ANALYZING OCCUPANTS’ CONTROL OVER LIGHTING SYSTEMS IN OFFICE SETTINGS USING VIRTUAL ENVIRONMENTS

A Master’s Thesis

by
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ANKARA

December 2020

To my parents

Raheleh and Mohammadreza

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

by
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In Partial Fulfillment of the Requirements for the Degree of
MASTER OF FINE ARTS

THE DEPARTMENT OF
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İHSAN DOĞRAMACI BİLKENT UNIVERSITY
ANKARA

December 2020

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.

Assoc. Prof. Dr. Yasemin Afacan
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Asst. Prof. Dr. Mohamad Nadim Adi
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ABSTRACT

ANALYZING OCCUPANTS' CONTROL OVER LIGHTING SYSTEMS IN OFFICE SETTINGS USING VIRTUAL ENVIRONMENTS

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This study systematically analyzed the impact of having personal control over lighting system on occupants' lighting choices, lighting satisfaction, and task performance in a virtual office setting. For this purpose, 30 participants took part in a 3-phased experiment with immersive virtual environments (IVEs). Each phase of the experiment offered a different degree of control over the lighting. Personality traits were also studied in relation to lighting choices. Finally, a technology acceptance model (TAM) was employed to further investigate the participants' attitude towards the virtual reality (VR) technology.

The findings of this study showed that using an interactive lighting system, which was as satisfactory compared to a conventional lighting system, encouraged the participants to use more natural light. The interactive lighting system imposed the same amount of cognitive load on the participants for performing a reading task as a conventional lighting system, which was significantly lower than their cognitive load scores for performing the task with automated lighting system. Personality analyses demonstrated that the participants with a high score on openness had a wide range of lighting choices either with conventional or with interactive lighting. This study’s results differed from the previous studies by highlighting that the participants considered VR as a better fit to an enjoyable experience rather than as a useful tool for performing serious tasks.

Keywords: Automated Lighting, Cognitive Load, Immersive Virtual Environments, Lighting Choices, Personality traits

ÖZET

OFİS ORTAMINDA SANAL ÇEVRE KULLANILARAK KATILIMCILARIN AYDINLATMA SİSTEMLERİ ÜZERİNDEKİ KONTROLÜN ANALİZİ

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Aralık 2020

Bu çalışma, katılımcıların aydınlatma sistemi üzerindeki kişisel kontrolunun, aydınlatma tercihlerinin ve aydınlatma memnuniyetinin görev performansı üzerindeki etkisini sanal ofis ortamında sistematik olarak analiz etti. Bu amaç doğrultusunda, 30 katılımcı 3 aşamalı olan etkileşimli sanal ortam deneyine katıldı. Deneyin her aşaması, aydınlatma üzerinde farklı bir kontrol derecesi sundu. Aydınlatma seçenekleriyle ilgili olarak kişilik özellikleri de incelendi. Son olarak, katılımcıların sanal gerçeklik teknolojisine yönelik tutumunu daha fazla araştırmak için bir teknoloji kabul modeli kullanıldı.

Bu çalışmanın sonucu gösteriyor ki etkileşimli bir aydınlatma sistemi, katılımcıları aydınlatma açısından geleneksel bir aydınlatma sistemi gibi memnun etti. Etkileşimli aydınlatma sistemi, bir okuma görevini yerine getirmek için katılımcılara geleneksel bir aydınlatma sistemi ile aynı miktarda iş yükü yükledi. Fakat, katılımcılar hem etkileşimli hemde geleneksel aydınlatma sistemine kıyasla otomatik aydınlatma sisteminden büyük ölçüde daha az memnun kaldılar. Ayrıca, katılımcılar otomatik aydınlatma sistemi ile okuma görevini gerçekleştirirken daha yüksek işyükü deneyimlediler. Kişilik analizlerinden elde edilen bulgular gösteriyor ki, ‘açıklık’ özelliklerinden yüksek puan alan katılımcılar ya geleneksel yada interaktif aydınlatma seçenekleri ile geniş bir aydınlayma yelpazesine sahip olmaktadır. Sonuç olarak bu çalışma sanal gerçekliği ciddi görevleri yerine getirmek için yararlı bir araçtan ziyade eğlenceli bir deneyime daha uygun bir araç olarak gördüklerini göstermiştir.

Anahtar Kelimeler: Otomatik Aydınlatma, Bilişsel Yük, Etkileşimli Sanal Ortamlar, Aydınlatma Seçenekleri, Kişilik özellikleri

ACKNOWLEDGEMENTS

First, I would like to express my profound gratitude to my advisors Prof. Dr. Yasemin Afacan and Prof. Dr. Mohamad Nadim Adi for their wise supervision, endless support, and encouragements. I could not have imagined having better supervisors and mentors than them to inspire me for life. Having the opportunity to learn from them through this process has made it an invaluable experience for me.

I would like to state my deepest appreciation to Prof. Dr. Andre Santos Nouri and Prof. Dr. İpek Memikoğlu. for honoring me by becoming my jury members. I truly appreciate them taking the time to review this research and their valuable comments. I would also like to thank IAED family and my friends Maryam Karbasi, Donya Dalirnaghadeh, and Tuğçe Elver Boz for their assistance and support through this research.

I would like to express my gratitude to my parents, Raheleh Ansarin and Mohammadreza Mahmoudzadeh, and my sister Parinaz Mahmoudzadeh, for always supporting unconditionally. They have always put my comfort and happiness above theirs and have encouraged me to follow my dreams. Without their sacrifices, enthusiasm, and encouragements, I would not be where I am today.

Finally, I would like to express my deepest gratefulness to my partner Alireza Sadeghi Tarakameh for his love, unfailing support, and constant motivations. He has supported me through the hardest steps of the way, cared for my success, and believed in me even when I did not. This accomplishment would not have been possible without him.

Additionally, this study was financially supported by the grant of Turkish Academy of Sciences (TUBA) The Young Scientist Award Program 2018 (GEBİP) received by my supervisor, Prof. Dr. Yasemin Afacan.

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LIST OF ABBREVIATIONS

BFI	Big five inventory
EF	Effort
FR	Frustration level
HDRP	high-definition render pipeline
IVE	Immersive virtual environment
NASA TLX	Nasa task load index
PIR	Passive Infra-Red
IU	Intention to use
PE	Perceived enjoyment
PEU	Perceived ease of use
PU	Perceived usefulness
SD	Standard deviation
TAM	Technology acceptance model
TD	Temporal demand
VR	Virtual reality
WWL	Weighted workload

CHAPTER 1

INTRODUCTION

1.1. Problem Statement

Studies have revealed that occupant behavior has a drastic effect on building energy consumption (Paone & Bacher, 2018; Tam, Almeida, & Le, 2018). In other words, occupant behavior brings about a large gap between the estimated and actual energy consumption of buildings. Among different building types, in the United States, commercial buildings consume about 45% of the primary energy (Shishegar & Boubekri, 2017). Moreover, a considerable share of world energy consumption is a result of using artificial lighting (De Bakker, Aries, Kort, & Rosemann, 2017). In commercial buildings, lighting systems are ranked the second after HVAC systems in consuming the most amount of energy (Heydarian, Carneiro, Gerber, & Becerik-Gerber, 2015a). In office buildings lighting systems are responsible for around 39 % of the total electricity consumption (EIA, 2011), and around 20% - 25% of the total energy consumption (Dubois & Blomsterberg, 2011). Additionally, lighting has subsidiary effects on thermal energy consumption in buildings.

In recent years, automated blinds, lighting control, and daylight responsive systems are significantly contributing to having smart and intelligent built environments (Jain & Garg, 2018). Research has shown that employing such systems in buildings can result in high levels of energy efficiency (Nagy, Yong, & Schlueter, 2016). A study by Mills (2002) indicated that using new control strategies cooperatively, like occupancy-based lighting control, daylight responsive systems, scheduling, and load shedding could preserve up to 40% of the electricity that lighting systems consume. Yet, generally developments in design of building control systems over time have mainly overlooked occupants' satisfaction (Park & Nagy, 2018).

Occupants' manner of interaction with lighting systems can considerably impact building energy consumption. In this context, understanding the way occupants interact with building systems can help to design and develop energy efficient buildings that improve occupants' satisfaction (Heydarian, Pantazis, Carneiro, Gerber, & Becerik-Gerber, 2016). Although automated building systems can be energy efficient, having control over the environment gives the occupants a sense of satisfaction and comfort (Carneiro, Aryal, & Becerik-Gerber, 2019a; Shishegar & Boubekri, 2017).

1.2. Aim of the Study

This study aims to analyze the influence of different levels of control over lighting system in an office environment and its effects on the lighting choices of occupants. This study achieves this aim by comparing occupants' choices in the context of three different lighting control scenarios. This study comparatively explores automation and having control over the surroundings as a user-centered design feature in a virtual office interior to increase occupants' satisfaction and performance while reducing building energy consumption. Moreover, the impact of different personality traits on lighting choices of the occupants is examined as a sub-aim. Finally, a technology acceptance model is implemented to understand the participants' attitude towards virtual reality technology.

1.3. Structure of the Thesis

Multiple sections cover different aspects of the research to reach the aims of this study, as follows: Chapter 2 covers the literature review on building energy performance and occupants' behavior, lighting systems and lighting choices of occupants in office settings, and immersive virtual environments. Chapter 3 explains the methodology of the study. It defines the research questions and the hypotheses. Then, describes the sample and elaborates on the experimental setting and virtual office design. Later, the chapter explains the experimental setup and procedure, instruments, and how the data was collected. After that, Chapter 4 represents the quantitative data analyses methods and results, discusses the findings and compares them with previous studies, then, explains the limitations of the study. Finally, Chapter 5 summarizes the key aspects, concludes the study, and gives suggestions for future studies.

CHAPTER 2

LITERATURE REVIEW

2.1. Occupants' Behavior and Building Energy Performance

Nowadays, climate change is considered to be the paramount environmental challenge. As a result, the global need to be more sustainable in energy consumption has been grown (Delzendeh, Lee, & Zhou, 2017). The building sector is one of the industries eminently responsible for energy demand, energy consumption, and subsequent carbon emission (US DOE, 2010). As a result, intellectual development of societies has put buildings in the center of attention to become more energy-efficient as the consumer of almost one-third of the entire primary energy (Janda, 2011; Paone & Bacher, 2018). Commercial buildings, particularly office buildings, are ranked as one of the top energy consumers among different building types (Dubois & Blomsterberg, 2011). Moreover, lighting has subsidiary effects on thermal energy consumption in buildings. Although, these effects rely on building characteristics, operation of systems, and climate (Shishegar & Boubekri, 2017). According to a study by Ramesh, Prakash and Shukla (2010), during the life cycle of a building about 80-90% of the energy consumed by a building belongs to the operation phase, while the remaining 10-20% corresponds to the construction and demolition phase. Therefore, to save energy in the long-term, managing the energy consumption in the operation phase of buildings is necessary (Al Amoodi & Azar, 2018)

In the design phase, architects and engineers employ energy simulation to estimate the energy consumption of buildings (Zou, Xu, Sanjayan, & Wang, 2018). However, according to several studies, there is a significant inconsistency between the estimated and the actual energy consumption of buildings (Calì, Osterhage, Streblow, & Müller, 2016; Fabi et al., 2013a; Maier, Krzaczek, & Tejchman, 2009; Martinaitis et al., 2015; Schakib-Ekbatan, Çakıcı, Schweiker, & Wagner, 2015; Yang, Santamouris, & Lee, 2016). Research has shown that the energy consumption of buildings, in reality, can sometimes be up to 300% greater than the estimated amount (Delzendeh et al., 2017). Some of the main factors influencing energy consumption in buildings are thermophysical properties of different building components, quality of construction, climate, building envelope, building energy systems such as HVAC and lighting, and occupants' behavior (Chen et al., 2015; Zhao & Magoulès, 2012).

Studies have discovered that occupant behavior and activities have a major effect on building energy consumption and should not be underestimated (Azar & Menassa, 2012; Branco, Lachal, Gallinelli, & Weber, 2004; Chen, Taylor, & Wei, 2012; Hong, Yan, D'Oca , & Chen, 2017; Norford, Socolow, Hsieh, & Spadaro, 1994; Schakib-Ekbatan et al., 2015; Sun, Yan, Hong, & Guo, 2014; Yan et al., 2015; Yan et al., 2017; Yu, Fung, Haghighat, Yoshino, & Morofsky, 2011). This effect is so significant that different studies have recognized occupant behavior as the key contributor to building energy performance gap (Haldi & Robinson, 2008; Korjenic & Bednar, 2012; Menezes, Cripps, Bouchlaghem, & Buswell, 2012). Over the past years, many studies have attempted to simulate occupant behavior in buildings in order to discover the impact of occupants' behavior, preferences and choices on energy consumption in the built environment (Andersen, Olesen, & Toftum, 2011; Fabi, Andersen, & Corgnati, 2013; Jang & Kang, 2016; Langevin, Wen, & Gurian, 2015; Pfafferott & Herkel, 2007; Sun & Hong, 2017; Yun, Kong, Kim, & Kim, 2012). However, these types of analysis are usually based on predetermined behavior models, which cannot represent the actual human behavior (Buso, Fabi, Andersen, & Corgnati, 2015). Consequently, the simulations do not give out accurate results because of the complexity of human behavior (Yu et al., 2011). Accordingly, a precise knowledge of occupant behavior and choices can contribute to upgrading human-building interactions and energy efficiency (Nguyen & Aiello, 2013; Yu et al., 2011).

Martinaitis et al. (2015) looked into the energy consumption of four different residential units with rigorous energy simulations. They introduced the occupant behavior and preference as one of the main sources of building energy gap. A study by Hong et al. (2017) presents ten questions focusing on the important issues about occupant behavior in building in relation to energy consumption. These questions intend to provide a valuable understanding of developments in research and assess the limitations of some studies concerning monitoring, analyzing, modeling, simulating, and discovering the roots of occupant behavior. This study states that occupants interact proactively with their indoor environments in order to provide their personal comfortable circumstances and this activity contributes to creating the energy gap, for example by interacting with openings like opening and closing windows, use of lighting and controlling solar shading like adjusting blinds, use of HVAC systems like turning air-conditioning on or off and adjusting thermostat temperature, use of hot water and electrical appliances.

The gap between estimated energy consumption and actual energy consumption in buildings is even greater for low-energy buildings with passive design features (Parker, Mills, Rainer, Bourassa, & Homan, 2012). High performance, Zero-Net Energy, low carbon emissions, and some passive designs can only reduce energy consumption in buildings and positively influence occupants' satisfaction and performance only if they are used as intended (Hong et al., 2017). This efficiency in the design stage is usually taken for granted; except, occupants do not operate the building systems accordingly and they tend to change the conditions of their environment in pursuit of comfort (Buso et al., 2015). Additionally, other different incentives can lead the occupants to interact with their environment, either consciously such as operating building systems to control their environment or unconsciously by using appliances (Fabi, Andersen, Corgnati, & Olesen, 2012).

Building energy consumption is highly susceptible to occupant behavior and activities. Yet, the influence of occupant on the amount of energy consumed in buildings is not taken into account through the design phase or the post-occupancy optimization phase (Paone & Bacher, 2018). Post-occupancy evaluation employs qualitative and quantitative techniques to evaluate energy performance (De Wilde, 2014). This method can be beneficial for acquiring elaborate details about occupant behavior towards lighting and electricity consumption (Menezes et al., 2012).

