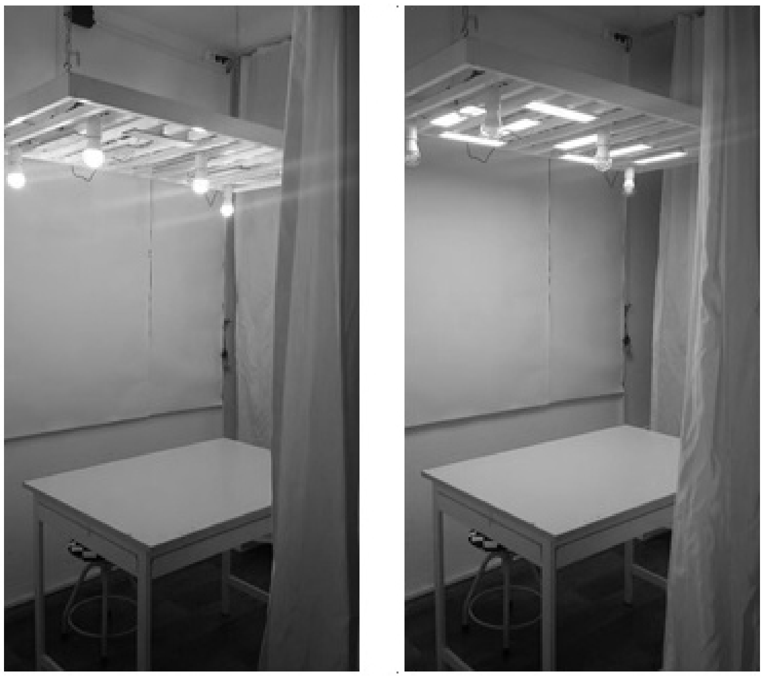

Figure 2. *Test cabin (LED lamps and white OLED panels) (Avcı, 2017).*

In order to understand the effects of different illuminances of LED and OLED lights on user visual comfort, the illuminances were determined for each light source. The lower and higher illuminances were investigated. According to the European standard EN 12464-1, which is also accepted as Turkish standard (TS EN 12464-1), the standard illuminance for reading, writing and data processing in an office environment is 500 lx. The lowest illuminance is stated as 200 lx for archives and the upper level for offices is stated as 750 lx for technical drawings. Although the upper illuminance is 750 lx for offices, 800 lx was identified in order to have an equal increment of illuminances as above and below the standard. So, three illuminances were identified as 200 lx (below standards), 500 lx (as standards), 800 lx (above standards). After contacting with the suppliers about the characteristics of the products and analyzing their IES (Illuminating Engineering Society) files, DIALux Evo 6.1, which is the lighting design program used in order to decide the number of LED lamps and OLED panels. Five LED lamps and ten white OLED (WOLED) panels were utilized to obtain the mentioned three illuminances (200, 500 and 800 lx). The light setting was designed accordingly. It consisted of a white frame that was installed to carry the suspended five LED lamps, ten WOLED panels and their drivers. The illuminance level depends on luminous flux as specified by the product manufacturer and their position with respect to the surrounding environment. The light 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. According to the research of Ferlazzo et al., (2014), they were also placed over the center of the desk to avoid glare or reflections on the paper. Three electrical systems that were connected in series were used to turn on the lamps. LED lamps and WOLED panels were controlled by a dimmable switch separately. Two adaptors were used for the WOLED panels and their drivers. The properties of LED lamp, WOLED panel and WOLED panel driver are shown in Table 1. The WOLED has different types of materials that can adjust the emitting peak wavelength enabling it to be

Table 1. Properties of LED lamp, WOLED panel and WOLED panel driver.

Brand/Model	Dimension	Lumen	CCT	CRI	Product
Osram LED Star Classic A 60	11 cm x 6 cm	806 lm	2700 K	≥80	
Philips Lumiblade OLED Panel Brite FL300 L WW	24.8 cm x 7 cm	300 lm	2900 K	80	
Philips Driver D024V 10W/0.1-0.4A/28V D/A	5.8 cm x 5 cm				

a good and eco-friendly product for users (Zhang, Xia & Yan, 2016). LED lamps and OLED panels have the same technical properties. lluminance levels inside the cabin were measured on the four corners of the table with the TES 1332A Illuminance Meter (range of 0.01 to 200.000 lx).

2.5. Procedure

The experiment was conducted between 3rd and 21st of October, 2016. Before each experiment, the participants were informed about the setting and the procedure. The experiment was conducted in the morning due to the cortisol (stress hormone) and melatonin hormones (sleep hormone) that play an important role on alertness and sleepiness. The cortisol hormone level increases in the morning to prepare the body for daily tasks (van Bommel & van den Beld, 2004). It remains in a high level over in the morning hours. However, there was no daylight penetration during the experiments; since it was blocked by blinds. Several studies indicated that time awake, hours of sleep, time spent outside, travelling across time zones, drinking coffee and smoking cigarettes are very important factors that affect task performance (Fortunati & Vincent, 2014; Hawes et al., 2012). Before the experiment, all participants declared that they had adequate sleep, did not travel across time zones nor spend time outside nor drank coffee or smoked cigarette.

