EFFECTS OF LIGHT-EMITTING DIODE (LED) LIGHTING COLOR ON HUMAN EMOTION, BEHAVIOR, AND SPATIAL IMPRESSION

By

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ABSTRACT

EFFECTS OF LIGHT-EMITTING DIODE (LED) LIGHTING COLOR
ON HUMAN EMOTION, BEHAVIOR, AND SPATIAL IMPRESSION

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With the rapid advancement of light-emitting diode (LED) lighting technology, the use of colored LED lighting has increased tremendously. However, few studies have examined the actual effects of lighting color in interior spaces. The purpose of this study was to investigate the effects of six colors of LED lighting (i.e., red, green, blue, yellow, orange, and purple) (1) on occupants' emotional states (i.e., pleasure and arousal) and behavioral intentions (i.e., approach or avoidance), and (2) on spatial impressions (i.e., cheerfulness, attractiveness, comfort, pleasantness, relaxation, and warmness/coolness) based on the Mehrabian and Russell's M-R model (1974). Additionally, this study examined (3) the impact of socio-demographics (i.e., gender, age, and cultural background) on color preference of LED lighting.

An experimental research project was conducted with 101 participants using a voluntary sampling method. The experiment measured participants' emotional states, behavioral intentions, spatial impression, and color preference under six different colors of LED lighting. One-way Analysis of variance (ANOVA) and regression analysis were conducted to analyze the collected data.

The results of the study demonstrated that LED lighting colors significantly affect people's emotional states, behavioral intentions, and spatial impressions. Cultural differences in color preference of LED lighting was significant, whereas no significant differences in gender or age were identified.

This study contributes to the body of knowledge on color and lighting studies and provides greater insight into the application of the M-R model. The findings are also expected to provide the basis for developing practical guidelines on usage of emotional lighting color for design professionals.

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CHAPTER 1

INTRODUCTION

Americans spend nearly 90% of their time indoors. According to the National Human Activity Pattern Survey (Klepeis et al., 2001), Americans spend 86.9% of their time indoors, 5.5% of their time in a vehicle, and the remaining 7.6% outdoors. As people spend most of their time inside, the indoor environment has become increasingly important for occupants' health, comfort, behavior, and overall well-being (Charlotte, 1992; Hwang, 2010; Igor, 2000; Lee, 2009; Önder, 2011; Read, 1996; Robert, 1992; Sansal, 2012; Salamone et al., 2009).

Among the different design elements of interior spaces, color and lighting have been documented as influential factors, both psychologically and physiologically, in people's lives. Multiple studies showed that interior color and lighting have significant effects on arousal (Kaufman, 2003; Park, Pae, & Meneely, 2010; Wu & Wang, 2015), cognitive performance (Igor, 2000; Igor, 2002; Lee, 2009; Robert, 1992; Sansal, 2012), health (Charlotte, 1992; Hwang, 2010; Salamone et al., 2009), memory (Dzulkifli & Mustafar, 2013; Kuhbandner & Pekrun, 2013), mood (Igor, 1995; Rikard, 2007), and behavior (Önder, 2011; Read, 1996; Bornstein, 1973; Cena et al., 2009; Valdez & Mehrabian, 1994).

Rapid advancements in light-emitting diode (LED) technology have increased people's interest in the use of colored LED lighting for interior spaces and building exteriors (Yam & Hassan, 2005). Because of its energy efficiency, LED lighting is an attractive alternative light source and it is already being used as a replacement for older forms of lighting such as incandescent or fluorescent light bulb. In addition to energy efficiency, LED lighting offers a variety of benefits including design flexibility, easy operation, and a wide range of colors. The use of colored LED lighting has increased tremendously because it is quick and easy way to create a dynamic atmosphere in an interior space.

However, despite a sharp increase in interest in the use of colored lighting in interior spaces, little is known about how lighting colors affect people's perceptions and behaviors. Although the effects of color and lighting on people's lives have long been recognized, there is a lack of empirical research on how people perceive lighting colors. With the absence of practical guidelines on how to most effectively use lighting colors, design professionals and technicians tend to use colored lighting based on their previous experience and intuition without any theoretical grounding (Laganier & van der Pol, 2011). As the use of colored LED lighting is expected to continuously increase, it is important to identify how people experience colored-lighting in interior spaces.

To examine how various features of interior environments such as color, lighting, music, scent, temperature, and layout affect occupants' emotions and behaviors, Mehrabian and Russell developed a framework called the Stimulus-Organism-Response (S-O-R) paradigm in their book, *Approach to Environmental Psychology* (1974). According to the S-O-R paradigm, also called the Mehrabian and Russell model (M-R), users have three emotional states (i.e., pleasure, excitement, and dominance) in response to environmental stimuli, and these emotional states influence two contrasting behaviors (i.e., approach or avoidance).

The M-R model (1974) has been used extensively to examine the effect of the physical environment on occupants' emotional and behavioral responses. Since the original M-R model was developed, researchers have extended and adapted the M-R model for use in their studies by focusing on other aspects such as spatial impression, satisfaction, perceived value, or quality of a space, in a place of emotional states (e.g., Countryman & Jang, 2006; Tantanatewin & Inkarojrit, 2018; Wu & Wang, 2015). However, few empirical studies have employed this model in a colored lighting context, although both the original and the extended M-R model have been demonstrated as effective frameworks in many studies (Laganier & van der Pol, 2011). Thus, it is meaningful to examine how people are affected by different colors of interior lighting by applying M-R model.

The Purpose of the Study

Given the research gaps and absence of theoretically based design guidelines, the primary purpose of this study is to examine the effects of LED lighting color on emotions and behavioral intention. According to the M-R model (1974), environmental stimuli affect occupants' emotional states, which, in turn, influence their behavioral responses, which suggests the mediating effects of emotional states (i.e., pleasure and arousal) between environmental stimuli and behavioral responses (i.e., approach or avoidance). By employing an experiment, this study aims to measure the effects of six colors of LED lighting (i.e., red, green, blue, yellow, orange, and purple) on emotional states (i.e., pleasure and arousal) and behavioral responses (e.g., approach or avoidance) based on the M-R model (1974).