Reviewing the literature shows that there are three different terms about occupants' interactions with building systems. The first term is behavior, which entails a broad sense. Occupant behavior represents human interaction with building systems in interest of regulating the interior environment to suit their health, thermal, visual, and acoustic comfort (Delzendeh et al., 2017). The second term is preference. Occupants' preferences embody a sequence of frequent decisions from a wide range of options over a long period (Carneiro, Aryal, & Becerik-Gerber, 2019b). Lighting preferences are typically studied in relation to lighting parameters such as color temperature and illuminance levels (Carneiro et al., 2019b). Last term is choice. Choices are temporary decision restricted by a number of possible options in a certain scenario (Carneiro et al., 2019b). In this respect, choices and preferences are not equivalent, but related in way that preferences may influence choices while the opposite is not necessarily valid (Carneiro et al., 2019b). Within this framework, this research explores occupants lighting choices.

The reason that occupants interact with building systems is to make their environment meet their comfort level (Harish & Kumar, 2016). These interactions are in the form of different activities such as: operating building openings, adjusting lighting and shading systems, setting HVAC systems, or using hot water and electrical appliances (Delzendeh et al., 2017). The main energy consumer systems in the buildings are HVAC systems, electrical appliances, and lighting systems. Therefore, the slightest alteration in these systems have the potential to impact energy consumption substantially (Harish & Kumar, 2016).

According to Andrews, Putra, and Brennan (2013), occupants can change building energy performance in both passive and active senses. The passive way indicates the alteration of occupant energy consumption pattern in the course of time. The active sense refers to operating the components of physical environment, like opening windows, blinds or equipment. Figure 1 shows the types of occupant activities that impact the energy consumption in buildings. Although many pieces of research have focused on the passive sense of occupant behavior, focusing on the active sense to provide more elaboration on this area has the potential to significantly contribute to less energy consumption (Jia & Srinivasan, 2015). In buildings, energy consumption rates are high even in non-operating times. Webber et al. (2006) researched on equipment usage in 4 office buildings out of the regular working hours in the US. They demonstrated that after-hours, only less than 50% of the electronic tools are switched off by the building occupants. In another broader study, Masoso and Groblera (2010) found that 50% of the whole building energy is generally consumed during non-operating hours because of occupant behavior.

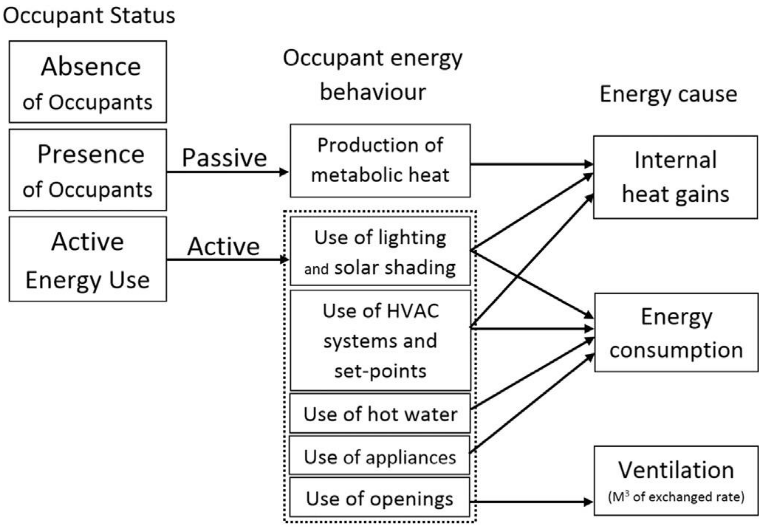

Figure 1. Types of occupant activities that impact the energy consumption in buildings (Page, Robinson, Morel, & Scartezzini, 2008).

Central systems and automated systems in buildings can reduce energy consumption and maintain the quality of indoor space close to standards (Buso et al., 2015; Carneiro et al., 2019a). However, studies have shown that office occupants, especially in individual offices, prefer to have personal control over the building systems (Boyce et al., 2006b; Doulos, Tsangrassoulis, & Topalis, 2007; Escuyer & Fontoynont, 2001). Various studies have identified the correlations between occupants' perceived control, satisfaction, and comfort (Boerstra, Beuker, Loomans, & Hensen, 2013; Kim & de Dear, 2012).

Occupant control does not have an explicit definition in the field of built environment yet and usually is regarded to in various contexts of individual and personal control (Kwon, Remøy, van den Dobbelsteen, & Knaack, 2019). Greenberger and Strasser (1986, p. 165), define personal control as an "individual's beliefs at a given point in time, in his or her ability to effect a change, in a desired direction on the environment". Yet, this explanation is not specific to the built environment (Kwon et al., 2019). In the environmental studies, the phrase personal control or occupant control, mostly, comes alongside with occupants' comfort (Kwon et al., 2019). Nevertheless, various studies address occupant control over the environment in two forms of adapting different qualities in workspace (Bluyssen, Aries, & van Dommelen, 2011; Boerstra et al., 2015; Joines et al., 2015; Toftum, 2010) and individualizing it (Wells, 2000).

Research has shown that having control over one feature of the environment contributes to perceived control over other features as well (Boerstra et al., 2015; Toftum, 2010). A perception of control over the work environment can be a result of having adjustable features such as lighting, temperature, and sound (Vischer & Wifi, 2017). Galasiu and Veitch (2006) in their review study about occupants' satisfaction and preferences concluded that occupants generally do not support entirely automated systems. Additionally, facility managers find these systems overly sophisticated and harder to maintain. Moreover, favorable indoor environmental qualities, such as lighting condition or thermal condition, are specific for each individual. Therefore, full automation or central control is less likely to respond to everyone's preference and can result in low satisfaction (Aryal & Becerik-Gerber, 2018; Karmann, Schiavon, & Arens, 2018). However, giving the occupants a sense of control over their environment can result in satisfaction, comfort, and more productivity (Vischer & Wifi, 2017). Consequently, having any type of control in an environment is associated with psychological and physical well-being (Colenberg, Jylhä, & Arkesteijn, 2020).

For occupants to accept the automated control systems having a perception of control is crucial and can lead to optimal operation of the systems (Nagy et al., 2016). The capability of overriding building systems is one of the significant features that can contribute to the acceptability of automation (Nagy et al., 2016). The association between occupant and personal control is complicated; particularly, knowing that occupants' preferences, personal characteristics, and awareness can influence their choices (Brown & Cole, 2009; Fabi et al., 2012; Stazi, Naspi, & D'Orazio, 2017).

The same way that occupants impact their environment, indoor environment and buildings systems, like lighting systems or HVAC systems, are capable of influencing occupant's' productivity, health, satisfaction, mood (Bluyssen, 2013; Carneiro et al., 2019a; Lamb & Kwok; 2016; Lan, Wargocki, & Lian, 2014; Spengler, 2012). Occupants can make different choices for controlling building systems according to their usability, accessibility, and undesirable effects (Rijal, Tuohy, Humphreys, Nicol, & Samuel, 2011). Additionally, if occupants are more aware of the environmental consequences of their choices, they might give up their comfort (Deuble & de Dear, 2012). Nevertheless, this is beyond the scopes of this research.

2.2. Lighting in Office Environments

Optimizing lighting condition in office environments has the potential to improve satisfaction and productivity of office occupants by providing an efficient ambient (Kim, Wang, & McCunn, 2019). Accordingly, different approaches in lighting design are emerging in office environments. To reduce the amount of energy consumption in office buildings, various studies have explored energy-efficient lighting systems such as new luminaires, daylight manifestation, and control strategies (Acosta, Campano, Domínguez-Amarillo, & Muñoz, 2018; Choi, Hong, Choi, & Sung, 2016; da Silva, Leal, & Andersen, 2013). Additionally, nonresidential building sector accounts for consuming 60% of the worldwide electricity consumption (Han et al., 2019).

Research has shown that sufficient light levels and high-quality lighting can improve the health and the mood of office occupants (Lamb & Kwok, 2016; Veitch, Newsham, Boyce, & Jones, 2008). Various studies show that when occupants consider a lighting level to be of high quality, the advantages are considerable (Veitch, 2017). First, in general, adjustable lighting control systems, as one of the foremost contributing features to the perceived lighting quality, consume 10% less energy than a fixed lighting level, resulting in environmental benefits (Boyce et al., 2006b; Galasiu, Newsham, Suvagau, & Sander, 2007). The occupants benefit from higher quality of lighting because it gives them a better mood (Veitch, Stokkermans, Newsham, 2013), more visual and physical comfort (Boyce et al., 2006a), and higher environmental and job satisfaction (Veitch et al, 2013). Finally, employers gain profit from staff that are more engaged in work (Veitch et al, 2013), take less time off work, and are more committed to their jobs (Veitch, Newsham, Mancini, & Arsenault, 2010).

Taking advantage of daylight as an environmental factor in buildings has a major effect on occupants’ health, performance, productivity, and circadian rhythm (Boyce, Hunter, & Howlett, 2003). As the use of daylight rises for its positive impacts on human psychology and physiology, researchers have shown more interest in investigating glare, indoor cooling loads, and energy saving by taking advantage of natural lighting in buildings (Goovaerts, Descamps, & Jacobs, 2017; Jakubiec & Reinhart, 2012; Lolli, Nocente, Brozovsky, Woods, & Grynning, 2019; Mangkuto, Rohmah, & Asri, 2016). Research has revealed that occupants can save energy up to 40% by using daylight instead of artificial lighting (Wolff et al., 2015). However, the strength and quality of natural light differs based on geography and building characteristics. Extreme daylight exposure can cause visual discomfort and greater cooling and heating load which can induce occupants to use artificial lighting instead of natural light in sunlight hours (O'Brien, Kapsis, & Athienitis, 2013).

2.2.1. Different Lighting Control Systems in Office Settings

Since lighting systems and the control strategies have the potential to contribute to energy efficiency, they have been subject to several studies. Many researches have concentrated on automated blind or lighting control technologies, since they pave the way for taking advantage of daylight supply and solar heat gains throughout winter, which directly impacts the amount of electricity demand for artificial lighting (Daum & Morel, 2010; Gunay, O'Brien, Beausoleil-Morrison, & Huchuk, 2014; Koo, Yeo, & Kim, 2010; Reinhart, 2004). However, according to Boyce et al. (2006b), inflexible illuminance fails to satisfy occupants. Considering the foremost role of buildings in satisfying the need of comfort and protection, providing acceptable lighting control strategies for occupants is crucial (De Bakker et al., 2017).

In controlling the illuminance level in office spaces, conventional light switches still remain in widespread use, while dimming controllers and wireless control networks offer extensive features (Boyce, 2014). In the past years, designing more efficient and intelligent control systems for buildings has received particular attention (Nagy et al., 2016). Accordingly, energy efficient systems capable of adapting to occupants' behavior and addressing their needs have been developed that not only employ adaptive and learning features, but also integrate available lighting options for optimization (Nagy et al., 2016). Integrating window blinds and artificial lighting control into a merged system can lead to regulating daylight as well as avoiding glare and heat (Galasiu, Atif, & MacDonald, 2004; Yang & Nam, 2010). Such strategy can substantially improve occupants' health, comfort, and performance while reducing energy consumption (Mukherjee et al., 2010). Previous studies have indicated that integrated daylighting systems can reduce building energy consumption up to 30%-80% (Shen, Hu, & Patel, 2014; Tzempelikos & Athienitis, 2007).

Innovations in the field of information and communication technology (ICT) have introduced advanced lighting systems, which incorporate sensors, actuators, and micro-controllers (Heydarian, Pantazis, Wang, Gerber, & Becerik-Gerber, 2017). These control systems supply artificial lighting when there is insufficient natural light in the presence of occupants (Park, Dougherty, Fritz, & Nagy, 2019). Occupancy sensors, commonly as passive Infra-Red (PIR) sensors, are one of the main elements in these systems. These sensors detect occupants' presence, turn on the artificial lights automatically, and turn them off after a time delay of about 10 to 15 minutes (Park et al., 2019). Occupancy sensors were one of the initiative developments to reduce lighting energy consumption in buildings (Nagy, Yong, Frei & Schlueter, 2015). These sensors, which have been practically used in the last two decades, have the potential to save energy up to 40% comparing to manual light switches (Reinhart, 2004). However, the major disadvantage about the PIR is that basically they are triggered by movement rather than presence which can give unfavorable results when occupants work in a still state on a computer or paperwork (Nagy et al., 2016; Park et al., 2019). Moreover, using occupancy sensors alone does not take the ambient condition into account (Nagy et al., 2016). Therefore, generally, occupancy-centered automated systems can lead to energy waste and occupants' discomfort by ignoring occupants' preferences (Gilani & O'Brien, 2018).

In interiors, daylight control systems can work in correspondence with artificial lighting systems. These daylight responsive systems regulate the artificial lighting level in regard to the available indoor daylight to retain the needed lighting level on a work plane on a real-time basis (Shishegar & Boubekri, 2017). These systems employ luminosity sensors to work in integration with occupancy sensors in order to actively make use of natural light in a system that turns artificial lights off when the indoor environment is provided with enough natural light (Park et al., 2019). The two types of daylight responsive systems use either dimming or stepped approaches to adjust the light level (Shishegar & Boubekri, 2017). In dimming control systems, artificial lighting can be set to a level in a range between a minimum and a maximum amount (Shishegar & Boubekri, 2017). However, in stepped systems, the status of the lights is either on or off (Shishegar & Boubekri, 2017). Studies have shown that daylight responsive control systems are not widely used because of complicated calibration process and set up of the sensors (Bellia, Fragliasso, & Stefanizzi, 2016; Motamed, Deschamps, & Scartezzini, 2017).

The three main constituents of any type of daylight responsive systems are photosensors (ALS), lighting controller, and dimming or relay unit (Topalis & Doulos, 2017). The photosensor obtains the value of luminous flux, transform it to a signal, and send it to the controller (Topalis & Doulos, 2017). The controller processes the signal, and sends out a signal to the dimming or relay unit that determines the lighting level (Topalis & Doulos, 2017). In dimming systems, the lighting level of the luminaires is adjusted on a range between a minimum and a maximum value based on the difference between the target and the work plane illuminance (Kim et al., 2019). However, a stepped system switches the artificial lights on when the illuminance level is lower than a fixed level and switches them off when it exceeds or reaches the target level (Li, Cheung, Wong, & Lam, 2010). The major disadvantage of stepped systems is that under volatile weather, daylight level can change consistently, switching lights on and off promptly and frequently (Shishegar & Boubekri, 2017). These changes can considerably disturb occupants and diminish the life cycle of lamps (Shishegar & Boubekri, 2017).

An experimental study by Onaygil and Güler (2003) compared daylight responsive lighting systems to conventional lighting systems under different weather conditions in Turkey. The results of their study showed up to 30% energy save when using daylight responsive lighting systems. One of the disadvantages of these daylight responsive systems is that they neglect occupants’ preferences by operating based on fixed limits (Park et al., 2019). This can induce occupants to override the optimal control settings or even to turn off the control system (Gunay, O'Brien, Beausoleil-Morrison, & Gilani, 2017). Although sensor integrated automated systems have the potential to reduce energy consumption significantly, they are not designed to be user-centered and they ignore occupants’ comfort and preferences (Park et al., 2019). Failure in responding to occupants’ need of comfort, however, can impact both their health and work productivity (Heydarian et al., 2016; Heydarian et al., 2017).

Control systems for integrated natural and artificial lighting based on their algorithm of control are categorized as closed loop and open loop (Jain & Garg, 2018; Shishegar & Boubekri, 2017). Figure 2 shows both closed loop and opened loop lighting control systems. The closed loop system actively measures the available lighting of both daylight and artificial lighting then adapts the dimming level or switches the lights to achieve a target level (Shishegar & Boubekri, 2017). Conversely, the open loop system merely measures the available daylight without taking artificial lights into account, hence receives no feedback from the environment (Choi et al., 2016; Jain & Garg, 2018). Another state-of-the-art approach that uses a closed loop algorithm evolves as a human-centric interactive lighting system, which launches through ceiling light fixtures and individualized workspace. These systems are thriving for simultaneously reacting to both environment and occupants in an interactive way (Kim et al., 2019).