2.6. Questionnaire

The questionnaire consisted of seventeen questions that were taken from "Office Lighting Survey" questions generated by Eklund and Boyce in 1996 (Sivaji et al., 2013). The reliability of these questions was determined statistically (Cronbach Alpha = 0.928). The questionnaire was divided into three parts. The first part consisted of four questions that aimed to obtain general information about the participants.

Before starting the test, participants were told that they should pay attention to the punctuations when reading the texts. The second part was divided into six sub-parts. All the sub-parts had the same questions, but the reading texts that the participants were given to read were different. Since reading on paper is more comfortable than reading on screen-keyboard for users, this method is useful for speed reading (Fortunati & Vincent, 2014). Thus, participants read six reading texts on white A4 papers that were the abstracts of six books. The books were "Little Prince", "My Left Foot", "Pomegranate Tree", "Of Mice and Men", "My Sweet Orange Tree" and "Madonna in a Fur Coat". These were chosen due to their popularity. In order to reduce the risk of memorization, abstracts of different books were selected. The word count of the reading texts was 380. In the sub-parts, familiarity with the books from which the reading texts were selected from were indicated. A seven-point Likert scale was used to evaluate the visual comfort criteria while reading the texts (see Appendix A). These criteria were indicated as visual distraction, visual clarity, visual fatigue, eye burning, focusing problem and glare. The questionnaire was approved by the university ethics board. The last part of the questionnaire aimed to get general information about all the illuminance levels.

Some studies have concluded that font character effects the visual performance and 12-point Times New Roman font style is comfortable (Fortunati & Vincent, 2014; Shen et al., 2009). Thus, the questionnaire and reading texts were printed in black ink on white A4 papers with the 12-point Times New Roman font style.

There were six lighting scenarios in the experiment that consisted of different illuminance levels (LED 200 - 500 - 800 lx and OLED 200 - 500 - 800 lx) and reading texts. Lighting scenarios were carried out in random to avoid the adaption of the eye. When the participants started to read the reading text, their reading speeds were timed. After the reading, participants answered the questions related to each scenario and got out of the test cabin. In between each lighting scenario, participants had time to rest about five minutes and they continued with the next scenario in the same way. The duration time for a participant was about forty minutes. The average reading speed for each text was between 150 and 190 seconds. All of the participants answered the questions in the same order.

3. Results

In the analysis of the data Statistical Package for the Social Sciences (IBM Corp. SPSS) 20.0 program was used. Results from the statistical analysis were given with respect to the stated research questions. According to the results, the participants mostly rated their current physical condition on a seven-point Likert scale as being "little tired" (33.8%) and "normal" (28.8%). The second part of the questionnaire was divided into six sub-parts. The reading texts were different, but the questions were the same. The participants were familiar with the first reading text more than others, but they read the fourth and sixth reading texts slightly quicker than the others. The results of the second part of the questionnaire are presented in Table 2.

According to the second part of the questionnaire, six visual comfort criteria were evaluated with respect to the illuminances of LEDs and OLEDs (200 - 500 - 800 lx). In order to find out the effects of illuminances on users' visual comfort, ANOVA was conducted. Visual comfort criteria correlated with each three illuminances and evaluated separately by statistical data.

Table 2. *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 lx	1.90 (SD = 0.56)
Pomegranate Tree	9 (11.3%)	LED	800 lx	1.83 (SD = 0.50)
My Left Food	38 (47.5%)	LED	500 lx	1.61 (SD = 0.42)
Of Mice and Men	48 (60.0%)	OLED	200 lx	1.50 (SD = 0.45)
Madonna In a Fur Coat	69 (86.3%)	OLED	800 lx	1.69 (SD = 0.49)
My Sweet Orange Tree	62 (77.5%)	OLED	500 lx	1.50 (SD = 0.43)

3.1. Related to the illuminances of OLED light

Visual Distraction: The mean of participants for OLED 500 lx (M = 6.03, SD = 1.28) was slightly higher than that of the OLED 200 lx (M = 5.66, SD = 1.68) and 800 lx (M = 5.16, SD = 1.90). There was a statistically no considerable difference between 200 and 500 lx on users' visual comfort in this criterion (Wilks' ʌ = 0.78, $F(3,80) = 10.76$, $p = 0.040 < 0.05$). However, there was a statistically significant difference between 500 and 800 lx on users' visual comfort in this criterion ($p = 0.000 < 0.05$). According to these results, 500 lx is visually more comfortable than 800 lx in terms of visual distraction. Results are shown in Table 3.

Visual Clarity: The mean of participants for OLED 500 lx (M = 5.98, SD = 1.38) was slightly higher than that of the OLED 200 (M = 5.80, SD = 1.53) and 800 lx (M = 5.14, SD = 1.78). There was a statistically no significant difference between 200 and 500 lx on users' visual comfort in this criterion (Wilks' ʌ = 0.83, $F(3,80) = 8.06$, $p = 0.335 > 0.05$). However, there were a statistically significant difference between 200 - 800 lx and 500 - 800 lx on users' visual comfort in this criterion ($p = 0.005 < 0.05$, $p = 0.000 < 0.05$). According to these results, 200 lx is visually more comfortable than 800 lx; 500 lx is visually more comfortable than 800 lx in terms of visual clarity. Results are shown in Table 3.