The second purpose of this study is to explore the effects of six colors of LED lighting on six spatial impression (i.e., cheerfulness, attractiveness, comfort, pleasantness, relaxation, and warmness/coolness) based on the extended M-R model and findings of previous lighting studies.

The third purpose of the study is to examine the effects of socio-demographic features on color preference of LED lightings. To achieve the purpose of the study, specific research questions and hypotheses to be tested along with the conceptual framework are developed and presented in the next chapter.

Significance of the Study

Theoretically, this study attempts to contribute to the body of knowledge on color and lighting. Although past studies have looked at the effects of color and lighting, few studies have examined the effects of lighting color on human emotions and behaviors as well as spatial impressions. The findings of this study are expected to provide people with a better understanding of the effects of color, lighting, and colored lighting in interior spaces. In addition, this study extends existing knowledge on the application of the M-R model. Although there has been extensive research on the effects of various environmental stimuli (e.g., store environment, atmosphere, product quality, music, signage layout) on emotional states and behavioral responses using the M-R model, few studies have focused on the effects of lighting color as an environmental stimulus. By investigating the effects of lighting color on emotional states and behavioral intention, this study is expected to provide greater insight into the application of the M-R model.

Practically, the findings of this study can provide the basis for developing design guidelines for design professionals. This study is expected to help design professionals understand better clients' perceptions toward lighting color and create interior lighting that can increase positive behavioral responses. The effective use of lighting colors in interior spaces such as restaurants, hotels, retail spaces, or other service facilities may enhance the occupants' pleasant experiences, which can lead to increased revenue and profits for business owners. The findings of this study are expected to provide good guidelines not only for professionals but also for individual users to design their personal space with colored lighting. This study is also expected to facilitate the use of LEDs, resulting in time, resources, and energy savings. Instead of using paint colors to change the impression of the interior space, changing the interior color with LED lightings can be faster, easier, and more energy saving.

Organization of the Dissertation

Chapter one presents a general background for the present study and its purpose and significance. Chapter two reviews relevant literature and conceptual framework with research questions based on theoretical background. The methodological specifications of this study including research design, experiment procedures, and data analysis are detailed in Chapter Three. The findings of this study are reported in Chapter Four. Finally, study results are discussed and implications derived from these findings are outlined in Chapter Five.

CHAPTER 2

LITERATURE REVIEW

This chapter consists of five sections. The first section introduces the fundamentals of color including color theory, basic terms, and principles. The second section explicates the basics of lighting for the better understanding of the research. In the third section, related studies are reviewed including studies on the effects of color and lighting, impression of the space, and color preference by gender, age, and cultural background. The fourth section provides the theoretical background of the study including an explanation of the M-R model and related studies. The conceptual framework of the study, research questions, and hypotheses are included in the last section.

Fundamentals of Color

Color Theory Basics

Color is a characteristic of a substance or object determined by the light it reflects (Best, 2017). As waves of light are received in the lens of the eye, they are understood by the brain as color. The perception of a colored object is due to the reflection of light from the surface of the object (Hornung, 2012). An apple is recognized as red because it reflects only red wavelengths while absorbing waves of other light frequencies.

Additive and subtractive colors. There are two different methods for mixing color, the additive color process and the subtractive color process. An additive color process is used for intermixing lighting colors whereas the subtractive color process is used for spectral colors in pigments. Two different sets of primary colors are used when understanding additive and subtractive colors: red, green, and blue (RGB) and cyan, magenta, yellow, and black (CMYK). RGB are the primary colors for light and CMYK are the primary colors for pigment. When all colors of lighting are combined, the result becomes white lighting. For pigments, the color becomes black when all colors are mixed (see Figure 1).

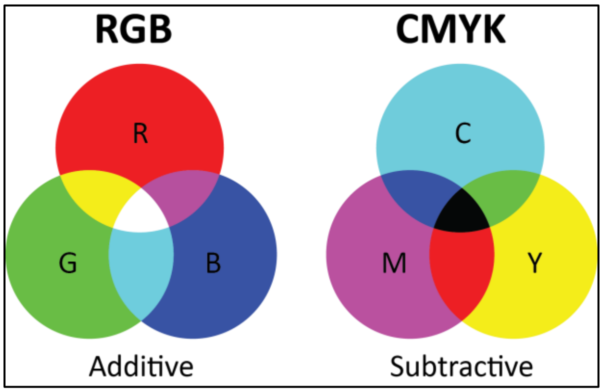
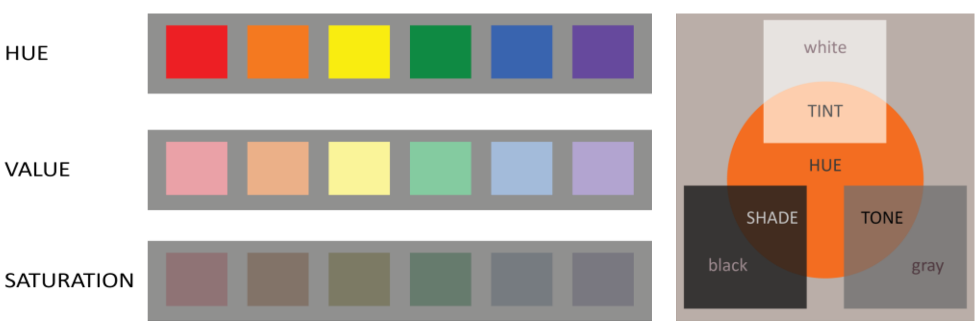


Figure 1. Additive & Subtractive colors

Color vocabulary. Figure 2 indicates examples of hue, value, and saturation and the relationship between tint, shade, and tone. A hue is used to designate the common name of a color and indicate its position in the spectrum on the color wheel. A value is the lightness or darkness of a color. A saturation, also known as chroma, refers to the purity of a color (Hornung, 2012). A tint is a color lightened by adding white. A shade is a color darkened by adding black. A tone is a color mixed with gray.