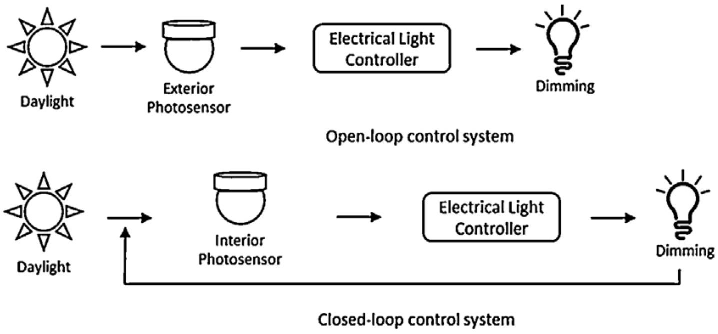

Figure 2. Diagrammatic representation of open loop and closed loop lighting control systems (Choi et al., 2016).

2.2.2. Occupant-Lighting System Interactions

To foster energy efficiency in in terms of lighting in office buildings, many energy efficient lighting devices and control strategies have been designed and put into work, such as: LEDs which have the potential to save energy (Soori & Vishwas, 2013), daylight responsive dimming systems (Kim et al., 2019), and occupancy-based lighting controls (De Bakker et al., 2017). In addition, understanding and improving occupants' lighting choices by implementing various lighting control systems have the potential to enhance energy efficiency in buildings (Boyce et al., 2000; Fabi, Corgnati, Andersen, Filippi, & Olesen, 2011; Galasiu, & Veitch, 2006). Research suggests that different factors beyond solely illuminance level can impact occupants' lighting choices (Yun et al., 2012). Fabi et al. (2012) and Stazi et al. (2017) in their literature reviews classified the factors that influence occupants' lighting choices in buildings into the seven following groups: (1) environmental factors such as illuminance levels, interior temperature, and acoustics, (2) time-related factors such as time of arrival and departure, (3) contextual factors such as orientation, size, and view of windows, lighting type, and lighting controls, (4) physiological factors such as age, gender, and health, (5) psychological factors such as environmental concerns and personality traits, (6) social factors such as interaction with co-workers, and (7) other random factors. For example, occupants can be less interested in artificial lighting when the exterior illuminance level is exceeding a particular amount (Boyce et al., 2006b). Occupants typically interact with artificial lighting switches when they arrive at their offices (Reinhart & Voss, 2003). Another study showed that occupants are less likely to change the light setting once it is set to a level (Moore, Carter, & Slater, 2003). Moreover, by studying the influence of default lighting settings on occupants' behavior, Heydarian et al. (2016) showed that when occupants are provided with natural lighting, they tend to keep the lighting setting. The role of personality traits, among the seven aforementioned factors, is also significant. Research on residential sector has shown that there is a substantial potential to minimize energy consumption by analyzing the occupants' responses' to promoting energy efficient behaviors based on personality traits (Shen & Cui, 2015). Since personality is the main driver of occupants' judgements, values, and perspective, it is expected that differences in individuals' personality can impact their environmental behavior (Milfont & Sibley, 2012). Research about the composition of personality traits proposes five main personality dimensions as a model called The Big Five Inventory (BFI) model (Costa & McCrae, 1992; DeYoung, Quilty, & Peterson, 2007; Goldberg, 1990, 1999; McCrae & John, 1992). The five personality dimensions are neuroticism, agreeableness, conscientiousness, openness to experience and extraversion (Milfont & Sibley, 2012). For example, a study showed that extraverted individuals had higher environmental concerns, while conscientious individuals had lower environmental concerns (Borden & Francis, 1978). This model is extensively used for analyzing the relationships between work environment behaviors and personality traits and consequences such as job satisfaction, working motives, and organizational commitment (Widiger, 2017).

Previous research has also explored lighting control preference of the occupants when they are provided with different lighting options (Escuyer & Fontoynont, 2001; Galasiu & Veitch, 2006; Guo, Tiller, Henze, & Waters, 2010; Heydarian et al., 2015a; Inoue, Kawase, Ibamoto, Takakusa, Matsuo, 1988; Veitch & Gifford, 1996). For example, Galasiu and Veitch (2006) showed that if occupants have control over lighting and shading in an office environment, they prefer natural lighting and an outdoor view. However, occupants hardly interact with manual blinds and if they do it is mostly to avoid glare (Gunay et al., 2017; Kim et al., 2009; Zhang & Barrett, 2012). In case there is no inconvenience, blinds and lighting usually stay in the same state (Jain & Garg, 2018). This condition commonly increases building energy consumption and obstructs the outdoor view (Jain & Garg, 2018). Additionally, former studies, have investigated the influence of design features on occupants' preference and use of natural light, such as the size of the windows (Boubekri, Hull, & Boyer, 1991; Butler & Biner, 1989), shader placements and building orientation (Escuyer & Fontoynont, 2001; Sutter, Dumortier, & Fontoynont, 2001). Consequently, developing an efficient control system is only possible by investigating occupants' behavior, features of blinds and lighting systems, and building geometry to increase user satisfaction and improve energy consumption (Reinhart & Voss, 2003; ul Haq et al., 2014).

Carter, Slater, and Moore (1999), showed that occupants are more satisfied with conventional manually controllable lighting systems, which do not even fit into the lighting standards than fully automated daylight responsive systems. Likewise, occupants rather set the light level themselves than to adapt themselves to a light level, even if it meets the standards (Moore, Carter, & Slater, 2002). Satisfaction with the lighting choices is not the only advantage of availability of personal control (Despenic, Chraibi, Lashina, & Rosemann, 2017). Previous research has shown that having control over the work plane lighting can also impact environmental satisfaction (Huang, Robertson, & Chang, 2004; Lee & Brand, 2005; Veitch, Charles, Farley, & Newsham, 2007), perceived lighting quality (Boyce et al., 2006a; Newsham & Veitch, 2001), concentration and motivation (Boyce et al., 2006a; Veitch, Newsham, Boyce, & Jones, 2008), and indirectly improve the productivity of occupants (Boyce et al., 2006a; O'Brien & Gunay, 2014).

One of the main factors associated with lighting satisfaction in an office setting is the illuminance level on the work plane (Boyce, 2014). The average recommended illuminance level for offices in North America and Europe is between 300-500 lx on the work plane (Boyce, 2014). However, building occupants have different lighting preferences (Despenic et al., 2017). In a study by Boyce, Eklund, and Simpson (2000) 18 subjects adjusted the light level for a consistent task with dimming controllers in two ranges of large, from 12 to 1240 lx, and small, from 7 to 680 lx. In the experiment, the means of the chosen light levels of the work plane were respectively 600 and 400 for the large and small ranges. The results indicated that different occupants choose different light levels for performing the same task. Moore et al. (2003) conducted a field study in 4 different office buildings in United Kingdom with 45 office occupants. In this study, the mean illuminance value set by the occupants was 288 lx of values ranging from 91 lx to 770 lx. In another study, Boyce et al. (2006a), by providing a fixed illuminance level in an office setting, indicated that any fixed value can only lie within 100 lx of 45% of occupants' preference at best.

2.2.3. Occupants' Control Over Lighting Systems and Subsequences

Considering that occupants pass most of their time indoors, the main purpose of building control systems should be should be to provide comfort for the occupants (Park et al., 2019). Occupants' comfort entails two modules: (1) physical comfort such as not feeling any pain, and (2) perception of control over their surrounding environment (Nagy et al., 2016). Supporting these modules requires a user-centered control system design. Implementing user-centered control systems is a feasible mean to mitigate the adversities of fully automated systems (Aghemo, Blaso, & Pellogrino, 2014; Park et al., 2019).

In a study Nagy et al. (2015) investigated building energy consumption and occupants' comfort in relation to a user-centered lighting control system (See Figure 3). This user-centered control system was designed based on statistical analysis of the set points derived from occupants' interactions with building systems and occupancy sensors. Similarly, set points of time-delay and illuminance level thresholds were obtained. The results of this study reveal that, such systems offer a high potential of energy saving with each office having specific set-points which are usually below the standards. In another research, the same team (Nagy et al., 2016) analyzed the comfort of office occupants with the aforementioned user-centered lighting control system. They realized that user-centered lighting controls could significantly reduce both the energy consumption and surplus lighting use. Although they could not find any improvements in occupants' comfort level, they indicated that there was no decrease in the comfort level either. This is a critical issue because any decrease in occupants' comfort level can lead to occupants disabling the control system (Nagy et al., 2016). User-centered lighting control allows for specified lighting control for each office that sets up the energy saving with occupants' comfort (Nagy et al., 2016). Additionally, authors asserted that user-centered lighting control holds fairly high acceptability. Further complicated studies, which implement fuzzy logic (Guillemin & Morel, 2001) and sensor networks (Schaeper, Palazuelos, Denteneer, & Garcia-Morchon, 2013) reveal that even a higher energy saving level can be achieved using intelligent lighting control systems (Nagy et al., 2016).

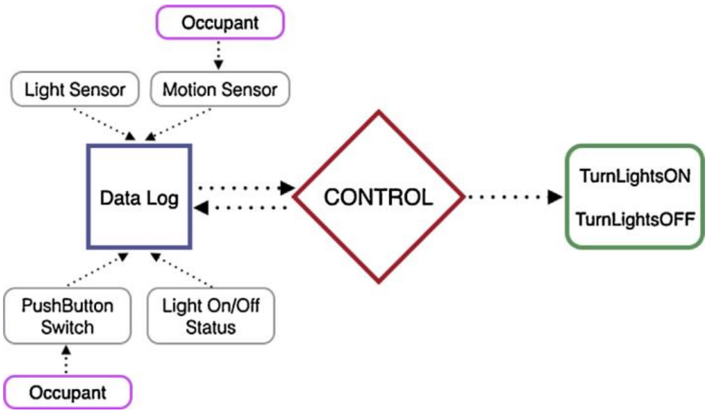

Figure 3. Outline of a user-centered lighting control system (Nagy et al., 2015).

A recent study by Kwon et al (2019), explored occupants’ satisfaction in relation to the degree of control over building systems in office settings. The results revealed that granting more control over the lighting and thermal systems to the occupants, increased their environmental satisfaction. This study connects visual comfort and satisfaction of the occupants to direct individual control over the lighting and shading. Other findings of this study suggest that having no control over the building systems in general is more acceptable to the occupants than not being able to operate an available control system. However, for visual comfort, having no control over the lighting systems made them more dissatisfied than not being allowed to operate the available systems. Furthermore, authors asserted that the influence of personal control on satisfaction is low with optimized automated systems.

Vischer and Wifi (2017) derived a list of environmental factors from practicable comfort studies that can affect task performance. Illumination and daylighting are among the main factors of this list since if they are appropriately provided for each task, they can result in occupants’ comfort. However, only office occupants themselves can judge the lighting level as professionals of each task. Therefore, to achieve comfort occupants need adaptable work environments in which adjustable lighting systems are essential (Vischer and Wifi, 2017).

2.3. Immersive Virtual Environments as a Tool for Studying Occupants' Behavior

Over the past years, a wide range of fields from military to medicine have extensively used virtual reality tools for training reasons and additionally to investigate human behavior and choices in different circumstances and settings (Bosch-Sijtsema, & Haapamäki, 2014; De Lillo & James, 2012; Duarte, Rebelo, Teles, & Wogalter, 2014; Larsen, Oestergaard, Ottesen, & Soerensen, 2012; Parsons, 2014; Pertaub, Slater, & Barker, 2002; Tanja-Dijkstra et al., 2014; Waller, Beall, & Loomis, 2004). Likewise, professionals in building industry have employed immersive virtual environments for design review and assessing alternative designs (Dunston, Arns, Mcglothlin, Lasker, & Kushner, 2011; Heydarian et al., 2015a; Leicht, Abdelkarim, & Messner, 2010; Majumdar, Fischer, & Schwegler, 2006; Maldovan, Messner, & Faddoul, 2006), instruction (Bosch-Sijtsema, & Haapamäki, 2014), engaging with environment and upgrading 3D models (Paes, Arantes, & Irizarry, 2017), communication among different groups involved (Majumdar, et al., 2006; Maldovan, et al., 2006) and particularly investigating human behavior and preferences in virtual environments which resemble real-world settings (Duarte et al., 2014; Heydarian et al., 2015b).

Observational and experimental studies that analyze occupants' behavior in buildings are extremely susceptible to experimental noises originating from inconsistent design and environmental features (Heydarian et al., 2016). In this light, immersive virtual environments are advantageous tools in data collection about users' behavior. A study by Kuliga, Thrash, Dalton, and Holscher (2015) suggests that virtual environments allow us to systematically manipulate the setting according to our desire. This is a feature that cannot be easily achieved in real-world settings. Virtual environments enable designing any type of environment and provide the opportunity to assess the influence of certain variables by keeping the others constant (Heydarian & Becerik-Gerber, 2017; Heydarian et al., 2015a; Heydarian et al., 2016). Moreover, they allow integrating different simulations into the designed immersive virtual environment (Heydarian & Becerik-Gerber, 2017).

Heydarian et al. (2015b) designed a benchmarking experiment in immersive virtual reality to explore occupants' daily behavior, particularly in relation to studying and lighting-related preferences, in a single occupancy office environment. The results of the comparison with real environment indicated that the participants had a strong sense of presence in virtual environment, and they behaved similarly in both environments. Consequently, they suggested that immersive virtual environments are useful instruments for acquiring information about users' preferences, behavior, and performance. This finding is also in accordance with the results from its previous studies that virtual environments are reliable representations of real-world settings (Adi & Roberts, 2014; Pertaub, et al., 2002; Roberts, Heldal, Otto, & Wolff, 2006; Slater, 2009). Research in this area has discovered no significant difference between participants' performance, immersion, and sense of presence between immersive virtual environments and real-world environments (Heydarian et al., 2017). Accordingly, in addition to providing more control over the variables, these environments can considerably lower the costs of the experiments and cover for experimental incompetency (Chan & Weng, 2005; Shiratuddin, Thabet, & Bowman, 2004).

Conducting research in actual office environments is essential for effectively understanding the influence of personal control options on occupants' lighting choices (Nguyen & Aiello, 2013). Yet, having full control over different variables during the experiment is challenging and sometimes not even possible (Heydarian, et al., 2015a). Many factors such as weather condition and different design features can impact the results (Heydarian, et al., 2015a). Accordingly, employing immersive virtual environments (IVEs) for such studies are advantageous. Using IVEs, gives the researchers the opportunity to better investigate the variable of interest by keeping other variables constant (Heydarian & Becerik-Gerber, 2017). Moreover, technology advancement nowadays has made virtual environment devices more accessible and user-friendly, which works in favor of using IVEs for research purposes.

CHAPTER 3

METHODOLOGY

3.1. Research Questions and Hypotheses

This study intends to increase performance and the sense of satisfaction among office occupants while improving lighting energy efficiency. In this study the main research question is:

RQ: How will providing interactive lighting options influence occupants’ lighting choices in an office setting?

There are also other sub research questions in this study:

Sub-RQ1: Does using interactive lighting systems in office settings increase the satisfaction of the occupants?

Sub-RQ2: Does using interactive lighting systems in office settings increase the productivity of the occupants?

Sub-RQ3: Is there a relationship between occupants’ personality and lighting choices?

Sub-RQ4: Do participants perceive immersive virtual environment technology as a useful tool for serious tasks (tasks with the value of responsibility)?

To meet the objectives of the study, the following hypotheses are proposed:

H1: The lighting choices of the participants with the interactive lighting system is significantly different from their lighting choices with the conventional lighting system.

H2: There is a statistically significant association between the availability of a degree of control over the lighting system and participants' satisfaction.