Table 3. *Results of visual distraction and visual clarity.*

Visual Distraction		
	200-500 lx	500-800 lx
No Sig. Dif.		
Sig. Dif.	p = 0.040 < 0.05	p = 0.000 < 0.05

Visual Clarity			
	200-500 lx	200-800 lx	500-800 lx
No Sig. Dif.	p = 0.335 > 0.05		
Sig. Dif.		p = 0.005 < 0.05	p = 0.000 < 0.05

Visual Fatigue: The mean of participants for OLED 500 lx (M = 5.50, SD = 1.59) was slightly higher than that of the OLED 200 (M = 5.38, SD = 1.71) and 800 lx (M = 4.51, SD = 1.89). There was a statistically no significant difference between 200 and 500 lx on users' visual comfort in this criterion (Wilks' ʌ = 0.78, F(3,80) = 10.76, p = 0.517 > 0.05). However, there were a statistically significant difference between 200 - 800 lx and 500 - 800 lx on users' visual comfort in this criterion (p = 0.001 < 0.05, p = 0.000 < 0.05). According to these results, 200 lx is visually more comfortable than 800 lx; 500 lx is visually more comfortable than 800 lx in terms of visual fatigue. Results are shown in Table 4.

Burning Eye: The mean of participants for OLED 500 lx (M = 5.98, SD = 1.47) was slightly higher than that of the 200 (M = 5.95, SD = 1.52) and 800 lx (M = 5.14, SD = 1.91). There was a statistically no significant difference between 200 and 500 lx on users' visual comfort in this criterion (Wilks' ʌ = 0.80, F(3,80) = 10.00, p = 0.893 > 0.05). However, there were a statistically significant difference between 200 - 800 lx and 500 - 800 lx on users' visual comfort in this criterion (p = 0.000 < 0.05). According to these results, 200 lx is visually more comfortable than 800 lx; 500 lx is visually more comfortable than 800 lx in terms of burning eye. Results are shown in Table 4.

Table 4. Results of visual fatigue and burning eye.

Visual Fatigue			
	200-500 lx	200-800 lx	500-800 lx
No Sig. Dif.	p = 0.517 > 0.05		
Sig. Dif.		p = 0.000 < 0.05	p = 0.000 < 0.05
Burning Eye			
	200-500 lx	200-800 lx	500-800 lx
No Sig. Dif.	p = 0.893 > 0.05		
Sig. Dif.		p = 0.000 < 0.05	p = 0.000 < 0.05

Table 5. Results of Focusing Problem and Glare.

Focusing Problem			
	200-500 lx	200-800 lx	500-800 lx
No Sig. Dif.			
Sig. Dif.	p = 0.026 < 0.05	p = 0.005 < 0.05	p = 0.000 < 0.05
Glare			
	200-500 lx	200-800 lx	
No Sig. Dif.	p = 0.074 > 0.05		
Sig. Dif.		p = 0.000 < 0.05	

Focusing Problem: The mean of participants for OLED 500 lx (M = 5.90, SD = 1.37) was slightly higher than that of the 200 (M = 5.46, SD = 1.79) and 800 lx (M = 4.76, SD = 1.92). There was a statistically significant difference between 200 and 500 lx in this criterion (Wilks' ʌ = 0.77, F(3,80) = 12.00, p = 0.026 < 0.05). There were a statistically significant difference between 200 and 800 lx (p = 0.005 < 0.05) and 500 and 800 lx in this criterion (p = 0.000 < 0.05). According to these results, 200 lx is visually more comfortable than 800 lx; 500 lx is visually more comfortable than 800 lx in terms of focusing problem. Results are shown in Table 5.

Glare: The mean of participants for OLED 200 lx (M = 6.35, SD = 1.19) was slightly higher than 500 (M = 6.07, SD = 1.41) and 800 lx (M = 4.72, SD = 2.03). OLED 200 lx was more comfortable than others. There was a statistically no significant difference between 200 and 500 lx on users' visual comfort in this criterion (Wilks' ʌ = 0.61, F(3,80) = 25.17, p = 0.074 > 0.05). However, there was a statistically significant difference between 200 and 800 lx on users' visual comfort in this criterion (p = 0.000 < 0.05). According to these results, 200 lx is visually more comfortable than 800 lx. Results are shown in Table 5.

All Criteria: The mean of participants for OLED 500 lx (M = 35.46, SD = 6.40) was slightly higher than 200 (M = 34.60, SD = 7.24) and 800 lx (M = 29.44, SD = 9.02). There was a statistically no significant difference between 200 and 500 lx on users' visual comfort generally (Wilks' ʌ = 0.65, F(3,80) = 20.62, p = 0.234 < 0.05). However, there was a statistically significant difference between 200 lx - 800 lx and 500 lx - 800 lx on users' visual comfort in general (p = 0.000 < 0.05). As a result, 200 lx is visually more comfortable than 800 lx; 500 lx is visually more comfortable than 800 lx in general.