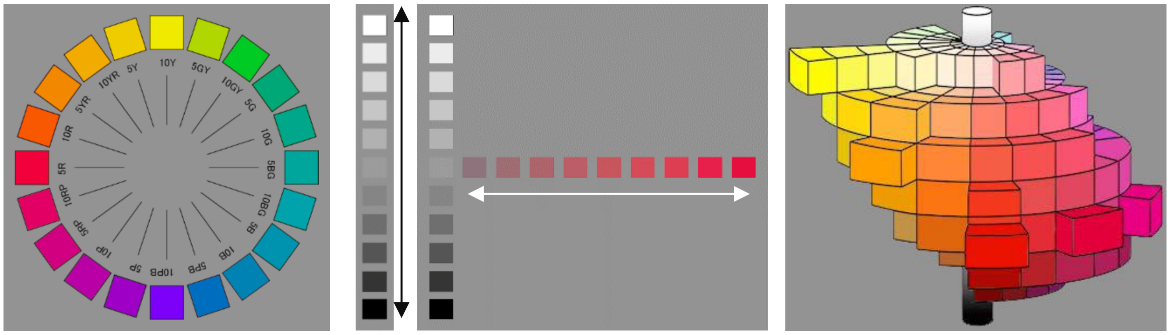
(1) Hue, Value, & Saturation (2) Tint, Shade, & Tone

Figure 2. Examples of hue, value, & saturation (1) and tint, shade, & tone (2)

Color Order System

A color order system is a set of principles that arrange and categorize colors according to certain rules for the ordering and denotation of colors (Choudhury, 2014; Nemcsics & Caivano, 2014). Since about 350 BC, more than 400 color order system have been proposed. The most well-known color system that has been used for a long time and worldwide is Munsell's color order system. More recently, the Natural Color System (NCS) has become preferred in design fields because it is easy to predict the color by its name.

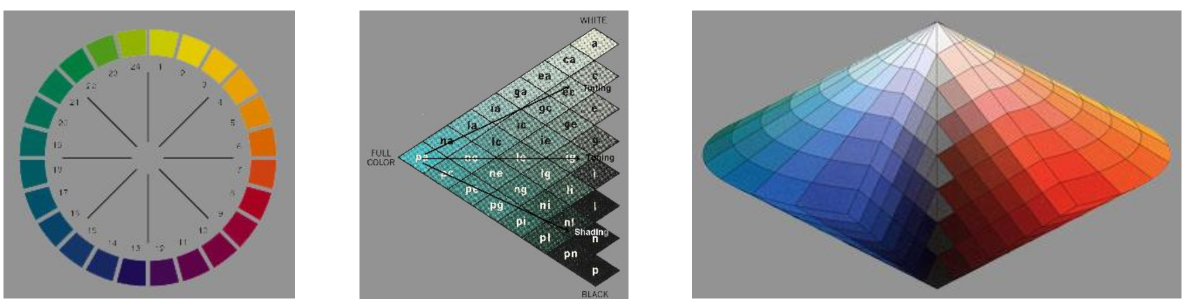
Munsell color system. Munsell's color order system contains three dimensions of color: Hue, Value, and Chroma (see Figure 3). Hues are separated into 20 equal steps on the Munsell's color order system. Twenty divisions in the circular form are expressed by the initial letter, for example, R for red, and BG for blue-green. Munsell assigned decimal numbers between divisions for people to easily predict where the given color falls on the model. He determined 20 steps of hues: 5R, 10R, 5YR, 10YR, 5Y, 10Y, 5GY, 10GY, 5G, 10G, 5BG, 10BG, 5B, 10B, 5PB, 10PB, 5P, 10P, 5RP, and 10RP (see Figure 3-1). The scale of value is expressed as a vertical pole and serves as an axis to the circle of hues. It consists of black at the lowest end (representing total absence of light) and white at the top (representing pure light). Black is numbered as 0, the darkest gray is 1, which continues to the lightest gray as 9, and pure white is 10 (see Figure 3-2). Chroma is expressed as a horizontal axis, which intersects the value pole within the hue circle (see Figure 3-3). Chroma describes any one of these hues on the circumference of the band growing inward toward the gray pole in the center, becoming grayer or weaker in color strength until it reaches its center pole and loses its color entirely (Munsell, 1937). The strongest red is twice as powerful as the strongest blue-green because colors differ by nature in their chroma strength, which explains the asymmetrical form of a three-dimensional model (see Figure 3-4).



(1) Hue (2) Value (3) Chroma (4) Color Order System model

Figure 3. Munsell's color order system (Munsell, 1937)

Many scholars and institutions have adapted Munsell's color order system. For instance, Ostwald color system looks very similar to Munsell's as indicated in Figure 4. The difference between the two systems is that Ostwald's system contains a symmetrical figure of a three-dimensional model.

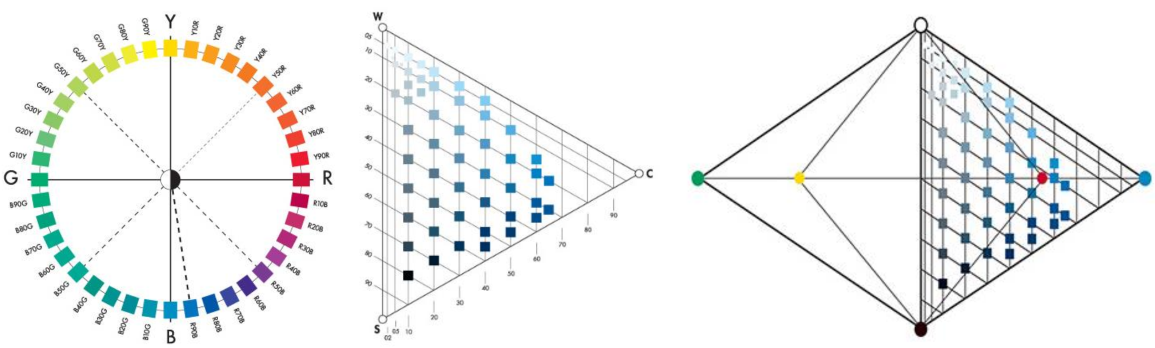


(1) Hue (2) Value & Chroma (3) Color Order System Model (double-cone)

Figure 4. Ostwald's color order system (Source: http://yousense.info/77696c68656c6d/wilhelm-ostwald-colorsystem.html)

Natural color system (NCS). The NCS was developed by the Swedish Color Centre Foundation in 1964 (see Figure 5). The NCS is a logical color system based on the way people view colors. The major difference between the NCS and Munsell's color system is that the NCS is based entirely on the phenomenology of human perception rather than color mixing, which makes it much easier to predict the color by its name and thus communicate better with it. There are four chromatic elementary colors: yellow (Y), red (R), blue (B), and green (G). Two neutral elementary colors are white (W) and black (S). All colors can be represented in terms of their degree of closeness to the elementary colors.