H3: There is a statistically significant association between the availability of a degree of control over the lighting system and participants' performance.

H4: The participants' personality trait affects their lighting choices.

H5: Participants perceive immersive virtual environment technology as a useful tool for serious tasks.

3.2. Sample and Setting

This study recruited a total number of 30 participants (18 females and 12 males). The participants were aged between 22 and 36 years old, with 63.3% of them aged between 25 and 28. Of all the participants 36.7% were students in the Graduate School of Economics and Social Sciences, 56.7% were students in the Graduate School of Engineering and Science, and 6.7% were students in the Graduate School of Education. Of these participants 66.7% of them were master's students and 33.3% were PhD students at Bilkent University. All participants had physical offices on Bilkent Univerity Campus, therefore, they were familiar with office environments.

The aim of this study is to understand how different control levels over lighting systems influence occupants' choices and performance in office settings. The ultimate purpose of the study is to pave the way for designing and providing lighting systems that are not only more supportive of occupants' satisfaction and performance, but also have the potential to reduce the lighting-related electricity consumption in buildings. To understand the effect of control and lighting choices of occupants, an experiment was designed to replicate a single occupancy office in an IVE. The virtual office space was designed to be similar to an existing single occupancy educational office setting in FF building, Bilkent University main campus. The reasons for choosing IVEs over real environments were providing control over the variables, offering the possibility to repeat scenarios, and their economic efficiency in creating scenarios.

The experiment represents three different lighting settings, which provide different degrees of control for lighting arrangement, for the same virtual office setting: (a) conventional ceiling fluorescent lamps with manual turn on switches and manually adjustable blinds, (b) automated integrated natural and artificial lighting setting, which regulates the illuminance level according to the available daylight, and (c) an interactive lighting setting, which allows the occupants to make a choice about the lighting type but keeps the illumination level at a certain amount for energy efficiency reasons. Within this framework, the participants’ tendency to use their perceived control to make a choice and alter the lighting type was investigated. Moreover, we explored participants’ cognitive load, overall satisfaction about lighting in each condition, their personality trait, and VR technology acceptance.

The experiment only authorized changing the variables of interest, simulated daylighting and electrical lighting, to minimize any undesired effect on the results. To avoid any disturbance on account of the time of day, the virtual environment represented the location of the sun for March 1, 09:00 A.M. in Ankara, Turkey. Also, the experiments were conducted consistently between 09:00 AM to 02:00 PM from March 2020 to August 2020 to avoid bias and preserve objectivity.

Additionally, to prevent participants from making choices under the influence of having a view, we replaced the view with a blue sky. Previous research has demonstrated that an outside view has a significant impact on the occupants’ interactions with the shading systems (Aries, Veitch, & Newsham, 2010; Matusiak &

Klöckner, 2016; Tuaycharoen & Tregenza, 2007). Before starting the experimental procedure, participants were informed that there is no view outside the windows.

This study was conducted following an Institutional Ethical Review Board-approved protocol. For safety and awareness issues, first, all the participants were introduced to the VR technology and the tasks. Then, they were asked to sign a consent form, which described the study in brief and the necessary precautions to avoid any risks. Moreover, they were notified about the confidentiality of their personal information and their right to cease participation anytime.

3.3. Experimental Setup

The primary office model, composed of walls, floor, ceiling, and windows, was designed in Revit. It was then imported to 3ds Max to improve the space by adding furniture to the office room. Material textures were rendered by V-Ray Next in 3Ds Max environment. The final modifications and lighting features were applied using Unity. To measure the light levels and have more of a natural representation of light, Unity’s High Definition Render Pipeline (HDRP) was used. HDRP is the only available Unity renderer that uses physical light values. Figure 4 shows the virtual office model.

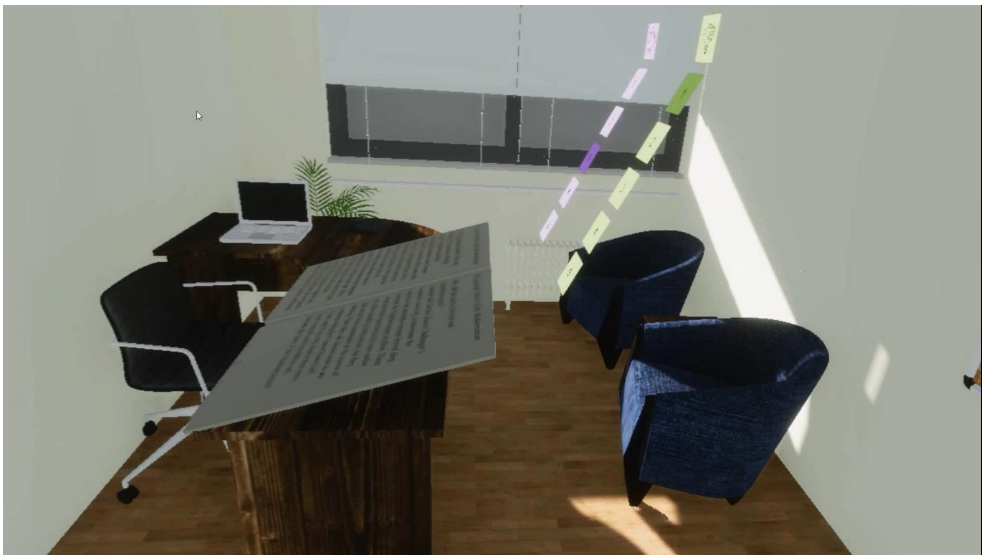

Figure 4. The virtual office model (Created by author, 2019)

The virtual model of the office setting was also imported into DIALux Evo to calculate the light level on the work plane to ensure that light levels in the immersive virtual environment match the light values in a corresponding physical environment. First, the light level was calculated for natural light only at 09:00 AM for a clear sky. Then, artificial light levels were calculated for each condition. Finally, the average lighting levels for the work plane were set according to light values obtained from DIALux Evo. Before launching the main experiment, a pilot study was conducted to confirm the experimental setting and procedure.

3.4. Experimental Procedure

This study was designed based on a systematic assembly of four subsequent phases as: phase I (definition of the environmental setting), phase II (developing the virtual setting), phase III (executing the experiment), phase IV (analyzing the data from the experiment). Each phase was implemented through different stages. In the first stage of the first phase, the design features and standard characteristics of a single occupancy office were retrieved from the literature. An existing single occupancy office in the FF building of the Bilkent University, which shared the same design features as the data derived from the literature, was selected for virtual simulation in the next stages. The second phase of study was comprised of two stages: first, the virtual office setting was designed, then the IVE equipment was set up. The execution phase consisted of stages IV to VI. During stage VI, we implemented the task scenario in the IVE and identified the required designed modifications through a pilot study to adapt the adjustments accordingly. In the next stage, the data was collected by conducting the experiment and asking the participants to fill out the questionnaires. In the last stage, in the analysis phase, the collected data was analyzed using SPSS and then interpreted to develop the final model. Figure 5 illustrates the procedure map of the study.

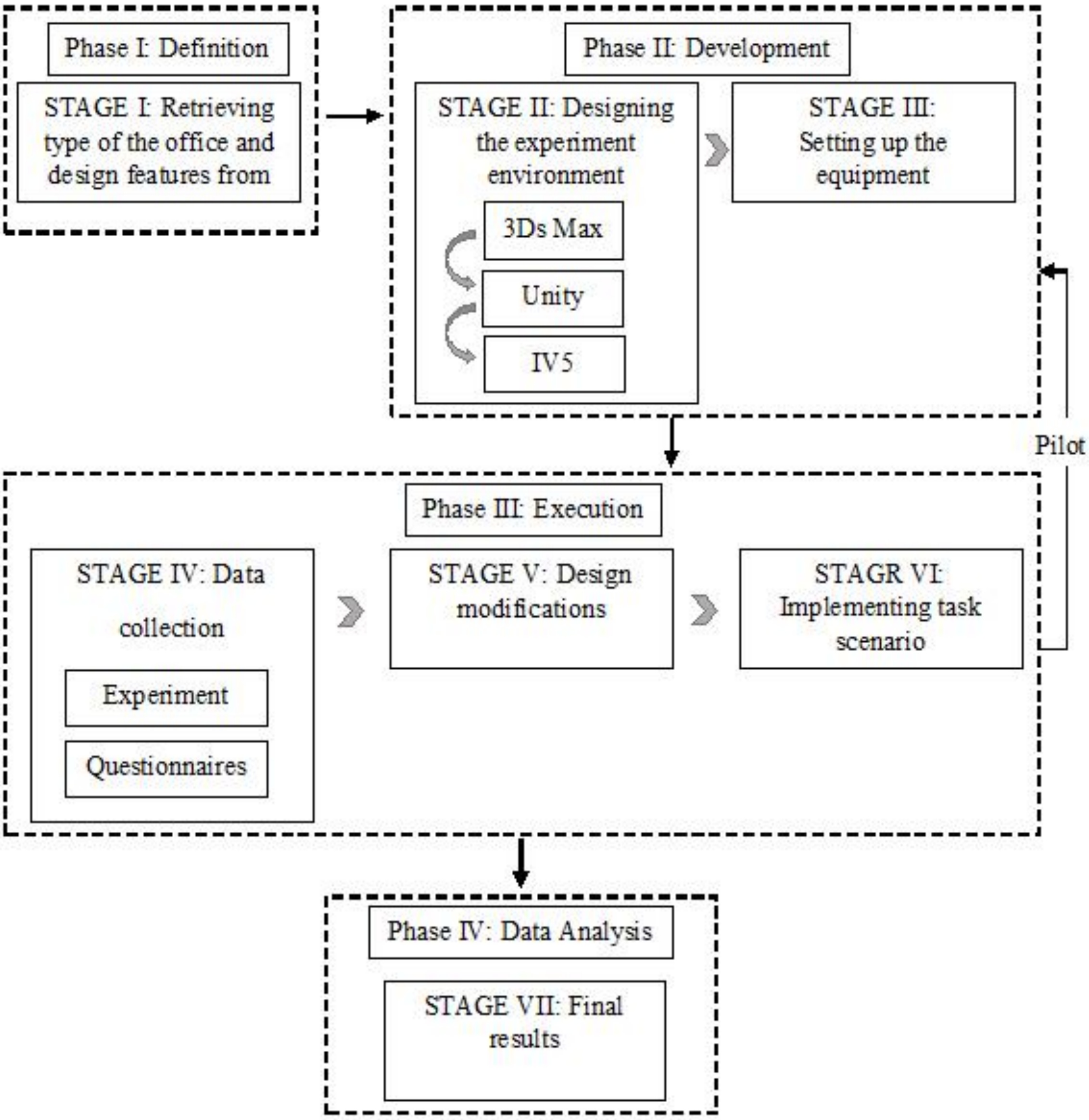

Figure 5. Procedure map of the study (drawn by the author, 2020).

The experiment consisted of three scenarios, each of which demonstrates one of the light settings. Table 1 shows the lighting system and the control level for each scenario. All the participants were asked to take part in all three scenarios. To minimize the learning effect, participants performed each scenario individually, with an interval of at least two days. Additionally, participants were assigned to attend the scenarios in a random order, which means they did not necessarily start the experiment with the first scenario, ending it with the third one.

Table 1. Experiment scenarios.

Experiment:	Scenario I	Scenario II	Scenario III
Lighting system:	Conventional lighting (Control group)	Daylight responsive lighting	Interactive lighting
Control level:	Full control No automation	No control Full automation	Semi-controlled Semi-automation

The scenarios I and III provide various lighting levels for the participants to choose from to meet their comfort to perform the reading task. In the scenario I, there are five modes for the blinds, from completely closed to completely open with three positions in between, and five modes for the artificial lights, from fully dim to fully bright with three dimming levels in between. This setting gives the participants complete authority to adjust the lighting level by either adjusting the blinds or choosing a level on artificial lights or selecting a combination of both. In scenario III, there are also five modes for each of the natural and artificial lighting. However, the lighting setting interactively responds to the lighting choices of the occupants to save energy by restricting their choices. Table 2 shows the average lux values on the work plane in each possible lighting arrangement.

Table 2. Average lux values on the work plane in each possible lighting arrangement.

Artificial **Natural**	**1**	**2**	**3**	**4**	**5**
1	50 lx	320 lx	620 lx	900 lx	1200 lx
2	250 lx	530 lx	840 lx	1120 lx	1440 lx
3	500 lx	780 lx	1070 lx	1360 lx	1660 lx
4	850 lx	1150 lx	1440 lx	1730 lx	2050 lx
5	1300 lx	1580 lx	1900 lx	2140 lx	2460 lx

3.5. Instruments and Data Collection

This study employs experimental research and questionnaires in the process. Prior to starting the experiment, the participants were briefed about the experiment. Then, they performed a test to make sure they do not experience any motion sickness and to get familiar with the virtual environment. Those participants who wished to proceed after the test were asked to sign a consent form. The data collection involved an experiment and different questionnaires about participants' demographic information, office lighting, the Big Five Inventory, and virtual reality technology.

The experiment consists of three parts, each representing a different lighting scenario. In the scenario I and the scenario III, the participants were asked to interact with the lighting setting and adjust the lighting to the level that suits them best to perform a reading task. In scenario II, the lighting setting automatically sets the light and participants had no role in adjusting the light. Therefore, they could start with performing the reading task. The lighting choices of each participant in scenarios I and III were recorded. After performing the reading task, participants answered a question about the text. Figure 6 shows the participants during the experiment with the IVE.

Figure 6. Participants during the experiment with the IVE (photo taken by the author, 2020)

3.5.1. Virtual Environment

The main equipment for conducting this study was a computer workstation and a complete set of virtual reality instruments. The computer used for launching the model and implementing the virtual environment was a Microsoft© Windows workstation with Radeon RX 580 graphics card. The virtual reality instruments included an HTC Vive Pro Head-Mounted Display, a Vive controller, and two SteamVR base stations (See figure 7).

Figure 7. HTC Vive pro starter kit. Retrieved from: https://www.vive.com/eu/product/vive-pro-starter-kit/

During the experiment, the participants oversaw adjusting the lighting level to meet their comfort, in the non-automated lighting scenarios. They were instructed to make their choice given the time and weather condition to meet their comfort for performing a reading task. Their lighting choices were documented in each scenario for further analysis. Figure 8 shows the user interface for adjusting the lighting level within the IVE for performing the reading task.

Figure 8. User interface for adjusting the lighting level within the IVE. (Developed by the author, 2020)

3.5.2. Reading Task Performance

This experiment's objective is to explore end users' lighting choices, cognitive load, and satisfaction when they have different degrees of control over lighting to perform an office-related task. The significance of the type of task chosen for this particular experiment is threefold. First, the task should be a common obligation for an office environment. Second, it should be feasible and compatible with virtual environments. Finally, it is crucial that performing the chosen task is affected by the lighting level.

Previous research has shown that reading and comprehension tasks are significantly affected by illumination (Smith & Rea, 1978; Rea, 2018). Given that a reading task satisfies the first two requirements as well, the participants were assigned to read a short passage in each experiment scenario. The passages were different in each scenario; however, they were about similar general topics. Topics were selected unrelated the sample's academic background to avoid any prejudice. Each passage was a standard English text with approximately 185 words and average Flesch–Kincaid readability score of 45. To assess the cognitive load in each scenario, the participants needed to read the text in 3 minutes and then answer a multiple-choice question about the it. Since, analyzing the reading speed and comprehension was beyond the scope of this study, the time restriction was 2 times the average reading time of the participants in the pilot study to cover for any constraints imposed by the font and size of the characters for the participants.