3.2. Correlations of the three illuminances of LED and OLED lights

The different illuminances were analyzed within themselves. The number of the participants who found OLED light comfortable were slightly more than LED light for all of the visual comfort criteria. To determine if there was a significant relationship between all visual comfort criteria in LED and OLED lights, paired-samples t-test was conducted.

For the 200 lx of LED and OLED lights, there was a statistically significant correlation between LED and OLED lights with respect to the criterion of visual distraction (t = -2.89, df = 79, two-tailed p = 0.005). There were statistically no significant correlations between LED and OLED lights with respect to the criteria of visual clarity, visual fatigue, burning eye and focusing problem (t = -1.75, -1.55, -0.76, -1.64, df = 79, two-tailed p = 0.08, 0.12, 0.45, 0.11; respectively). There was a statistically significant correlation between LED and OLED lights with respect to the criterion of glare (t = -3.78, df = 79, two-tailed p = 0.000). There was a statistically significant correlation between LED and OLED lights with respect to all of the visual comfort criteria (t = -3.07, df = 79, two-tailed p = 0.003). The results indicated that LED and OLED lights differ with respect to criteria of visual distraction and glare but not respect to other criteria. Results are shown in Table 6.

For the 500 lx of LED and OLED lights, the participants who found OLED light comfortable were slightly more than LED light for all of the visual comfort crtieria. To determine if there was a significant relationship between all visual comfort criteria on LED and OLED lights, paired-samples t-test was conducted. There was statistically no significant correlation between LED and OLED lights with respect to all visual comfort criteria (two tailed p values = 0.15, 0.43, 0.08, 0.30, 0.16, 0.07, 0.07; respectively) According to these results, LED and OLED lights didn't differ for all visual comfort criteria. Results are shown in Table 7.

Table 6. *Correlation results for LED and OLED 200 Lx.*

Visual Comfort Criteria	No Sig. Cor.	Sig. Cor.
Visual Distraction		$p = 0.000 < 0.05$
Visual Clarity	$p = 0.08 > 0.05$	
Visual Fatigue	$p = 0.12 > 0.05$	
Burning Eye	$p = 0.45 > 0.05$	
Focusing Problem	$p = 0.11 > 0.05$	
Glare		$p = 0.000 < 0.05$
All Criteria		$p = 0.003 < 0.05$

Table 7. *Correlation results for LED and OLED 500 Lx.*

Visual Comfort Criteria	No Sig. Cor.	Sig. Cor.
Visual Distraction	$p = 0.15 > 0.05$	
Visual Clarity	$p = 0.42 > 0.05$	
Visual Fatigue	$p = 0.08 > 0.05$	
Burning Eye	$p = 0.30 > 0.05$	
Focusing Problem	$p = 0.16 > 0.05$	
Glare	$p = 0.07 > 0.05$	
All Criteria	$p = 0.07 > 0.05$	

Table 8. *Correlation results for LED and OLED 800 Lx.*

Visual Comfort Criteria	No Sig. Cor.	Sig. Cor.
Visual Distraction		$p = 0.027 < 0.05$
Visual Clarity	$p = 0.80 > 0.05$	
Visual Fatigue	$p = 0.18 > 0.05$	
Burning Eye	$p = 0.17 > 0.05$	
Focusing Problem	$p = 0.91 > 0.05$	
Glare	$p = 0.77 > 0.05$	
All Criteria	$p = 0.19 > 0.05$	

For the 800 lx of LED and OLED lights, number of the participants who found OLED light comfortable were slightly more than LED light for all visual comfort criteria. To determine if there was a significant relationship between all visual comfort criteria on

LED and OLED lights, paired-samples t-test was conducted. There was a statistically significant correlation between LED and OLED lights with respect to visual distraction (t = -2.25, df = 79, two-tailed p = 0.027). There was a statistically no significant correlation between LED and OLED lights with respect to visual clarity, visual fatigue, burning eye, focusing problem and glare (two tailed p values = 0.80, 0.18, 0.17, 0.91, 0.77; respectively). According to all criteria, there was no statistically significant correlation between LED and OLED lights (t = -1.32, df = 79, two-tailed = 0.192). The results indicated that LED and OLED lights differ with respect to criterion of visual distraction but not respect to other criteria. Results are shown in Table 8.

3.3. Correlations of LED and OLED lights with respect to reading speed

Seven physical condition types were evaluated together in all of the lighting scenarios from the point of reading speed. Correlation analysis was conducted to search the relationship between different illuminance and reading speeds.