The NCS color system also includes three-dimensional color space. The horizontal view of the color space is a color circle with four chromatic primary colors (i.e., yellow, red, blue, and green) placed on the points of the compass (see Figure 5-1). Each color on the circle is expressed as a combination of letters and number. For example, Y20R means colors in this hue have 20% resemblance to red and 80% resemblance to yellow. A vertical section through the color space is the NCS Color Triangle (see Figure 5-2).



(1) NCS color circle (2) NCS color triangle (3) NCS color space

Figure 5. Natural color system (Source: https://ncscolour.com/)

On the NCS color triangle, it is possible to find different nuances of the hue. The points of the triangle represent whiteness (W), blackness (S), and chromaticness (C) of the color. The scales are divided into 100 steps for each, which can be perceived as percentages in the color circle. An example of NCS notation is S1050-R90B. S means that the color is part of the NCS system. The first part of the code 1050 describes that the color has 10% blackness and 50%

chromaticness. The second part, R90B means that colors in this hue have 10% resemblance to red and 90% resemblance to blue.

Color Emotion and Image Scale

It has been shown that there is a common impression or feeling for each color even though the images and meanings that people perceive from colors differ from individual to individual (Kobayash, 1981). Many scholars have observed universal psychological associations with the aesthetic values related to basic hues and neutral colors. Table 1 indicates one of the examples developed by Goethe in 1971.

Table 1. *Universal Psychological Color Associations (Goethe, 1971)*

Color		General Associations
Red		Strength, dynamism, brutal, warm, power, hot, exciting, tension, love, hate, war, active, erotic, triumph, and Mars.
Green		Sympathy, hope, soft, pacific, tranquil, thinking, mediation, cool, fresh, health, hope of new life, and fields.
Blue		Vertical, height, depth, deep, relaxed, mature, inner life, not violent, quiet, cold, wet, feeling blue, mental depression, clear, cool, transparent, summer, and water.
Yellow		Intuition, intellect, luminous, brightest, young, vivacious, extrovert, coward, caution, warmth, joy, sickness, and spring.
Orange		Radiation, communication, receptive, warm, intimate, fireplace, joy, happy, dynamic, cheerful, and autumn.
Purple		Nostalgia, memories, power, spirituality, sublimation, melancholia, meditative, mystical, thought, and aesthetic.

As a practical guideline for the use of colors, Kobayashi (1981) and the Nippon Color and Research Institute (NCD) in Japan developed a color image scale (see Figure 6). By visually illustrating the common impressions and feelings for colors, the color image scale is used as an effective tool for design professionals. Two axes of the color image scale represent warm-cool and soft-hard. Munsell's color system was used to identify 140 colors that are placed in the color image scale.

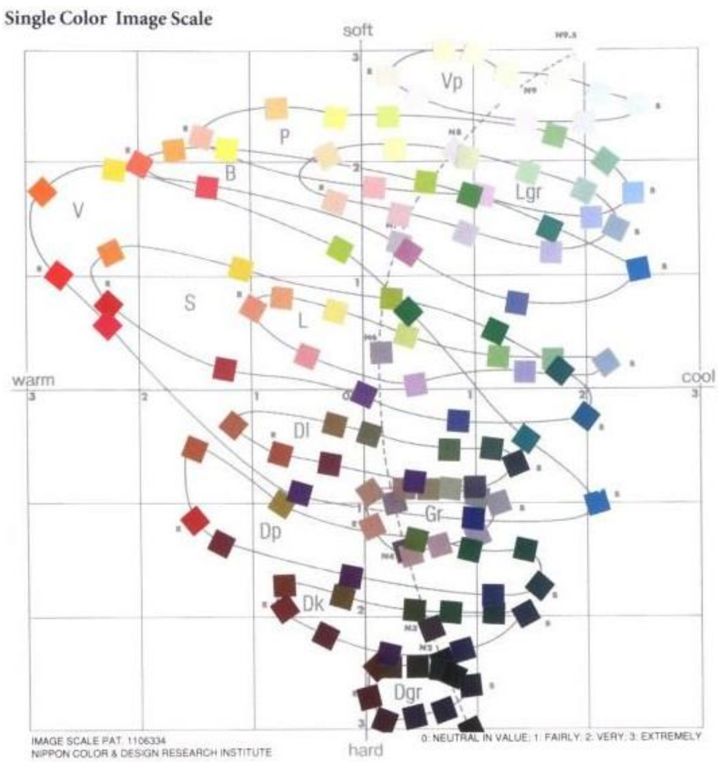


Figure 6. Kobayashi's Color Image Scale (Kobayashi, 1981)

Basics of Lighting

Lighting Perception

Visible light. What people perceive as light is the electromagnetic spectrum that the human eye can view. Only wavelengths in a limited range of the full spectrum stimulate receptors in the eye to permit vision. The range of wavelengths is typically from 380 to 760 nanometers, which is called visible light or visible energy (Gordon, 2015). Light of a specific wavelength determines the color and all colors of the rainbow are determined within the visible light spectrum. The shortest visible wavelengths between 380 and 450 nm appear as violet, whereas the longest wavelengths between 630 and 780 nm appear as red. All other colors appear between violet and red (see Figure 7).