3.5.3. Cognitive Load Measurement

Previous studies have proposed three main methods for measuring cognitive load (1) task performance; (2) subjective impressions of cognitive load; (3) physiological reaction (Zhang, de Dear, & Hancock, 2019). This study employs task performance and subjective impressions of cognitive load methods to evaluate participants' cognitive load in different scenarios. Task performance has been presented diversely by probability of error, response time, response accuracy, response consistency, and response range. Among these factors speed and accuracy are the most commonly used forms of assessment, especially in field-based research (Zhang et al., 2019). Studies demonstrated that in indoor environmental science research, response speed is used more often than response accuracy to measure performance (Lan, Wargocki, & Lian, 2011; Lan et al., 2014). Also, for many different types of tasks there is a speed-accuracy balance for measuring performance (Lan et al., 2014; Wickelgren, 1977).

The concurrent alterations in mental effort might not be obvious in merely task performance measurements since people tend to adjust to changes in task demands in ways to protect their performance (Hockey, 1997). If so, subjective impressions of cognitive load can be valuable (Zhang et al., 2019). NASA Task Load Index (TLX) is one of the most popular subjective measurements of cognitive load. NASA TLX has a multidimensional structure to present a comprehensive workload score, which relies on weighted average values on six subscales: mental demand, physical demand, temporal demand, performance, effort, and frustration level (Hart & Staveland, 1988). Parsons (2000) indicated that subjective evaluations are convenient in process and proper assessment of psychological responses. They can also be helpful when the drivers of a response are unidentified (Zhang et al., 2019). However, subjective evaluations are often not suitable for measuring influence on health, because the environmental stressor can also interfere with the capacity to make a reliable subjective assessment (Zhang et al., 2019).

Considering the type of task and the intention to analyze the effect of level of control over lighting and lighting quality on the cognitive load of the participants, NASA TLX was used. The participants were asked to complete an adapted version of NASA TLX after each scenario as a subjective measurement of workload for performing the task. This study adapted the NASA TLX by eliminating the irrelevant subscales. Therefore, the adapted version only used 4 subscales of temporal demand (TD), performance (PR), effort (EF), and frustration level (FR). Additionally, for calculating the workload a 10-point scale was used.

3.5.4. Questionnaires

Before starting the experiment, participants answered questions about their personal information such as age, gender, and education. After taking part in each scenario, participants filled out an adapted version of the office lighting survey (OLS) by Eklund and Boyce (1996). The adapted version of the questionnaire consists of 9 questions about visual comfort, general light distribution, and rating the lighting for the task scenario. The first 7 questions followed an agree-disagree format, question 8 had a 3-point Likert Scale, and the last question had a 6-point Likert Scale format.

After completing the third part of the experiment, participant filled out two additional sets of questionnaires: a technology acceptance model (TAM) questionnaire and the Big Five Inventory (BFI) (John, Donahue, & Kentle, 1991; John, Naumann, & Soto, 2008) for assessing the personality traits. The TAM questionnaire was adapted from various technology acceptance studies. The TAM questionnaire aimed to evaluate the perceived usefulness, ease of use, and enjoyment of the participants during the use of the immersive virtual environment technology, in addition to their intention to use it again in the future. Moreover, the BFI was employed to seek for potential relations between the participants' personality traits and their attitude towards various lighting control systems, choices, and alterations of their cognitive load in different scenarios. Accordingly, the original version of the questionnaire was used, which consists of 44 questions on a five-point Likert Scale from strongly disagree to strongly agree.

CHAPTER 4

RESULTS

This chapter of the thesis demonstrates the results and the statistical analysis of the data gathered for this study. The data was analyzed using IBM SPSS Statistics 24 software. The study was conducted with 30 participants who completed the experiment with no special difficulty in the given time. Hence, the analysis of the data in all sections was based on the data gathered through experimenting with 30 participants.

4.1. Lighting Control Systems’ Scenarios

As discussed in chapter 3, the participants were asked to interact with the lighting systems when necessary to perform a reading task in 3 different scenarios. The first scenario was the control group in which the participants had full control over a lighting system with different options. The second scenario represented a fully automated daylight responsive lighting system with no available control options. Finally, the third scenario offered a limited degree of control over a semi-automated interactive lighting system.

To explore the effect of having different levels of control on lighting system in the virtual office setting various comparisons were made between scenarios. First, the participants' lighting choices in different scenarios were assessed. The first hypothesis (H1) was 'the lighting choices of the participants with the interactive lighting system is significantly different from their lighting choices with the conventional lighting system'. Since the data was not normally distributed, non-parametric analyses were implemented to find the results. To get the initial results, a Friedman test was applied to the data. The Friedman test, which the counterpart of two-way ANOVA, is an approach to explore differences between group classifications caused by independent variable (Hutchinson, 1996). Following the hypothesis, a Friedman test showed that the participants' lighting choices were significantly different from one another in the three scenarios (p=0.000). To determine the differences, a Wilcoxon signed-rank test was run with applying the Bonferroni correction (α=0.017). The Wilcoxon signed-rank test is a non-parametric one-sample test that in a matched pair context that examines the equivalence of the probability distribution between samples (Woolson, 2007). The Bonferroni test modifies the significance level for multiple comparisons (Mayers, 2013). When multiple tests are performed on single data set, there is higher chance to get a significant result as the number of tests increase. Therefore, the Bonferroni correction divides the confidence interval by the number of the tests performed (Mayers, 2013). Confirming the hypothesis (H1), the results showed that the lighting choices of the participants in scenario III were significantly different from their lighting choices in scenario I (z=-3.748, p=0.000). Table 3 summarizes the participants' choices in scenarios I and III. As the table shows, more participants tend to use natural lighting when they had a degree of control over an optimized interactive lighting system. In scenario III, initially, all the participants attempted to change the default lighting setting. However, in the course of the experiment 16.7% of the participants (n=5) chose the default setting as their final decision.

Table 3. Frequency of participants' lighting choices in scenarios I and III.

	Scenario I		Scenario III	
	Frequency	**Percent**	**Frequency**	**Percent**
Natural lighting	7	23.3	19	63.3
Artificial lighting	1	3.3	9	30
Combination of both	22	73.3	2	6.7
Total	30	100.0	30	100.0

Next, the participants' satisfaction with the office lighting in different scenarios was analyzed. The data indicating participants' satisfaction with lighting condition was obtained through an office lighting survey at the end of each scenario experiment. A Friedman test revealed that the participants' satisfaction with lighting conditions in all scenarios was significantly different from each other (p=0.000). To identify the differences, a Wilcoxon signed-rank test was applied with the Bonferroni correction (α=0.017). The test results demonstrated that the participants' satisfaction with the lighting was significantly different in scenario II comparing to scenario I (z=-4.077, p=0.000) and scenario III (z=-2.988, p=0.003). Comparing the mean satisfaction scores, participants were less satisfied with lighting condition in scenario II (Figure 9). However, the Wilcoxon signed-rank test with the Bonferroni correction (α=0.017) showed no significant difference between the participants' satisfaction with lighting conditions in scenarios I and III (z=-2.080, p=0.038). As a result, hypothesis 2 (H2) stating that 'there is a statistically significant association between the availability of a degree of control over the lighting system and participants' satisfaction' was affirmed. To gain a more distinct understanding of participants' satisfaction in each scenario the descriptive statistic values (mean, standard deviation (SD), minimum, and maximum) of their satisfaction scores was obtained. Table 4 shows the information about the participants' satisfaction scores.

Table 4. Participants' satisfaction scores.

	Lighting condition satisfaction score			
	Mean	**SD**	**Min**	**Max**
Scenario I	9.33	1.03	6	10
Scenario II	6.97	2.14	4	10
Scenario III	8.73	1.41	5	10

Finally, the participants' cognitive loads in performing the reading task in different scenarios were explored. The hypothesis (H3) was 'there is a statistically significant association between the availability of a degree of control over the lighting system and participants' cognitive performance'. A Friedman test demonstrated that the participants cognitive load scores in all 3 scenarios were significantly different from each other (p=0.000). In investigating the differences, a Wilcoxon signed-rank test with the Bonferroni correction (α=0.017) confirmed that the participants' cognitive load in performing the task in scenario II was significantly different from their cognitive load in scenario I (z=-3.117, p=0.002). Similarly, the participants' cognitive load in performing the task in scenario II was significantly different from their cognitive load in scenario III (z=-2.733, p=0.006). Participants' cognitive load was higher in scenario II compared to both scenarios I and III. Additionally, a Wilcoxon signed-rank test with the Bonferroni correction (α=0.017) showed that there was no significant difference between the participants' cognitive load in scenario III comparing to scenario I (z=-1.334, p=0.182). The results supported the hypothesis (H3). Table 5 summarizes the average cognitive load values in each scenario.

Table 5. The average cognitive load values in each scenario.

	WWL Scores	
Scenarios	Mean	SD
Scenario I	4.20	1.81
Scenario II	5.60	1.79
Scenario III	4.57	185

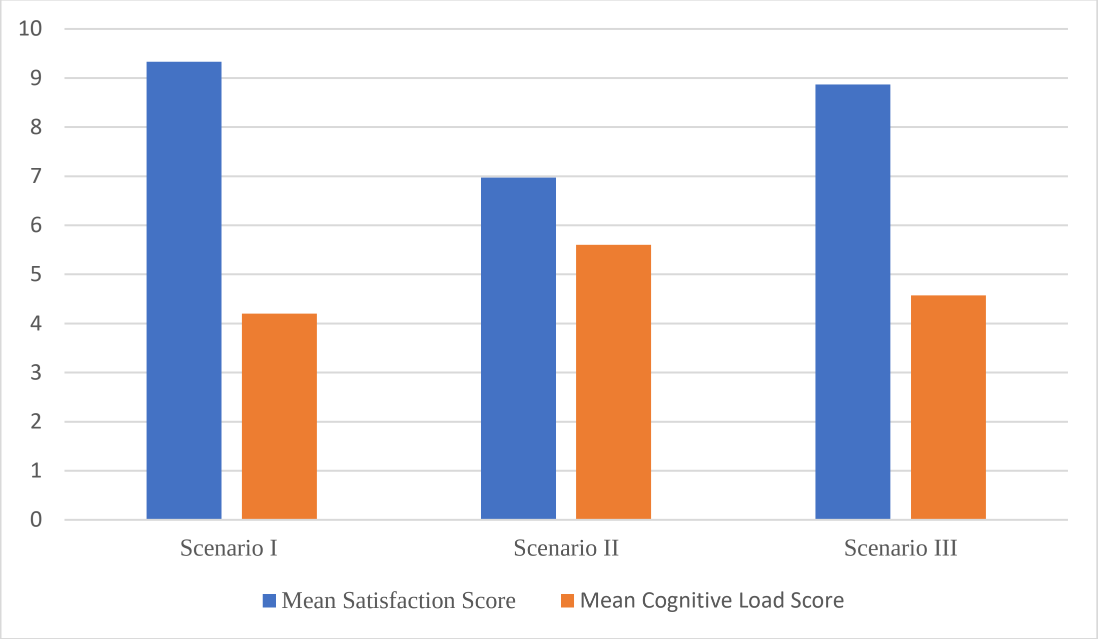

Figure 9. Mean satisfaction scores and mean cognitive load scores in all 3 scenarios.

4.2. Personality Traits and Lighting Choices

The lighting choices of the participants in scenarios I and III were analyzed in relation to the big five personality traits of the participants. Since the sample was small and the data was not normally distributed and each variable had multiple levels, it was not possible to reach any significant results. Therefore, no specific correlation between the participants' personality traits and their lighting choices was found. However, through aggregating and recoding the data a few conclusions were drawn using scatter plot graphs and cross tabulation (figures 10 and 11). It was shown that participants who were open to experiences had a wider range of choices in both scenarios I and III. Participants with extravert personality tended to choose a combination of both natural and artificial lighting in scenario I. They chose to have natural lighting in scenario III. Participants with conscientious personality, mostly, chose a combination of both natural and artificial lighting in scenario I. Finally, in scenario III participants with high scores at agreeableness and conscientiousness were inclined towards natural lighting. Although the results were not conclusive, it can be said that the hypothesis 'the participants' personality trait affects their lighting choices' (H4) is consistent. Tables 6 and 7 summarize the frequencies of choices by different personalities in each scenario.

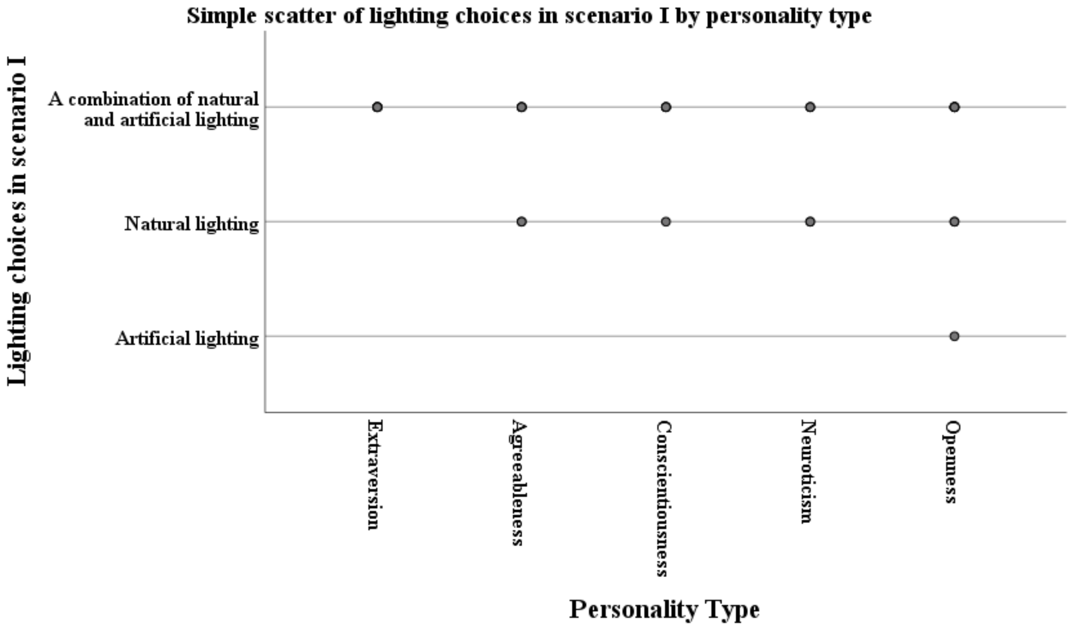

Figure 10. Scatter plot of lighting choices in scenario I by personality type.

Table 6. Frequencies of choices by different personalities in scenario I.

	Personality type frequency					
	Extraversion	Agreeableness	Conscientiousness	Neuroticism	Openness	Total
Artificial lighting	0	0	0	0	1	1
Natural lighting	0	2	1	2	2	7
A combination of natural and artificial lighting	5	4	4	3	6	22
Total	5	6	5	5	9	30

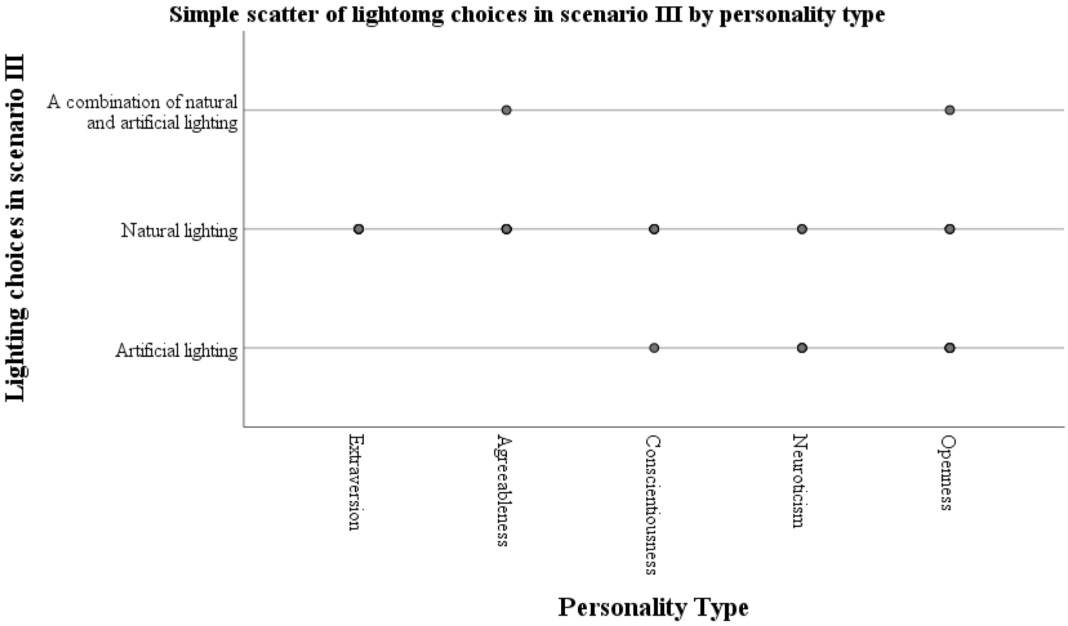

Figure 11. Scatter plot of lighting choices in scenario III by personality type.