In the first lighting scenario, there was no statistically significant correlation between LED 200 lx and reading speed (R = 0.053, p = 0.641 > 0.05). In the second lighting scenario, there was also no statistically significant correlation between LED 500 lx and reading speed (R = 0.093, p = 0.411 > 0.05). However, in the third lighting scenario, there was a statistically low significant correlation between LED 800 lx and reading speed (R = -0.240, p = 0.032). In the fourth lighting scenario, there was no statistically significant correlation between OLED 200 lx and reading speed (R = -0.127, p = 0.260 > 0.05). In the fifth lighting scenario, there was no statistically significant correlation between OLED 500 lx and reading speed (R = -0.064, p = 0.571 > 0.05). In the sixth lighting scenario, there was also no statistically significant correlation between OLED 800 lx and reading speed (R = -0.156, p = 0.168 > 0.05) The results show that only OLED 500 lx had a positive effect on the reading speed of the participants.

3.4. Other results related to LED and OLED lights with respect to physical condition

Seven physical condition types that were used in the questionnaire was divided into three groups as “felt tired” (very tired, tired and little tired), “felt normal” and “felt good” (very good, good and little good). ANOVA was conducted to compare the three groups from the point of illuminances of LED and OLED lights.

In the LED 200 lx scenario, the mean of the “felt good” group (M = 34.17, SD = 7.15) was slightly higher than the “felt normal” group (M = 32.91, SD = 8.64) and the “felt tired” group (M = 29.40, SD = 8.89). There was no statistically significant difference between the physical conditions and this lighting scenario (p = 0.191 > 0.05). However, there was a statistically low significant difference between the “felt tired” and the “felt good” groups (p = 0.036 < 0.05).

In the LED 500 lx scenario, the mean of the “felt normal” group (M = 34.87, SD = 8.13) was slightly higher than the “felt good” group (M = 34.25, SD = 8.62) and the “felt tired group (M = 32.55, SD = 8.36). There was no statistically significant difference between physical conditions and this lighting scenario (p = 0.951 > 0.05).

In the LED 800 lx scenario, the mean of the “felt normal” group (M = 30.83, SD = 8.58) was slightly higher than the “felt good” group (M = 29.17, SD = 9.43) and the “felt tired” group (M = 25.70, SD = 9.84). There was no statistically significant difference between physical conditions and this lighting scenario (p = 0.432 > 0.05).

In the OLED 200 lx scenario, the mean of the “felt good” group (M = 36.67, SD = 6.34) was slightly higher than the felt normal group (M = 36.26, SD = 6.14) and felt tired group (M = 31.94, SD = 7.89). There was no statistically significant difference between physical conditions and this lighting scenario (p = 0.241 > 0.05). However, there was a statistically significant difference between the “felt tired” and the “felt normal” groups (p = 0.025 < 0.05) and the “felt tired” and the “felt good” groups (p = 0.014 < 0.05).

In the OLED 500 lx scenario, the mean of the "felt normal" group (M = 36.65, SD = 6.09) slightly was higher than the "felt good" group (M = 35.88, SD = 6.82) and the "felt tired" group (M = 34.33, SD = 6.30). There was no statistically significant difference between physical conditions and this lighting scenario ($p = 0.851 > 0.05$).

In the OLED 800 lx scenario, the mean of the "felt good" group (M = 30.71, SD = 8.59) was higher than the "felt normal" group (M = 29.87, SD = 9.00) and the "felt tired" group (M = 28.21, SD = 9.45). There was no statistically significant difference between physical conditions and this lighting scenario ($p = 0.655 > 0.05$). As can be seen in all LED lighting scenarios, due to their physical conditions, they were not positively or negatively affected by illuminances. However, 200 lx of OLED light affected their task performance within this research.

4. Discussion

The aim of this study was to analyze the effects of different illuminances of LED and OLED lights on user visual comfort during a reading task. It also aimed to research whether LED or OLED lights were visually more comfortable and identify which illuminances of LED and OLED lights were visually more comfortable than the others. Therefore, the effects of illuminances of LED and OLED lights on visual comfort were compared according to lighting scenarios that consisted of six reading texts and three different illuminances (200 - 500 - 800 lx).

In the first hypothesis, it was supposed that there would be a statistically significant difference between the illuminances that 200 lx would be visually more comfortable than 500 lx and 800 lx. For OLED light, the results indicated that 500 lx was found visually slightly more comfortable than the other illuminances with respect to visual distraction, visual clarity, visual fatigue, burning eye and focusing problem. In addition, OLED 200 lx was found visually slightly more comfortable than others with respect to glare. According to Kim and Kim (2007), as the illuminance increases above 500 lx, brightness and glare negatively affect visual comfort. The preferred illuminances of work plane are either above or below 500 lx, but the resulting visual criteria may be different (Borisuit et al., 2015).

The results revealed that there was a statistically significant correlation between the 200 lx of LED and OLED lights according to visual distraction and glare. There was also a statistically significant correlation between them in total. Although there was no statistically significant correlation between these two light sources according to other visual comfort criteria, due to the mean scores, it can be said that the OLED 200 lx was slightly more comfortable than LED 200 lx. There was no statistically significant correlation between 500 lx of LED and OLED lights according to all the visual comfort criteria. Due to the mean scores, it can be concluded that the illuminance of OLED 500 lx was visually slightly more comfortable than LED 500 lx. For 800 lx, there was a statistically significant correlation in the visual distraction. Through the mean scores, it can be said that the illuminance of OLED 800 lx was visually slightly more comfortable than LED 800 lx. In the work of Smolders et al. (2012), it was stated that the type of light source affected users' task performance. As stated in the second hypothesis, the illuminances of OLED light is accepted more comfortable than LED light. There is not any research about the differences between LED and OLED lights with respect to the illuminances in the literature. The reason for finding the OLED light slightly more comfortable than LED light can be the features of OLED light that they are producing a pleasing visual effect and low light pollution (Eley, 2015; Kar & Kar, 2014).