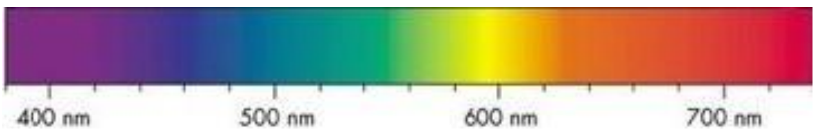
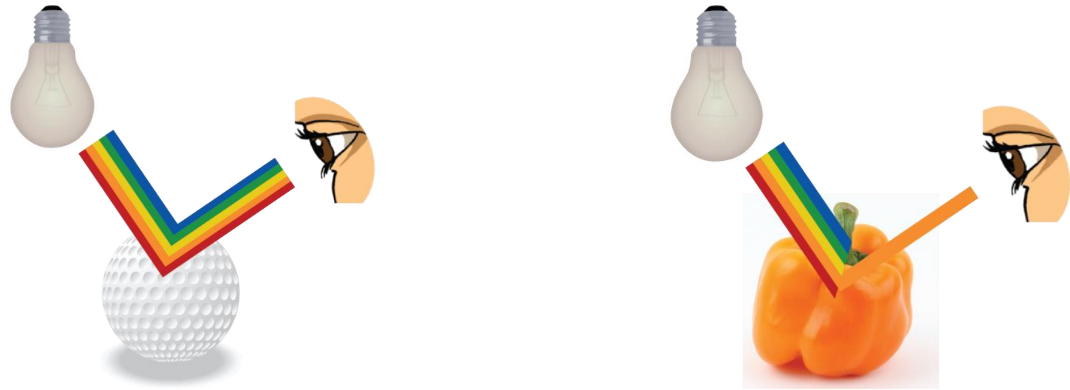


Figure 7. Visible light spectrum (Gulley, 2011)

Color perception. The retina of the eye contains cells called rods and cones: rod cells are very sensitive to dim light and perceive the lightness of the object, whereas cone cells are sensitive to bright light and allow for color vision. Red, green, and blue are the three types of cone cells. These light sensors detect different ranges of light frequencies and roughly correspond to the red, green, and blue parts of the spectrum. All other colors can be produced by combining the light of these primary colors in various amounts (Sudjic, 1985).

The color of an object or surface is perceived in the eye based on which part of wavelengths is reflected or transmitted (Gordon, 2015). For instance, a white golf ball appears white in the eye because it reflects all the wavelengths from all parts of the spectrum (see Figure 8-1). An orange pepper appears orange because it absorbs most of the light waves except the orange part of the spectrum (see Figure 8-2).



(1) White color perception (2) Orange color perception

Figure 8. Relationship among light source, object and eyes in perceptual process (Burns, 2000; Hornung, 2012)

Color temperature of lighting. The color temperature of lighting is the temperature of a blackbody at which it emits light of color that corresponds to the color of light source (Color temperature, 1915; Gordon, 2015). It is measured in degrees of Kelvin (K), which is a scale that starts at absolute zero. A Kelvin degree increases when a blackbody is heated and the color of the light changes from red (1,000 – 1,800 K) to yellowish white (2,500 – 2,800 K), to daylight white (5,000 K), to bluish white (6,500 – 7,500 K), to brilliant blue (8,000 – 12,000 K). Commonly used incandescent lamps produce a continuous full spectral distribution (Gordon, 2015). Figure 9 indicates how the color of lighting changes by its Kelvin degree.

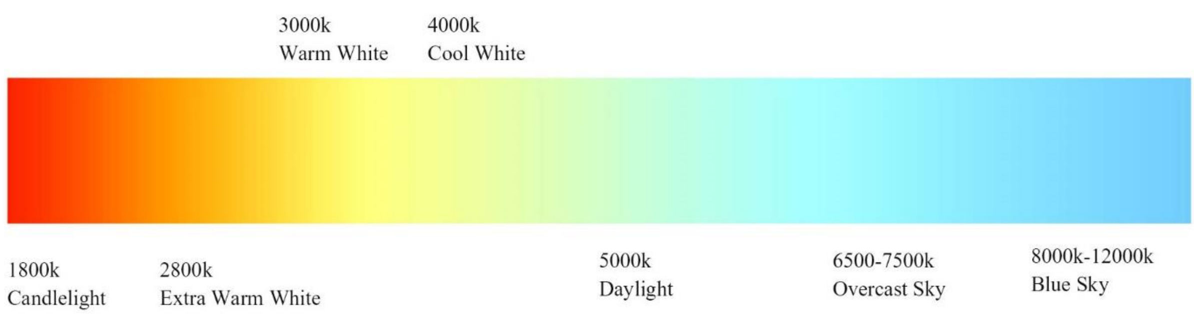


Figure 9. Color change of lighting by Kelvin. (Source: https://www.upshine.com/blog/what-is-the-best-color-temperature-for-office.html)

Light Source

Development of light source. Before electric lighting was invented oil lamps and candles were common tools. Gaslights were used in the 19th century, which made it easier to read and write or do things in the evening (Bowers, 1998). All of these light sources depended on a flame until electric lighting was invented. Well-known American inventor Thomas Alva Edison was one of the incandescent lighting inventors. After hundreds of tries, Edison and his team finally made their first successful lamp in October 1879.

The next form of lighting was fluorescent lighting, which has been commonly used in interior spaces. It is available in a wide range of shapes, sizes, and colors (Bowers, 1998). Incandescent and fluorescent lighting are still widely used in indoor and outdoor spaces, such as schools, offices, hospitals, and residences. However, incandescent lights are inefficient because they waste a lot of energy as heat. They also break easily and do not last very long. Fluorescent lights are more energy efficient and they last longer compared to incandescent lights. However, fluorescent lights contain toxic chemicals and are easily broken. LED lighting, a new and better product to traditional forms of lighting, is starting to replace these older models (Mangesh, 2019).

Light Emitting Diode (LED) lighting. Interest in LEDs and use of LED lighting is continuously increasing worldwide. Advancement of LED technology and declined prices result in LED lighting market growth. According to the report from the U.S. Department of Energy [DOE] (2014), LED lighting would achieve a market share of 68% of sales in 2020 and over 90% by 2030. India LED industry expects to see 15% growth for the next two years according to a news from CNBC (Shenoy, 2018). The LED market in Japan is expected to grow about 18%

over the period of 2014 to 2019 as stated in the analysis from a global technology research company, Technavio (2014, December).