Table 7. Frequencies of choices by different personalities in scenario III.

	Personality type frequency					
	Extraversion	Agreeableness	Conscientiousness	Neuroticism	Openness	Total
Artificial lighting	0	0	1	3	5	9
Natural lighting	5	5	4	2	3	19
A combination of natural and artificial lighting	0	1	0	0	1	2
Total	5	6	5	5	9	30

4.3. Technology Acceptance Model (TAM)

To analyze the virtual reality technology acceptance questionnaire, first, the reliability of the gathered data for consistency was investigated. Nunnally (1978) suggests that the attained Cronbach's alpha value should be higher than 0.7 to be an indicator of internal consistency. The items of TAM were studied under four different categories of perceived usefulness (PU), perceived ease of use (PEU), intention to use (IU), and perceived enjoyment (PE). A Cronbach's alpha test was performed for each category to understand if the gathered data were reliable. Table 8 summarizes the Cronbach's alpha values for each category.

Table 8. Cronbach's alpha values for each category.

TAM Categories	Cronbach's Alpha Values
PU	0.916
PEU	0.815
IU	0.786
PE	0.865

Then, hypothesis 5 (H5), 'participants perceive immersive virtual environment technology as a useful tool for serious tasks', was tested. Comparing the mean values of the components of the TAM questionnaire shows that the participants enjoyed their experience with the virtual reality technology rather than considering it as a useful device they intend to employ for other purposes. The lower mean scores for the PU (mean=3.19) indicate that, overall, the participants potentially did not perceive the VR technology as a tool for performing serious tasks. Moreover, generally, the participants reviewed the virtual reality as a technology that is quite easy to use. Accordingly, hypothesis 5 (H5) was rejected. Table 9 summarizes the information of the rated values for each category of the TAM.

Table 9. Mean scores of for each category of the TAM.

TAM Categories	Mean	SD
PU	3.19	0.95
PEU	3.68	0.80
IU	3.55	0.91
PE	4.25	068

Four components of TAM were also analyzed for correlation. Since the data were not normally distributed, Spearman's Rho as a suitable non-parametric test for association was implemented. The results indicated that there is moderate positive correlation between perceived usefulness and intention to use of TAM components (r=0.627, p=0.000). Perceived usefulness has also found to have a low positive correlation with perceived enjoyment (r=0.357, p=0.026). Additionally, there was a low positive correlation between perceived ease of use and intention to use (r=0.332, p=0.37). Finally, the analyses revealed a moderate positive correlation between perceived enjoyment and intention to use (r=0.695, p=0.000). Figures 12 to 15 illustrate the relationship between the correlated components.

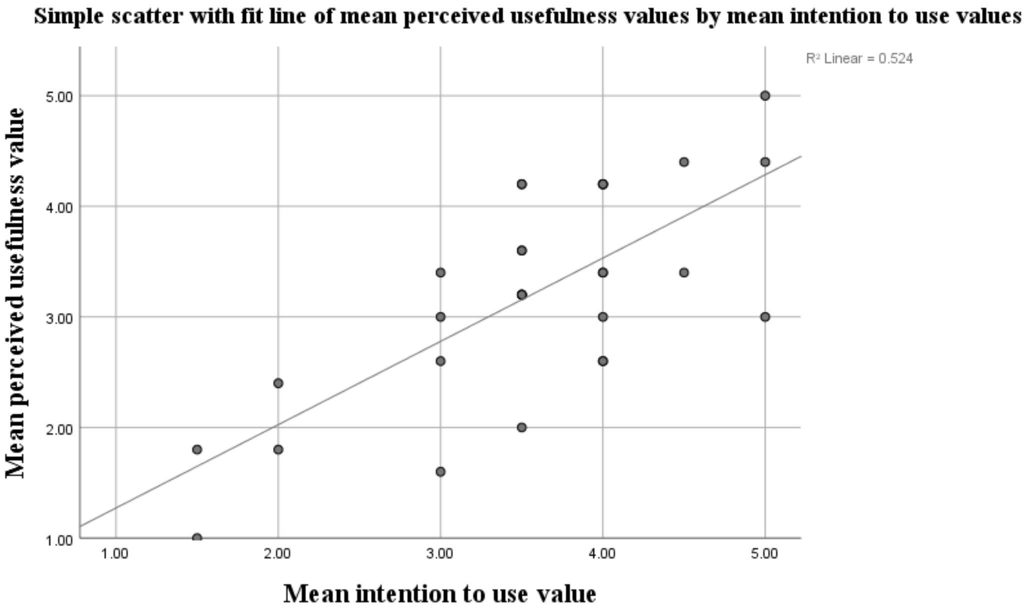

Figure 12. Scatter plot of perceived usefulness values by intention to use values.

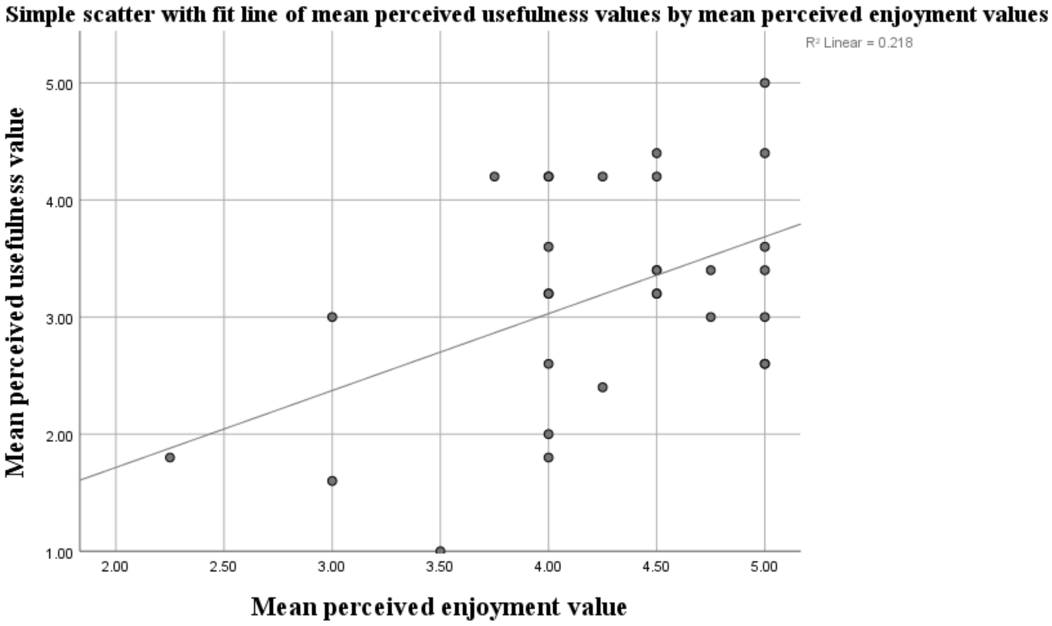

Figure 13. Scatter plot of perceived usefulness values by perceived enjoyments values.

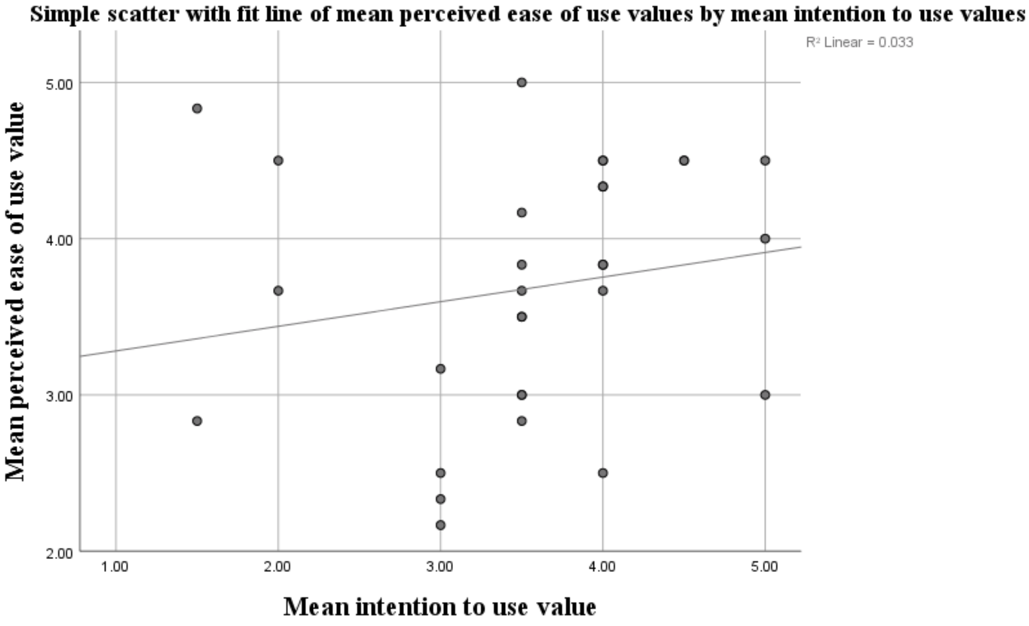

Figure 14. Scatter plot of perceived ease of use values by perceived intention to use values.

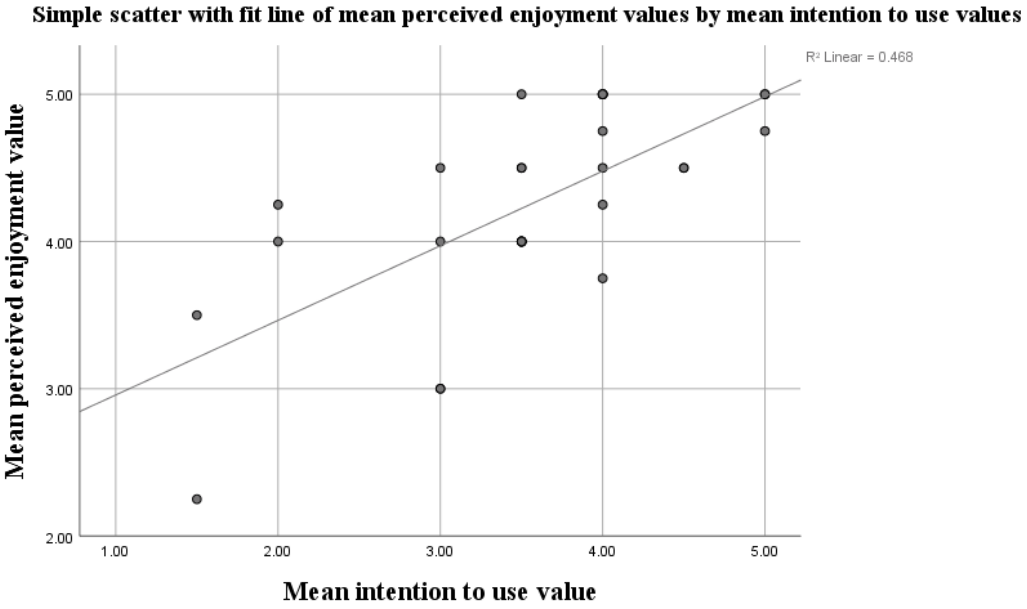

Figure 15. Scatter plot of perceived enjoyment values by intention to use values.

4.4. Discussion

This study investigated how having different lighting systems, which provide different degrees of control over the lighting conditions affect participants' lighting choices, satisfaction with lighting conditions, and their cognitive load in performing a task. Then, the influence of participants' personality traits on their lighting choices were analyzed. Finally, participants' attitude towards virtual reality technology was assessed through a technology acceptance model questionnaire.

The results indicated that the participants were more likely to choose to have natural lighting over artificial lighting when interacting with more energy efficient lighting systems, which gives them a perception of control. This state happened in a condition that participants maintained their satisfaction with the lighting system compared to the circumstances where they had full control over a conventional lighting system and no significant increase in their WWL score was revealed. Additionally, the data gathered with OLS in three scenarios demonstrated that the participants were significantly less satisfied with fully automated daylight responsive lighting systems in contrast to manually controllable systems or semi-automated interactive lighting systems. These findings are aligned with the literature suggesting that having no control over the building systems fails to satisfy occupants (Carneiro et al., 2019a; Galasiu & Veitch, 2006; Shishegar & Boubekri, 2017; Vischer & Wifi, 2017). Overall, the assessments suggested that the participants were equally satisfied with semi-automated lighting systems, which gives them a perception of control over lighting comparing to conventional lighting systems, which provides them full control. Comparing the participants' task performance through their WWL scores in different scenarios showed that the participants underwent a higher cognitive load when they performed a task with fully automated lighting system when compared to the conditions where they had full control or a perception of control over the lighting system. This is in contrast with a previous research which showed that having the option to control the lighting had no effect on task performance by participants (Boyce et al., 2000). However, the research stated that it made the tasks seem less difficult (Boyce et al., 2000). Moreover, the participants expressed the same level of cognitive load for performing the task in both interactive lighting scenario and conventional lighting scenario.

Analyses of the personality traits showed that in both scenarios I and III the participants who scored high on openness had a wide range of lighting choices regardless of having different degrees of control over lighting. In case of having full control, participants with bold extraversion dimension mostly chose a combination of both natural and artificial lighting. In a study, Heydarian et al. (2017) showed that extraverts are more inclined to have all shades and electric lights open simultaneously when they are given control over lighting. However, with interactive lighting system that limited they choices in this study, they mostly preferred natural lighting. Conscientious participants chose to have a combination of natural and artificial lighting when they had full control over the lighting. On the other hand, in the other scenario when they had to deal with an interactive lighting system, they mostly chose to have natural lighting.

Finally, evaluating the technology acceptance by the participants showed that the participants had more of an enjoyable experience with virtual reality in this study rather than considering virtual reality a useful tool for performing serious tasks. Furthermore, correlation analyses between the TAM components suggest that intention to use virtual reality technology by the participants was positively related with perceived enjoyment and perceived usefulness. Perceived enjoyment was mildly and positively associated with perceived usefulness. Analogously, a weak association showed increases in perceived ease of use values led to increases in intention to use the virtual reality technology. A part of the correlation findings also corresponded to former research about usability of virtual reality in design education that had discovered positive relationships between perceived usefulness with both perceived enjoyment and intention to use (Özgen, Afacan, & Sürer, 2019).

There were some limitations in conducting this study. First, the environmental factors and conditions were static and in favor of having natural light throughout the experiment. Yet, in real environments, these factors can change and occupants' choices can alter accordingly. Occupants' attitudes and choices can also be different in different office types and during performing different types of tasks. Additionally, since this study was designed for virtual environments, the obtained average lux levels in the real work environments might result in different associations. Finally, due to the COVID-19 pandemic, the sample size was kept small, which resulted in constraints for data analysis. For example, the sample was not large enough to generate generalizable results about the effect of personality traits on lighting choices. Analyzing the effect of personality traits on lighting choices needs more comprehensive investigations in large sample sizes.