There was no statistically significant difference between the 200 and 800 lx of LED light from the point of visual distraction and visual clarity. However, there was a statistically significant difference between them from the point of other visual comfort criteria. Due to the mean scores, LED 200 lx was visually more comfortable than 800 lx. For OLED light, there was a statistically significant difference between

200 and 800 lx from the point of all visual comfort criteria. According to all mean scores and p values, 200 lx of LED and OLED lights were found visually more comfortable than 800 lx. Shen et al. (2009) stated a different result that an illuminance of 300 lx was uncomfortable than 700 lx. Ricciardi and Buratti (2018) found a strong relationship between illuminances and visual comfort. The relationship is observed between increased illuminances and glare, which resulted in a decrease user visual comfort levels.A study conducted by Castaldo et al., (2017) also observed a correlation between illuminances and performance, where users were satisfied with levels less than the suggested minimum of 500 lx.

For LED light, there were statistically no correlations between the illuminances and reading speed except in 800 lx. There was no statistically significant correlation that as the illuminance increases, reading speed decreases. The mean scores of the reading speeds of 800 lx were more slower than the other illuminances. For OLED light, there were no statistically significant correlation between all illuminances and reading speeds. The mean score of the reading speed of OLED 200 lx and 500 lx was faster than other illuminances. In addition, participants found 500 lx visually more comfortable than others. It can be stated that illuminances of the light source have an effect on visual comfort and reading performance. The results are not in line with many studies (Chang et al., 2013; Lee, Shieh, Jeng & Shen, 2008; Smolders et al., 2012; Wang, Haisong, Gong & Cai, 2015). Lee and colleagues (2008) indicated that reading speeds increased as the illuminances increased from 300, 700 to 1500 lx. According to Smolders et al. (2012), higher illuminances could result in better performance for fluorescent tubes. Chang et al. (2013) proposed that illuminances of 1000 and 1500 lx supported faster reading than did those of 200 and 500 lx. Moreover, in the work of Wang et al. (2015), in the lighting scenario of the illuminance level of LED 1000 lx, participants read faster than the illuminances of LED 300 and 500 lx. However, except the technical information, there is not any sufficient information about OLED light related to the reading task in the literature.

The results revealed that the participants read the text of first lighting scenario slower than other texts (M = 1.90). The illuminance of this lighting scenario was LED 200 lx. LED light was found visually slightly uncomfortable than OLED light and 200 lx was also found slightly uncomfortable than 500 lx. On the other hand, the familiarity ratio of this text was the highest ratio (88.8%). Therefore, it can be stated that the illuminances of light source has an effect on reading speed, but familiarity does not have an effect on it.

There was a statistically significant difference between the "felt tired" and the "felt good" groups in OLED 200 lx scenario. According to the mean scores and p values, the "felt tired" group found visually uncomfortable than the "felt good" group for these lighting scenarios. It can be stated that when the user felt tired, they are affected from the illuminances that are below the standards more than users who felt good, and the physical condition and the illuminance are in a relationship between each other. In the LED 800 lx and OLED 200 lx lighting scenarios, there was a statistically significant difference between the "felt tired" group and the "felt normal" group. Due to the mean scores and p values, the "felt tired" group found visually uncomfortable than the "felt normal" group for these lighting scenarios in terms of all visual comfort criteria. There is not any sufficient information about OLED light related to the relationship between reading performance and physical condition in the literature.

5. Conclusion

The study aimed to analyze the effects of different illuminances of LED and OLED light on users' visual comfort and reading performance, and compare LED and OLED lights with respect to the different illuminances. The result of this study revealed that illuminances have a significant effect on users' visual comfort. The illuminance of LED 500 lx was generally found visually more comfortable than the rest of LEDs; on the other hand, the illuminance of LED 200 lx was found visually more comfortable than the other illuminances with respect to the criterion of burning eye. Likewise, OLED 500 lx was generally found visually more comfortable; on the other hand, OLED 200 lx was visually more comfortable than the other illuminances with respect to the criterion of glare. Generally, OLED light was accepted visually more comfortable than LED light.

There has been no research on the effects of OLED with respect to the users' visual comfort and task performance. OLED, as the next step of the Solid-State Light (SSL) technology, has mainly been used in automobiles, mobile phones and television industry, but this study has considered OLED as an element of an interior environment affecting user visual comfort and task performance and compared it with LED. The results of this study might shed light to interior architects, psychologists, lighting designers and manifacturers. They might use the results of this study in order to create visually comfortable and innovative interiors and decide how the good qualified lighting should be manufactured. Unlike LEDs, OLEDs are flexible, transparent, sustainable, durable, produce very little heat, have a long life span and consume less energy than traditional lighting technologies. In addition, OLEDs emit the same apparent radiance when viewed from various angles and reduce the space required for light installations (Eley, 2015). It is possible that OLED will begin to be used more than other artificial light sources in indoor environment due to these advantages.