A major benefit of using LEDs as a light source are their energy efficiency. According to the DOE (2014), it is expected that LED will reduce consumption of light energy by 15% in 2020 and 40% in 2030, saving more than $2.6 billion by reducing 261 TWh (terawatt hours) in 2030 alone. LED technology can generate large amounts of light for only a fraction of the energy required for incandescent or fluorescent bulbs. Compared with other light sources that rely on thermal radiation, LED lighting does not release the majority of energy input as heat energy and is therefore much more efficient. The DOE (2014) has estimated that if all currently in-use incandescent and fluorescent bulbs were replaced with LED bulbs, the potential cumulative energy savings from 2013 to 2030 could be over 2,216 terawatt hours, worth over $220 billion.

In addition to energy efficiency, LEDs have other advantages. LED lights are ecologically friendly because they are free from toxic chemicals (Daniel, 2012). Fluorescent light bulbs contain materials that are dangerous to the environment, such as mercury. LEDs are ideal for operation under extreme cold or hot temperatures, which means they are suitable for outdoor lighting systems as well (Daniel, 2012). They also brighten immediately, which has great advantages for traffic signal lights and vehicles (Whitaker, n.d.).

Another important characteristic of LED lighting is its design flexibility. LEDs can be combined in various shapes to produce highly efficient illumination. Individual LEDs can be dimmed resulting in dynamic control of light, color, and distribution (Daniel, 2012). Moreover, unlike traditional lighting, LED lighting can express a wide range of colors, which is a great quality that allows designers to easily integrate LED lighting into their designs (Daniel, 2012).

With many advantages, the use of LED lighting became more and more popular for indoor and outdoor environments (see Figure 10).

(1) (2) (3)

(1) Switch restaurant in Saudi Arabia and (2) Morimoto restaurant in USA designed by Karim Rashid. (Source: http://www.karimrashid.com) (3) Beijing Olympic Stadium designed by Herzog & De Meuron. (Source: https://en.wikipedia.org/wiki/Beijing_National_Stadium)

Figure 10. Examples of colored LED lighting application

Effects of Color and Lighting

The effects of color and light of interior space have been examined in many studies because color and light are key elements of interior design that affect emotion and space perception (e.g., Bellizzi, Crowley, & Hasty, 1983; Quartier, Vanrie, & Van, 2014). The effects of color and lighting on emotion and behavior are overwhelmingly dominant among previous studies (e.g., Al-Ayash, Kane, Smith, & Green-Armytage, 2016; Kim & Moon, 2009; Magnini & Kim, 2016; Quartier et al., 2014; Siamionava, Slevitch, & Tomas, 2018; Wu & Wang, 2015; Yildirim, Çapanoğlu, Çağatay, & Hidayetoğlu, 2015). However, few studies have examined the effects of lighting colors (e.g., Abbas, Kumar, & Mclachlan, 2006; Odabaşioğlu, 2009).

Effects of Color

Physiological effects of color. Many earlier studies on the effects of color focused on the physiological effects on nervous system functions such as heart rate, respiration, and skin response. Studies have shown that cool colors (e.g., green and blue) tend to have calming effects on people, while warm colors (e.g., red and yellow) tend to have arousal effects (Gerard, 1958; Jacobs & Hustmyer, 1974; Kaufman, 2003; Wilson, 1966). Wilson (1966) found red to be more arousing than green on skin response. Jacobs and Hustmyer (1974) partially supported Wilson's (1966) findings by proving that red is significantly more arousing than blue but found no significant difference between red and green. Similarly, Kaufman (2003) investigated the physiological effects of colors by measuring people's EMG (smile and frown), EKG (heart rate), and skin conductance measurements when exposed to various colored trees. The results showed that the presence of green trees is physiologically calming whereas the presence of plants with yellow and red colors is physiologically arousing.

Psychological effects of color. More recent studies have addressed the psychological effects of indoor colors. Studies found that interior colors significantly related to people's emotions and perceptions. The majority of color studies demonstrated that people perceived cool colors more positively than warm colors. Yıldiırım, Akalın-Baskaya, and Hidayetoğlu (2007) conducted two-stage experiments in a café/restaurant setting to measure participants' mood in a room with yellow walls in the first stage and violet walls in the second stage. Participants completed a questionnaire of eight semantic differentials (i.e., roomy/cramped, high/low, pleasant/unpleasant, attractive/unattractive, interesting/boring, imposing/poor-looking, calm/restless, and warm/cold). The findings indicated that people had more positive perceptions about violet interiors than yellow interiors.

Similar research by Yildirim et al. (2015) also confirmed that people perceive blue more positively than pink. They investigated whether three different colors on the interior walls of the classrooms would impact the perceptual performance of male students. The experiment was conducted in classrooms, each painted in cream, blue, and pink (see Figure 11). Eleven semantic differential scales regarding the perception of the classroom environment (i.e., happy-unhappy, roomy-cramped, peaceful-non-peaceful, warm-cold, light-dark, attractive-unattractive, pleasant-unpleasant, exciting-unexciting, dynamic-static, calm-restless, and comfortable-comfortless) were given to the participants to answer. The findings were in line with the results of other studies showing that students perceived blue-walled classrooms more positively than both pink-walled and cream-walled classrooms.

Figure 11. Classrooms with different colors: cream, blue, and pink (Yildirim et al., 2015)

Another experiment conducted by Al-Ayash et al. (2016) also verified that blue had more positive effects on people's perception than warm colors. They investigated how pale and vivid tones of blue, red, and yellow influenced participants' emotions. Their findings revealed that blue color conditions put the participants into a more positive state. Both pale and vivid blues were rated more pleasant, fresh, calming, relaxing, cooler, lighter, more interesting, and less sharp, compared to yellow and red. Twenty-three students participated in the experiment in two experimental rooms. A control room with light gray walls and ceiling and furnished with a table and two chairs served as a neutral. Corflute panels on the wall were used to manipulate the room colors. The panels were painted in vivid red, vivid yellow, vivid blue, pale red, pale yellow, and pale blue (see Figure 12). Participants were given seven-point, semantic differential rating scales (dark-light, pleasant-unpleasant, fresh-stale, heavy-light, calm-exciting, dull-sharp, tense-relaxed, warm-cool, and interesting-boring) to answer. The results showed that both hue and whiteness had a strong influence on the participants' emotional reactions.