CHAPTER 5

CONCLUSION

This research systematically analyzed the impact of having personal control over lighting system in office settings on occupants lighting choices, lighting satisfaction, and task performance. Accordingly, virtual environments were used as a tool to control the variables and conduct the experiment. Personality traits were also studied in relation to lighting choices. Finally, a technology acceptance model was employed to further investigate the participants' attitude towards the virtual reality technology.

Literature suggests that using automated building systems has the potential to save considerable amounts of energy (Nagy et al., 2016). However, recent developments in control strategies for building systems have ignored occupants' satisfaction (Park & Nagy, 2018). In this light, acquiring knowledge about occupants' manners of interaction with building systems can simultaneously lead to both energy efficiency and addressing occupants' satisfaction (Heydarian et al., 2016). In this respect, this research attempted to understand the consequences of implementing automation or perception of control over lighting in occupants' aspect.

The results of the research revealed that an energy efficient interactive lighting system that gave the participants a perception of control satisfied the participants in terms of lighting the same as a conventional lighting system that gave them full control. While performing a reading task with an interactive lighting system, participants reported a similar workload score as performing the same task with a conventional lighting system. Comparing these two systems in terms of lighting choices showed that were more likely to choose to have natural lighting over artificial lighting when interacting with the interactive lighting system. However, findings suggested that the participants were significantly less satisfied with fully automated daylight responsive lighting system in contrast to conventional lighting system or interactive lighting system. Comparing the participants' cognitive loads in different scenarios indicated that the participants experienced a higher cognitive load when they performed a task with fully automated lighting system compared to the conditions where they had full control or a perception of control over the lighting system.

The findings of the personality analyses showed that the participants with a high score on openness had a wide range of lighting choices either with conventional or with interactive lighting. With conventional lighting, participants with bold extraversion dimension mostly chose a combination of both natural and artificial lighting. However, with interactive lighting system that limited they choices, they mostly preferred natural lighting. Conscientious participants chose to have a combination of natural and artificial lighting with conventional lighting. On the other hand, with interactive lighting system, they mostly chose to have natural lighting. Obtaining the personality profiles of the occupants can be helpful for designing user-centered lighting systems that can meet the occupants' lighting preferences and detect the occupants' who consume more energy (Heydarian et al., 2017).

Finally, this study showed that the participants rather considered virtual reality a better fit to an enjoyable experience than a useful tool for performing serious tasks. Additionally, intention to use virtual reality technology by the participants was positively related with perceived enjoyment and perceived usefulness. Perceived enjoyment was found to be positively associated with perceived usefulness. Moreover**,** perceived ease of use was weakly yet positively associated with intention to use the virtual reality technology.

The significance of this study lies in demonstrating that satisfaction can be achieved by giving the occupants a perception of control over semi-automated energy-efficient building systems. This is in contrast with the previous studies suggesting that occupants are, generally, more satisfied with conventional manually controllable lighting systems (Carter, Slater, & Moore, 1999). Consequently, it is critical to design building systems that allow the occupants to override their initial preferences and give them an adaptable level of energy-efficient control.

Future research could focus on implementing energy simulations to assess the energy performance of semi-automated systems. Further studies could also consider the mutual relationship between other visual comfort factors such as glare or thermal comfort factors, such as temperature, humidity, etc. along lighting satisfaction.

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APPENDICES

APPENDIX A

APPROVED ETHICS FORMS BY BILKENT UNIVERSITY

İhsan Doğramacı Bilkent Üniversitesi
Bilkent Üniversitesi
Akademik İşler Rektör Yardımcılığı

Tarih : 30 Eylül 2020

Gönderilen : Parisa Mahmoudzade

Danışman : Yasemin Afacan, Mohamad Nadim Adi

Gönderen : H. Altay Güvenir
İnsan Araştırmaları Etik Kurulu Başkanı

Konu : *"Analysing occupants' ..."* çalışması etik kurul onayı

Üniversitemiz İnsan Araştırmaları Etik Kurulu, 30 Eylül 2020 tarihli görüşme sonucu, *"Analysing occupants' control over lighting systems in office settings using virtual environments*" isimli çalışmanız kapsamında yapmayı önerdiğiniz etkinlik için etik onay vermiş bulunmaktadır. Onay, ekte verilmiş olan çalışma önerisi, çalışma yürütücüleri ve bilgilendirme formu için geçerlidir.

Bu onay, yapmayı önerdiğiniz çalışmanın genel bilim etiği açısından bir değerlendirmedir. Çalışmanızda, kurulumuzun değerlendirmesi dışında kalabilen özel etik ve yasal sınırlamalara uymakla ayrıca yükümlüsünüz.

Kovid-19 salgını nedeniyle konulmuş olan kısıtlamaların yürürlükte olduğu süre içinde, tüm komite toplantıları elektronik ortamda yapılmaktadır; aşağıda isimleri bulunan Bilkent Üniversitesi Etik Kurulu Üyeleri adına bu yazıyı imzalama yetkisi kurul başkanındadır.

Etik Kurul Üyeleri:

Ünvan / İsim	**Bölüm / Uzmanlık**	
Prof.Dr. H. Altay Güvenir	Bilgisayar Mühendisliği	Başkan
Prof.Dr. Erdal Onar	Hukuk	Üye
Prof.Dr. Haldun Özaktaş	Elektrik ve Elektronik Müh.	Üye
Doç.Dr. Işık Yuluğ	Moleküler Biyoloji ve Genetik	Üye
Dr. Öğr. Üyesi Burcu Ayşen Ürgen	Psikoloji	Üye
Doç.Dr. Çiğdem Gündüz Demir	Bilgisayar Mühendisliği	Yedek Üye
Dr. Öğr. Üyesi A.Barış Özbilen	Hukuk	Yedek Üye

Kurul karar/toplantı No: 2020_09_30_01

(Form Staff_EN*)

Staff Application Form for Experiments with Human Participants

(A separate application form must be completed for each experiment and staff member.)

Please check one: ___ ***I need a formal approval letter for an external agency (TÜBİTAK, etc.)***

X ***An internal communication letter informing me of the approval will be sufficient***

1. Name of applicant (graduate students should indicate their supervisors)

Graduate Student: Parisa Mahmoudzadeh; Supervisor: Assoc. Prof. Dr. Yasemin Afacan Co-Supervisor: Assit. Prof. Dr. Mohamad Nadim Adi

2. Funder of grant/studentship if any:

3. Full title of experiment/project

Analysing occupants' control over lighting systems in office settings using virtual environments

4. When do you wish to start data collection: ____25.09.2020____________

5. Aims of project:

The aim of this study is to understand how different control levels over lighting systems can influence occupants' behaviour and performance in office settings.

6. What will the participants have to do? (Provide a brief outline of procedure, *for survey work, a copy of the survey should be attached to this form.*) Please indicate if the participants may be exposed to stimuli which may upset them:

The participants of this study will be asked to fill out different questionnaires and take part in an experiment consisted of three different scenarios. The experiment will be conducted in a virtual environment using HTC Vive Pro head-mounted display. Before the experiment, first, participants will be briefed about the experiment. Then, they will perform a test to make sure they do not experience any motion sickness and to get familiar with the virtual environment. They will be asked to sign a consent form if they still want to participate in the experiment. Experiment scenarios analyse occupants' lighting choices when they are provided with different lighting systems and evaluate their own performance after doing a reading task in each scenario. Each participant will be asked to take part in all three scenarios with an interval of two days between them to minimize the learning effect. All the participants will be asked to fill out a survey about lighting after each scenario and two other sets of questionnaires by the end of the third scenario experiment. The questionnaires comprise The Big Five Inventory for personality type, Office Lighting Survey, and Technology Acceptance Model Questionnaire for VR. Additionally, participants will be asked for information about their age, sex, and level of education in the questionnaires. The obtained data from the experiment and questionnaires will be processed using SPSS software. The names of the participants will be coded into the numbers and personal information will be held confidential.

7. What sort of people will the participants be and how will they be recruited? In the case of children state age range. (*Any participant who has not lived through his/her 18th birthday is considered to be a child!*)

The participants of this study will be volunteers of graduate students and faculty of Interior Architecture and Environmental Design Department in Bilkent University. The minimum number of participants will be 30 people who are aged between 22-40.

I have CRB clearance yes / no**

8. Arrangements for consent and debriefing (attach information sheet and consent form)

Participants will be briefed about the study prior to the experiment. Then, each participant will be asked to read and sign a consent form, which explains the procedure. Also, prior to the experiment, they will be given instructions about using the virtual reality technology for the experiment.

---

* Adapted from *www.york.ac.uk/depts/psych/www/research/ethics/StaffPGEthicsForm.doc*

** Criminal Records Bureau – clearance is required for non-university personnel, including students, for experiments involving children. Please attach relevant documentation.

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9. How will you guarantee confidentiality of participants?

All the participants of the study will be asked to sign a consent form to satisfy ethical procedures (See consent form attached). The names of the participants will be coded into the numbers. All personal information of participants obtained during the research will be held in confidence by the researcher. In the information consent form, there is a statement which is signed by the graduate student and the supervisor that "we confirm that the confidentiality and anonymity will be maintained and the participant will not be identified from any publications".

M.N.A 2.10.2020

PM 05/10/20

YA. 01/10/20

10. Please e-mail an electronic version of this word processed form (without signatures) along with other application material to the committee to start the evaluation process. Paper copies of all application material, (properly signed where indicated, and initialed on all other pages) should be sent after possible modifications suggested by the committee are finalized.

Signature(s):

Person carrying out the work

......Parisa Mahmoudzadeh...

Supervisor, grant holder, or Principal Investigator: I am satisfied that that the procedures adopted will ensure the dignity, welfare and safety of all participants in this work.

Assoc. Prof. Dr. Yasemin Afacan.............................

Assistant Prof Dr. Mohamad Nadim Adi

The signature above signifies that researchers will conform to the accepted ethical principles endorsed by relevant professional bodies, in particular to

Declaration of Helsinki (WMA):
https://www.wma.net/policies-post/wma-declaration-of-helsinki-ethical-principles-for-medical-research-involving-human-subjects/

Ethical Principles of Psychologists and Code of Conduct (APA):
http://www.apa.org/ethics/code2002.html

Ethical Standards for Research with Children (SCRD):
http://www.srcd.org/about-us/ethical-standards-research

Bilkent University does not allow the use of students of research investigators as participants. Students who have the potential of being graded by the investigators during or following the semester(s) in which the study is being carried out should not participate in the study. Students may not receive any credit for any university course, with the exception of the GE250/GE251 courses, for their participation. The GE250 and GE251 (Collegiate Activities I and II) courses include an optional activity which encompasses volunteering as a participant in a research project.

M.N.A 2.10.2020

PM 05/10/20

YA 01/10/20

(Form Student_EN*)

Ethics form for graduate and undergraduate students - human participants

Note - group projects fill in one copy with all your names on it. Consult your project supervisor for advice before filling in the form.

Your name(s): **Parisa Mahmoudzade**
Project Supervisor: **Assoc. Prof. Dr. Yasemin Afacan, Co-supervisor: Assit. Prof. Dr. Mohamad Nadim Adi**

A. Write your name(s) and that of your supervisor above.
B. Read section 2 that your supervisor will have to sign. Make sure that you cover all these issues in section 1. Discuss what you are going to put on the form with your project supervisor.
C. Sign the form and get your project supervisor to complete section 2 and sign the form.

1. **Project Outline (to be completed by student(s))**

(i) **Full Title of Project:**

Analysing occupants' control over lighting systems in office settings using virtual environments

(ii) **Aims of project:**

The aim of this study is to understand how different control levels over lighting systems can influence occupants' behaviour and performance in office settings.

(iii) **What will the participants have to do? (brief outline of procedure; please draw attention to any manipulation that could possibly be judged as deception;** ***for survey work, a copy of the survey should be attached to this form*****):**

The participants of this study will be asked to fill out different questionnaires and take part in an experiment consisted of three different scenarios. The experiment will be conducted in a virtual environment using HTC Vive Pro head-mounted display. Before the experiment, first, participants will be briefed about the experiment. Then, they will perform a test to make sure they do not experience any motion sickness and to get familiar with the virtual environment. They will be asked to sign a consent form if they still want to participate in the experiment. Experiment scenarios analyse occupants' lighting choices when they are provided with different lighting systems and evaluate their own performance after doing a reading task in each scenario. Each participant will be asked to take part in all three scenarios with an interval of two days between them to minimize the learning effect. All the participants will be asked to fill out a survey about lighting after each scenario and two other sets of questionnaires by the end of the third scenario experiment. The questionnaires comprise The Big Five Inventory for personality type, Office Lighting Survey, and Technology Acceptance Model Questionnaire for VR. Additionally, participants will be asked for information about their age, sex, and level of education in the questionnaires. The obtained data from the experiment and questionnaires will be processed using SPSS software. The names of the participants will be coded into the numbers and personal information will be held confidential.

(iv) **What sort of people will the participants be and how will they be recruited? In the case of children state age range. (*Any participant who has not lived through his/her 18th birthday is considered to be a child!*)**

The participants of this study will be volunteers of graduate students and faculty of Interior Architecture and Environmental Design Department in Bilkent University. The minimum number of participants will be 30 people who are aged between 22-40.

*If you are testing children or other vulnerable individuals, state whether all applicants have CRB** clearance*

(v) **What sort stimuli or materials will your participants be exposed to? Tick the appropriate boxes and then explain the form that they take in the space below, please draw attention to any content that could conceivably upset your participants).**

Questionnaires[x]; Pictures[ ]; Sounds [ ]; Words[ ]; Caffeine[ ]; Alcohol[ ]; Other[x].

Other: Immersive virtual environment using HTC Vive Pro Head-mounted display. Some participants may experience motion sickness. Therefore, they will be asked to do a trial and sign a consent form before taking part in the experiment.

---

* Adapted from *www.york.ac.uk/depts/psych/www/research/ethics/HumanProjForm.doc*

** Criminal Records Bureau – Please attach relevant clearance documentation.

N. Adi
M.N.A 2.10.2020

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(vi) Consent Informed consent must be obtained for all participants before they take part in your project. The form should clearly state what they will be doing, drawing attention to anything they could conceivably object to subsequently. It should be in language that the person signing it will understand. It should also state that they can withdraw from the study at any time and the measures you are taking to ensure the confidentiality of data. If children are recruited from schools you will require the permission of the head teacher, and of parents. Children over 14 years should also sign an individual consent form themselves. When testing children you will also need Criminal Records Bureau clearance. Testing to be carried out in any institution (prison, hospital, etc.) will require permission from the appropriate authority. (Please include documentation for such permission.)

Who will you seek permission from?

Participants full permission will be obtained prior to the experiment. All participants will be aged between 22 and 40 years old.

Please attach the consent form you will use. Write the "brief description of study" in the words that you will use to inform the participants here.

The experiment will be conducted using a set of virtual reality (VR) head-mounted display.

The experiment has three scenarios. You are kindly asked to take each scenario on different days with an interval of two days. In each scenario, you will be displayed an office setting where you will be asked to interact with lighting systems if needed. Then, you will read a text of approximately 180 words and answer a question about the text. The question is only to make sure you actually read the text but the answer you provide will not affect you. Also, you will be asked to assess your performance at the end of each scenario. By the end of the experiment, you will be asked to fill out questionnaires about your personality, office lighting, and VR technology.

No personal information will be released at any stage of this research and all your data will be held in confidence by the researcher, and will be deleted after analysing the data. Moreover, you will be given instructions about using the VR technology prior to the experiment.