References

Aries, M. (2005). Human Lighting Demands. Technische Universiteit Eindhoven.

Avcı, A. N., & Memikoğlu, İ. (2016). Aydınlık düzeylerinin kullanıcının okuma hızı ve görsel konforu üzerindeki etkisi. *İÇLİS- İç Mimarlık Lisansüstü Çalışmalar Sempozyumu-I,* İstanbul, Türkiye, 29-36.

Avcı, A. N. (2017). *Effects of illuminance levels of solid state lighting sources on visual comfort* (Unpublished Master Thesis). Çankaya Üniversitesi.

Bellia, L., Bisegna, F., & Spada, G. (2011). Lighting in indoor environments: Visual and non-visual effects of light sources with different spectral power distributions. *Building and Environment,* 46, 1987-1992. http://doi.org/10.1016/j.buildenv.2011.04.007

Borisuit, A., Linhart, F., Scartezzini, J. L., & Münch, M. (2015). Effects of realistic daylighting and electric lighting conditions on visual comfort, alertness and mood. *Lighting Research & Technology,* 47, 192-209. https://doi.org/10.1177/1477153514531518

Boyce, P. R., Veitch, J. A., Newsham, G. R., Jones, C. C., Heerwagen, J., Myer, M., & Hunter, C. M. (2006a). Lighting quality and office work: two field simulation experiments. *Lighting Research & Technology, 38*(3), 191-223. https://doi.org/10.1191/1365782806lrt161oa

Boyce, P. R., Veitch, J. A., Newsham, G. R., Jones, C. C., Heerwagen, J., Myer, M., & Hunter, C. M. (2006b). Occupant use of switching and dimming controls in offices. *Lighting Research & Technology, 38*(4), 358-376. https://doi.org/10.1177/1477153506070994

BSI Standards Publication, (2015). Light and lighting- Lighting of work places. Retrieved from http://www.ahjzu.edu.cn/_upload/article/files/50/b5/ 4e0248ef47278e4dead0447bd16a/89a6cb4c-2303-42e6-97a3-34d8adc7a5eb.pdf

Castaldo, V. L., Pigliautile, I., Rosso, F., Pisello, A. L., & Cotana, F. (2017). Investigation of the impact of subjective and physical parameters on the indoor comfort of occupants: A case study in central Italy. *Energy Procedia, 126,* 131-138. https://doi.org/10.1016/j.egypro.2017.08.132

Chang, P.-C., Chou, S.-Y., & Shieh, K.-K. (2013). Reading performance and visual fatigue when using electronic paper displays in long-duration reading tasks under various lighting conditions. *Displays*, 34(3), 208-214. https://doi.org/10.1016/j.displa.2013.06.001

De Korte, E. M., Spiekman, M., Hoes-van Oeffelen, L., van der Zande, B., Vissenberg, G., Huiskes, G., & Kuijt-Evers, L. F. (2015). Personal environmental control: effects of pre-set conditions for heating and lighting on personal settings, task performance and comfort experience. *Building and*

Environment, 86, 166-176. https://doi.org/10.1016/j.buildenv.2015.01.002

Dubois, M.-C., Gentile, N., Bisegna, F., Knoop, M., Matusiak, B., Osterhaus, W., Stoffer, S., & Tetri, E. (2016). *Daylighting and lighting retrofit to reduce energy use in non-residential buildings: A literature review.* (A Technical Report of IEA SHC Task 50 Subtask D Report T50.D2). Germany: Fraunhofer-Institut für Bauphysik.

Eley, L. (2015). OLEDs-Lighting's new wave. *Canadian Consulting Engineer,* 51-52. Retrieved from https://www.canadianconsultingengineer.com/digital-archives/augustseptember-2015/.

European Standards, (2002). Light and lighting - Lighting of work places - Part 1: Indoor work places. Retrieved from https://lumenlightpro.com/wp-content/themes/lumenlightpro/assets/EN_12464-1.pdf.