Figure 12. The six colors used in the study: pale blue, pale yellow, pale red, vivid blue, vivid yellow, and vivid red (Al-Ayash, Kane, Smith, & Green-Armytage, 2015)

Inconsistent with the results of aforementioned studies, other studies found different results on effects of colors on participants' perceptions. In a restaurant setting, Magnini and Kim (2016) found no significant effects of two different background colors on consumers' perceptions. Unusually, gold and white were used in the study as stimuli. Siamionava et al. (2018) discovered that red hotel rooms increased arousal levels of participants, but there was no difference between hotel rooms of red color and blue color in terms of the pleasure level of the guests.

Effects of Lighting

Studies found that lighting, as well as color, has significant effects on people in various ways such as social interaction, memory, perception, emotion, and behavior (Baron et al., 1992; Gifford, 1988; Knez, 2001; Miwa & Hanyou, 2006; Park & Farr, 2007; Quartier et al., 2014; Wu & Wang, 2015). According to Gifford (1988), lighting levels affect people's social interaction. In his study, Gifford explored how indoor lighting conditions influence communication between two participants, and he found that brighter lighting increased communication while dim lighting decreased communication. The finding indicated that people feel more relaxed and intimate under dim lighting, and bright lighting makes people more active.

On the other hand, Miwa and Hanyu (2006) found that people tend to share more information and have higher rates of self-disclosure in dim lighting conditions. They investigated the effects of dim and bright light settings in a counseling room on participants' self-disclosure and impressions of the counselor. They suggested that the lighting intensity can affect communication and relationships between people by showing that dim incandescent lighting not only yields more self-disclosure but is also more pleasant and calming than bright fluorescent lighting. Similarly, it was found that subjects disclosed at a more intimate level in an intimate room with indirect lighting through a floor lamp and small table lamp, compared to a room with overhead fluorescent light (Chaikin et al., 1976).

Knez (2001) investigated the effects of lighting color temperature (i.e., warmness and coolness) on participants' mood, memory, and problem-solving skills. He found that people have better short-term memory and problem-solving abilities in warm white lighting than cool or artificial daylight lighting. No significant results were obtained with a positive or negative mood about the lightings.

In terms of lighting effects on emotion and behavior, Wu and Wang (2015) found that people are more likely to enjoy the atmosphere in warm lighting with a low color temperature and bright illuminance where they felt happier, more joyful, more pleasant, and more relaxed than in a cool lighting setting. The study aimed to examine the relationship between customers' emotional responses and their impressions of LED lighting in restaurants. The experimental room was designed with a table and a set of silverware on top, so participants would be easily reminded of a restaurant. Six different LED lighting conditions (2700K*150Lux, 2700K*300Lux, 2700K*500Lux, 5600K*150Lux, 5600K*300Lux, and 5600K*500Lux) were displayed randomly (see Figure 13). The participants answered bipolar scale questionnaires (unhappy-happy, annoyed-pleased, unsatisfied-satisfied, melancholic-contented, despairing-hopeful, and bored-relaxed). The results confirmed that pleasure and arousal levels are influenced by color temperature. Pleasure was enhanced under 2700K lighting compared to 5600K lighting, while 5600K lighting enhanced arousal more than 2700K lighting.

Figure 13. Six combinations of LED color temperature and illuminance (Wu & Wang, 2015)

Although research on the effects of colored lighting is very limited, Abbas et al. (2006) explored physiological effects (i.e., hear rate) of lighting color on space users. They found that heart rate differs under varying color and illumination. Blue, green, red, white, and natural lightings of high and low intensity were used for the experiment. Participants' heart rates under all colored lightings were compared to the heart rates under white lighting. The results revealed that heart rates under colored lightings are significantly different from the heart rates under white lighting. Blue lighting with high intensity was found to be the most arousing light, while the green lighting with the low intensity was the least arousing light. Heart rate was also high under red lighting with low intensity.

Effects of Color and Lighting on Impression of Space

Many studies showed that the impression of a space is affected by color and lighting condition. Pioneering researcher Flynn (1977) identified six spatial impressions including clarity, spaciousness, relaxation, privacy, pleasantness, and order in his lighting study. Beginning with early research on the effects of lighting on spatial impression (Flynn, 1973; Flynn & Spencer, 1977; Flynn, Spencer, Martyniuk, & Hendrick, 1973; Hendrick, Martyniuk, Spencer, & Flynn, 1977), factors affecting spatial impressions have been identified (Countryman & Jang, 2006; Tantanatewin & Inkarojrit, 2016; Tantanatewin & Inkarojrit, 2018; Wu & Wang, 2015).

Countryman and Jang (2006) determined that atmospheric elements have significant effects on customer impression of hotel lobbies. The impression was measured by four expressions: good, beautiful, inviting, and comfortable. The elements chosen to compose the physical environment of the hotel lobby were color, lighting, layout, style, and furnishings. Three of these atmospheric elements (i.e., color, lighting, and style) were significantly related to the overall impression of a hotel lobby. Moreover, the results found that color was the most significant of these three elements.

Tantanatewin and Inkarojrit (2016) discovered that different color and lighting conditions have a significant impact on the impression of a bank and perceptions of its identity. The results showed that a space with yellow colors are perceived more positively than with other colors. A seven-point scale semantic differential method was used to evaluate the computer-simulated space of the bank in different color and lighting conditions. The adjective pairs used to measure the impression were attractive-unattractive, relaxed-dramatic, spacious-confined, uniform-differentiated, bright-dark, warm-cool, and diffused-contrast lighting. The combinations of wall color and lighting conditions were general lighting with a grey wall, general and accent daylight lighting with a grey wall, general and accent warm white lighting with a grey wall, general lighting with a yellow wall, general lighting with a blue wall, and general lighting with a purple wall. The results showed that yellow background received higher score for impressions of warm, spacious, and uniform compared to blue, purple and neutral color scene. This result did not support the findings of previous studies which proved that cool colors such as blue or purple tended to affect the impression more positively than warm colors like yellow (Babin, Hardesty, & Suter, 2003; Bellizzi & Hite, 1992; Yildirim, Akalin-Baskaya, & Hidayetoglu, 2007).