(vii) Debriefing - how and when will participants be informed about the experiment, and what information you intend to provide? If there is any chance that a participant will be 'upset' by taking part in the experiment what measures will you take to mitigate this?

Participants will be briefed about the study prior to the experiment. Then, each participant will be asked to read and sign a consent form, which explains the procedure. Also, prior to the experiment, they will be given instructions about using the virtual reality technology for the experiment.

(viii) What procedures will you follow in order to guarantee the confidentiality of participants' data? Personal data (name, addresses etc.) should only be stored if absolutely necessary and then only in such a way that they cannot be associated with the participant's experimental data.

All the participants of the study will be asked to sign a consent form to satisfy ethical procedures (See consent form attached). The names of the participants will be coded into the numbers. All personal information of participants obtained during the research will be held in confidence by the researcher. In the information consent form, there is a statement which is signed by the graduate student and the supervisor that "we confirm that the confidentiality and anonymity will be maintained and the participant will not be identified from any publications".

(vii) Give brief details of other special issues the ethics committee should be aware of.

(viii) Tick any of the following that apply to your project

[x] it uses Bilkent facilities;
[ ] it uses stimuli designed to be emotive or aversive;
[ ] it requires participants to ingest substances (e.g., alcohol);
[ ] it require participants to give information of a personal nature;
[ ] it involves children or other vulnerable individuals;
[ ] it could put you or someone else at risk of injury.

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M.N.A 2.10.2020

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Student's signature: ....Parisa Mahmoudzadeh................. date: ......17.09.2020...............
(all students must sign if this is a group project, please initial all other pages)

PM 05/10/20

The signatures here signify that researchers will conform to the accepted ethical principles endorsed by relevant professional bodies, in particular to

Declaration of Helsinki (WMA):
http://www.wma.net/en/30publications/10policies/b3/index.html

Ethical Principles of Psychologists and Code of Conduct (APA):
http://www.apa.org/ethics/code2002.html

Ethical Standards for Research with Children (SCRD):
http://www.srcd.org/about-us/ethical-standards-research

2. Supervisor's assessment (supervisor to complete - circle yes or no)

Yes/No - I confirm that I have secured the resources required by this project, including any workshop time, equipment, or space that are additional to those already allocated to me.

Yes/No - The design of this study ensures that the dignity, welfare and safety of the participants will be ensured and that if children or other vulnerable individuals are involved they will be afforded the necessary protection.

Yes/No - All statutory, legislative and other formal requirements of the research have been addressed (e.g., permissions, police checks)

Yes/No - I am confident that the participants will be provided with all necessary information before the study, in the consent form, and after the study in debriefing.

Yes/No - I am confident the participant's confidentiality will be preserved.

Yes/No - I confirm that students involved have sufficient professional competency for this project.

Yes/No - I consider that the risks involved to the student, the participants and any third party are insignificant and carry no special supervisory considerations. If you circle "no" please attach an explanatory note.

No/Yes - I would like the ethics committee to give this proposal particular attention. (Please state why below)

Supervisor's signature: .... date: 01/10/20

<u>Please e-mail an electronic version of this word processed form (without signatures) along with other application material to the committee to start the evaluation process.</u> Paper copies of all application material, (properly signed where indicated, and initialed on all other pages) should be sent after possible modifications suggested by the committee are finalized.

Bilkent University does not allow the use of students of research investigators as participants. Students who have the potential of being graded by the investigators during or following the semester(s) in which the study is being carried out should not participate in the study. Students may not receive any credit for any university course, with the exception of the GE250/GE251 courses, for their participation. The GE250 and GE251 (Collegiate Activities I and II) courses include an optional activity which encompasses volunteering as a participant in a research project.

Co Supervisor Signature : N. date: 2.10.2020

M.N.A 2.10.2020

PM 05/10/20

ZA. 01/10/20

Bilkent University Informed Consent Form

Please fill in the blanks after read the form carefully.

1 **Name and Surname of the participant:** ____________________

2 **The contact information (adress, e-mail, mobile phone) of the person chosen by the participant in case of any trouble** ____________________

Name of the Research:
ANALYZING OCCUPANTS' CONTROL OVER LIGHTING SYSTEMS IN OFFICE SETTINGS USING VIRTUAL ENVIRONMENTS

The aim, method and the expected benefits of the research

The aim of the study is to analyze the influence of different levels of control over lighting system in an office environment and its effects on the lighting choices of occupants.

The participants of this study will be asked to take part in a 3-phased experiment with immersive virtual environments and fill out some questionnaires. Each phase of the experiment offers a different degree of control over the lighting. After each phase, the participants will assess their own cognitive load, and fill out a questionnaire about lighting satisfaction. By the end of the experiment participants will also fill out questionnaires about personality traits and technology acceptance. All questionnaires were adapted from the literature and they were modified according to the study. No significant risks is foreseen to threat the participants of this study.

Part A

A1	The participants have the right to terminate their participation in the research at any time without any explanation or the participants could be omitted if the researcher finds it necessary.
A2	Participants' decisions to not to volunteer or terminate being part of the research will not influence the nature of the ongoing relationship they may have with the researchers, the involved faculty members, and the nature of their relationship with Bilkent University either now, or in the future.
A3	No personal information will be released at any stage of this research and all the personal data will be held in confidence by the researcher.
A4	Participants should terminate their participantion in case of experiencing any discomfort with the VR system during the study.
A5	The information participants supply, which are directly related to the research, may be published for academic purposes. However, the participants will not be identified and the personal results will remain confidential.
A6	Participants will be chosen from people who those have not mental health disorders to preclude the their cognitive abilities.

Part B – Signatures

B1 **The Participant**

I am ____________________
I have understood the nature of this project and wish to participate. My signatue below indicates my consent.

Signature: ____________________ **Date:** ____________________

B2 **The Researcher**

I am **Parisa Mahmoudzadeh**
I explained the aim, the method and the expected benefits of this research to the participant and I admit to preserve the confidentiality of given infomation by the participant and the results of the research.

Signature: ____________________ **Date:** ____________________

M.N.A 2.10.2020

PM 05/10/20

01/10/20

APPENDIX B

QUESTIONNAIRES

Bilkent University Faculty of Art, Design and Architecture

Department of Interior Architecture and Environmental Design

ANALYZING OCCUPANTS' CONTROL OVER LIGHTING SYSTEMS IN OFFICE SETTINGS USING VIRTUAL ENVIRONMENTS

Master's Thesis Study by Parisa Mahmoudzadeh

Supervisor: Assoc. Prof. Dr. Yasemin Afacan

Co-Supervisor: Assit. Prof. Dr. Mohamad Nadim Adi

Demographic information list

Age:

Sex:

Education:

Department:

Occupation: Student/Faculty member

Note: Your confidentiality will be preserved

Date:

Participant number:

Questionnaire I: Office Lighting Survey

All of statements below refer to work area. Please put a check to the right of each statement if you agree with them. If you disagree, leave them blank.

1) Overall, the lighting is comfortable.

2) The lighting is uncomfortably bright for the tasks that I perform.

3) The lighting is uncomfortably dim for the tasks that I perform.

4) The lighting is poorly distributed.

5) The lighting causes undesired deep shadows.

6) Reflections from the light fixtures hinder my work. agree/disagree

7) The light fixtures are too bright.

Please answer the following question by selecting one of the adjectives:

8) How do you evaluate the lighting compared to the lighting to the similar workplaces you have been to?   worse /same / better

9) Please rate the available lighting for the task performed.

Excellent ☐	Pretty good ☐	Neutral ☐	Not very good ☐	Poor ☐	Not applicable ☐

Official permission obtained from Peter Robert Boyce for adapting the questionnaire from:

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

Questionnaire II: The Big Five Inventory (BFI)

Here are a number of characteristics that may or may not apply to you. For example, do you agree that you are someone who likes to spend time with others? Please write a number next to each statement to indicate the extent to which you agree or disagree with that statement.

Strongly disagree 1	Disagree a little 2	Neither agree nor disagree 3	Agree a little 4	Strongly agree 5

I see myself as someone who...

___1. Is talkative
___2. Tends to find fault with others
___3. Does a thorough job
___4. Is depressed, blue
___5. Is original, comes up with new ideas
___6. Is reserved
___7. Is helpful and unselfish with others
___8. Can be somewhat careless
___9. Is relaxed, handles stress well
___10. Is curious about many different things
___11. Is full of energy
___12. Starts quarrels with others
___13. Is a reliable worker
___14. Can be tense
___15. Is ingenious, a deep thinker
___16. Generates a lot of enthusiasm
___17. Has a forgiving nature
___18. Tends to be disorganized
___19. Worries a lot
___20. Has an active imagination
___21. Tends to be quiet
___22. Is generally trusting
___23. Tends to be lazy
___24. Is emotionally stable, not easily upset ___25. Is inventive
___26. Has an assertive personality
___27. Can be cold and aloof
___28. Perseveres until the task is finished
___29. Can be moody
___30. Values artistic, aesthetic experiences
___31. Is sometimes shy, inhibited
___32. Is considerate and kind to almost everyone
___33. Does things efficiently
___34. Remains calm in tense situations
___35. Prefers work that is routine
___36. Is outgoing, sociable
___37. Is sometimes rude to others
___38. Makes plans and follows through with them
___39. Gets nervous easily
___40. Likes to reflect, play with ideas
___41. Has few artistic interests
___42. Likes to cooperate with others
___43. Is easily distracted
___44. Is sophisticated in art, music, or literature

Questionnaire III: Technology Acceptance Model Questionnaire for VR

Please rate the following items using a scale from 1 to 5:

Strongly disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly agree 5

No.	*Perceived usefulness:*	1	2	3	4	5
1	Virtual reality enabled me to accomplish tasks more quickly.					
2	Virtual reality has improved my quality of work.					
3	Virtual reality makes it easier to do the job.					
4	Virtual reality gives me greater control over the job.					
5	Virtual reality enhances my effectiveness on the job.					
No.	*Perceived ease of use:*	1	2	3	4	5
1	My interaction with the virtual reality has been clear and understandable.					
2	Overall, virtual reality is easy to use.					
3	Learning to operate the virtual reality was very easy for me.					
4	I rarely become confused when I use virtual reality.					
5	I rarely make errors when I use virtual reality.					
6	I am rarely frustrated when using virtual reality.					
No.	*Intention to use:*	1	2	3	4	5
1	Assuming I had access to virtual reality system, I intend to use it.					
2	I predict that I would use virtual reality frequently.					
No.	*Perceived enjoyment:*	1	2	3	4	5
1	Virtual reality is fun to use.					
2	Virtual reality is pleasant.					
3	I would like to repeat the same experience.					
4	It was an interesting experience.					

Official permission obtained from Dilay Seda Özgen for retrieving the questionnaire from:

Özgen, D. S. (2018). Asessing usability of virtual reality for basic design education (Master's thesis, Bilkent University, Ankara, Turkey). Retrieved from http://hdl.handle.net/11693/4773

APPENDIX C

NASA TLX

Date:

Participant number:

Subjective perceptions of cognitive load: *NASA TLX Rating Scale Description*

Title	End points	description
Temporal Demand (TD)	Low/High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance (PR)	Good/Poor	How successful do you think you were in accomplishing the goals of the task set by the experimenter? How satisfied were you with your performance in accomplishing these goals?
Effort (EF)	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration Level (FR)	Low/High	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

*Select the member of each pair that provided the most significant source of workload variation during the task:

TD / PR
TD / EF
TD / FR
PR / EF
PR / FR
EF / FR

***** Place give each factor a scale from o to 10 that represents the magnitude it in the task you just performed:

- Temporal Demand (**1** being the **lowest** and **10** being the **highest**)
- Performance (**1** being the **best** and **10** being the **poorest**)
- Effort (**1** being the **lowest** and **10** being the **highest**)
- Frustration Level (**1** being the **lowest** and **10** being the **highest**)

APPENDIX D

TEXTS AND QUESTIONS FOR THE TASK SCENARIOS

Scenario I:

The geologic history of the Mediterranean

In 1970 geologists Kenneth J. Hsu and William B. F. Ryan were collecting research data while aboard the oceanographic research vessel Glomar Challenger. An objective of this particular cruise was to investigate the floor of the Mediterranean and to resolve questions about its geologic history. One question was related to evidence that the invertebrate fauna (animals without spines) of the Mediterranean had changed abruptly about 6 million years ago. Most of the older organisms were nearly wiped out, although a few hardy species survived. A few managed to migrate into the Atlantic. Somewhat later, the migrants returned, bringing new species with them. Why did the near extinction and migrations occur?

Another task for the Glomar Challenger's scientists was to try to determine the origin of the domelike masses buried deep beneath the Mediterranean seafloor. These structures had been detected years earlier by echo-sounding instruments, but they had never been penetrated in the course of drilling. Were they salt domes such as are common along the United States Gulf Coast, and if so, why should there have been so much solid crystalline salt beneath the floor of the Mediterranean?

Which of the following is NOT mentioned in text as a change that occurred in the fauna of the Mediterranean?

1. Most invertebrate species disappeared during a wave of extinctions.
2. A few hardy species wiped out many of the Mediterranean's invertebrates.

3. Some invertebrates migrated to the Atlantic Ocean.
4. New species of fauna populated the Mediterranean when the old migrants returned.

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Scenario II:

Extinction of the dinosaurs

Paleontologists have argued for a long time that the demise of the dinosaurs was caused by climatic alterations associated with slow changes in the positions of continents and seas resulting from plate tectonics. Off and on throughout the Cretaceous (the last period of the Mesozoic era, during which dinosaurs flourished), large shallow seas covered extensive areas of the continents. data from diverse sources, including geochemical evidence preserved in seafloor sediments, indicate that the Late Cretaceous climate was milder than today’s. The days were not too hot, nor the nights too cold. The summers were not too warm, nor the winters too frigid. The shallow seas on the continents probably buffered the temperature of the nearby air, keeping it relatively constant.

At the end of the Cretaceous, the geological record shows that these seaways retreated from the continents back into the major ocean basins. no one knows why. Over a period of about 100,000 years, while the seas pulled back, climates around the world became dramatically more extreme: warmer days, cooler nights; hotter summers, colder winters. Perhaps dinosaurs could not tolerate these extreme temperature changes and became extinct.

Which of the following is true of the Late Cretaceous climate?

1. Summers were very warm and winters were very cold.
2. Shallow seas on the continents caused frequent temperature changes.
3. The climate was very similar to today's climate.
4. The climate did not change dramatically from season to season.

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Scenario III:

Agriculture, iron, and the Bantu people

There is evidence of agriculture in Africa prior to 3000 *B.C.* It may have developed independently, but many scholars believe that the spread of agriculture and iron throughout Africa linked it to the major centers of the Near East and Mediterranean world. The drying up of what is now the Sahara Desert had pushed many peoples to the south into sub-Saharan Africa. These peoples settled at first in scattered hunting and-gathering bands, although in some places near lakes and rivers, people who fished, with a more secure food supply, lived in larger population concentrations. Agriculture seems to have reached these people from the Near East, since the first domesticated crops were millets and sorghums whose origins are not African but West Asian. Once the idea of planting diffused, Africans began to develop their own crops, such as certain varieties of rice, and they demonstrated a continued receptiveness to new imports. The proposed areas of the domestication of African crops lie in a band that extends from Ethiopia across southern Sudan to West Africa. Subsequently, other crops, such as bananas, were introduced from Southeast Asia.

Why do researchers doubt that agriculture developed independently in Africa?

1. African lakes and rivers already provided enough food for people to survive without agriculture.
2. The earliest examples of cultivated plants discovered in Africa are native to Asia.
3. Africa’s native plants are very difficult to domesticate.
4. African communities were not large enough to support agriculture.

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