Ferlazzo, F., Piccardi, L., Burattini, C., Barbalace, M., Giannini, A. M., & Bisegna, F. (2014). Effects of new light sources on task switching and mental rotation performance. *Journal of Environmental Psychology,* 39, 92-100. https://doi.org/10.1016/j.jenvp.2014.03.005

Fortunati, L., & Vincent, J. (2014). Sociological insights on the comparison of writing/reading on paper with writing/reading digitally. T*elematics and Informatics,* 32, 39-51. https://doi.org/10.1016/j.tele.2013.02.005

Fotios, S. A., & Cheal, C. (2010). Stimulus range bias explains the outcome of preferred-illuminance adjustments. *Lighting Research & Technology,* 42, 433-447. https://doi.org/10.1177/1477153509356018

Hawes, B. K., Brunye, T. T., Mahoney, C. R., Sullivan, J. M., & Aall, C. D. (2012). Effects of four workplace lighting technologies on perception, cognition and affective state. *International Journal of Industrial Ergonomics,* 42(1), 122-128. https://doi.org/10.1016/j.ergon.2011.09.004

Kar, A., & Kar, A. (2014). Advancements in solid state lighting technology for smart and energy efficient illumination system design. *IEEE Proceedings of 2014 International Conference on Green Computing Communication and Electrical Engineering (ICGCCEE 2014),* 1-6. https://doi.org/10.1109/ICGCCEE.2014.6922395

Kim, S., & Kim, J. (2007). The effect of fluctuating illuminance on visual sensation in a small office. *Indoor Built Environment,* 16, 331-343. https://doi.org/10.1177/1420326X06079947

Lee, D.-S., Shieh, K.-K., Jeng, S.-C., & Shen I.-H. (2008). Effect of character size and lighting on legiblity of electronic papers. *Displays,* 29(1), 10-17. https://doi.org/10.1016/j.displa.2007.06.007

Newsham, G. R., Mancini, S., & Marchand, R. G. (2008). Detection and acceptance of demand-responsive lighting in offices with and without daylight. *Leukos, 4*(3), 139-156. https://doi.org/10.1582/LEUKOS.2007.004.03.001

Newsham, G. R., & Veitch, J. A. (2001). Lighting quality recommendations for VDT offices: A new method of derivation. *Lighting Research & Technology,* 33, 97-116. https://doi.org/10.1177/136578280103300205

Ricciardi, P., & Buratti, C. (2018). Environmental quality of university classrooms: Subjective and objective evaluation of the thermal, acoustic, and lighting comfort conditions. *Building and Environment, 127*, 23-36. https://doi.org/10.1016/j.buildenv.2017.10.030

Shen, I.-H., Shieh, K.-K., Chao, C.-Y., & Lee, D.-S. (2009). Lighting, font style, and polarity on visual performance and visual fatigue with electronic paper displays. *Displays*, 30(2), 53-58. https://doi.org/10.1016/j.displa.2008.12.001

Sivaji, A., Shopian, S., Nor, Z. M., Chuan, N. K., & Bahri, S. (2013). Lighting does matter: Preliminary assessment on office workers. *Social and Behavioral Sciences,* 97, 638-647. https://doi.org/10.1016/j.sbspro.2013.10.283

Smolders, K. C. H. J., de Kort, Y. A. W., & Cluitmans, P. J. M. (2012). A higher illuminance induces alertness even during office hours: Findings on subjective measures, task performance and heart rate measures. *Physiology & Behavior,* 107, 7-16. http://doi.org/10.1016/j.physbeh.2012.04.028

van Bommel, W. J. M., & van den Beld, G. J. (2004). Lighting for work: A review of visual and biological effects. *Lighting Research & Technology,* 36(4), 255-266. http://doi.org/10.1191/1365782804li122oa

Veitch, J. A., & Gifford, R. (1996). Choice, perceived control, and performance decrements in the physical environment. *Journal of Environmental Psychology, 16*(3), 269-276. https://doi.org/10.1006/jevp.1996.0022

Wang, Q., Xu, H., Gong, R., & Cai, J. (2015). Investigation of visual fatigue under LED lighting based on reading task. *Optics*, 126(15-16), 1433-1438. https://doi.org/10.1016/j.ijleo.2015.04.033

Xu, L., Pan, Y., Yao, Y., Cai, D., Huang, Z., & Linder, N. (2017). Lighting energy efficiency in offices under different control strategies. *Energy and Buildings, 138,* 127-139. https://doi.org/10.1016/j.enbuild.2016.12.006

Zhang, E., Xia, W., & Yan, X. (2016). A novel lighting OLED panel design. *Molecules,* 21, 1-8. http://doi.org/10.3390/molecules21121615

Appendix
Appendix A

Number of Respondent: Time:

1. Age:

2. Gender: Female ☐ Male ☐

3. Usage of Eye Glass or Contact Lens: Yes ☐ No ☐

4. How do you feel now? Please choose one of them.

Very Tired	Tired	Little Tired	Normal	Little Good	Good	Very Good
☐	☐	☐	☐	☐	☐	☐

LITTLE PRINCE Reading Time: Lamp Type: LED Illuminance Level: 200lx

5. Have you ever heard this book which was mentioned before? Yes ☐ No ☐

6. Please specify the rates of visual comfort criterias what you feel while reading a part.

	Comp. Agree			Neutral			Comp. Disagree
Visual Distraction	-3	-2	-1	0	1	2	3
Visual Clarity	-3	-2	-1	0	1	2	3
Visual Fatigue	-3	-2	-1	0	1	2	3
Eye Burning	-3	-2	-1	0	1	2	3
Focusing problem	-3	-2	-1	0	1	2	3
Glare	-3	-2	-1	0	1	2	3
Others, (please specify)	-3	-2	-1	0	1	2	3