A more recent study by Odabaşioğlu and Olguntürk (2015) discovered different colors of lighting significantly affect people’s perception of space. They conducted an experiment to understand the effects of colored light on perceptions of interior spaces. A total of 97 students (59 female and 38 male) participated in the experiment. Red and green lights were used as independent variables, and white light was used as a control variable (see Figure 14). Six evaluative factors (pleasantness, aesthetics, usefulness, comfort, spaciousness, and lighting quality) were used in an eight-point bipolar scale questionnaire. The results revealed that red and green lightings were more aesthetically perceived than a white lighting. Red lighting was found to be the least comfortable lighting compared to green and white lighting.

Figure 14. View of the room with three lighting colors (Odabaşioğlu & Olguntürk, 2015)

An aforementioned study conducted by Wu and Wang (2015) found that the lighting color affects not only emotions but also spatial impressions. Six spatial impressions were measured: clarity-not clarity, spaciousness-not spaciousness, privacy-not privacy, pleased-annoyed, relaxed-stimulated, and ordered-disordered. Among six lighting conditions; three conditions with 2700K emit warm white lighting while other three conditions with 5600K express cool white lighting. The warm-colored lighting enhanced privacy impressions compared to cool-colored lighting. The lighting with higher illuminance enhanced people's impressions of spaciousness, which was consistent with Odabaşioğlu and Olguntürk (2015). The conditions of warm-colored lighting with a low color temperature and bright illuminance had positive effects on pleasantness, happiness, joyfulness, and relaxation.

Color Preference

Color preference is one subject that has received heavy focus in color studies. A number of previous color studies have addressed color preference either as main topics or sub-topics (Beke, Kutas, Kwak, Sung, Park, & Bodrogi, 2008; Hurlbert & Ling, 2007; Jalil, Yunus, & Said, 2013; Madden, Hewett, & Roth, 2000; Ou, Luo, Woodcock, & Wright, 2004; Park, et al., 2010; Yi & Shamey, 2015). Among these studies, the influence of socio-demographics (i.e., gender, age, and cultural background) on color preference prevailed.

In most color studies, gender differences in color preference were analyzed continuously. The results of the studies varied according to the objectives and what colors were used in the experiment. According to Ou et al. (2004), females tend to prefer light, relaxed, feminine, and soft colors whereas males did not show any significant preference. In the study of Yildirim et al. (2007), male users perceived space more positively than female users regardless of color. Some studies shared a similar conclusion in that both genders preferred cool colors. Jalil et al. (2013) revealed that both genders preferred cool colors including blue, green, and purple. The color preference was the highest for the pink color in female groups and the blue color in male groups. Overall, the most favorable color was blue. Similarly, Madden et al. (2000) discovered that for all participants the overall preferred color was blue. Hurlbert and Ling (2007) found that female preference was the highest in the reddish-purple region and the lowest in the greenish-yellow region. Male preference was the highest in the blue-green region. Contrary to the described studies with significant gender differences of color preference, other studies did not discover any gender differences in color preference (Odabaşioğlu & Olguntürk, 2015; Xin, Cheng, Taylor, Sato, & Hansuebsai, 2004).

Although not much research exists on age group differences in color preference compared to gender or cultural difference, age group difference has been considered an influential factor in some color research. It is known that visual acuity is poor in young children and increases rapidly to reach a maximum at about 20 years old. It declines gradually from age 20 to 45 and drops rapidly after that (Chapanis, 1950; Galton, 1885). Based on this, researchers mostly focused on either elderly groups or young groups in terms of color perception including color preference. Laufer, Lang, Izso, and Nemeth (2009) proved that adults who are over 65 years of age tended to feel more pleasant under red lighting compared to the blue lighting. The blue lighting was more activating to them. The results from Beke et al. (2008) showed that participants in older groups preferred colors of higher chroma in blue and red compared to younger groups. According to Adams (1987), infants preferred red and yellow, while adults preferred blue and green. Michaels (1924) found that children over age 6 are dependable in their preference of color, but their aesthetic judgments of color are unreliable. The research of color and form preference in young children from Suchman and Trabasso (1966) confirmed that young children tend to prefer color while older children prefer form.

Cultural difference is another dominant factor that appears in color preference studies. Madden et al. (2000) found that blue, green, and white are preferred across countries (i.e., Austria, Brazil, Canada, Colombia, Hong Kong, China, Taiwan, and United States) among 10 colors (i.e., black, blue, brown, gold, green, orange, purple, red, white, and yellow). According to

Xin et al. (2004), British participants preferred colors that felt cool whereas Chinese participants preferred colors that felt clean, fresh, and modern. In a cultural comparison of color preference of dyed fabric color, Yi and Shamey (2015) discovered that there are differences in color preference between American and Korean observers. A cultural preference for lighting was also explored (Park et al., 2010). North American participants preferred warm colored lighting with low intensity in a hotel guestroom, and Korean participants preferred warm colored lighting with high intensity.

Theoretical Background

Mehrabian-Russell Model (M-R model)

By summarizing basic concerns in environmental psychology from previous studies related to physical and social environments and their effects on humans, Mehrabian and Russell (1974) proposed a model based on the Stimulus-Organism-Response paradigm that describes how people react to physical or social stimuli in the environment using three steps: stimulus, organism, and response (S-O-R). Mehrabian and Russell's model posits that environmental stimuli such as color, sound, scent, image, and lighting affect individuals' emotional states (i.e., pleasure, arousal, and dominance) which, in turn, affect their behavioral responses (i.e., approach or avoidance) (see Figure 15).

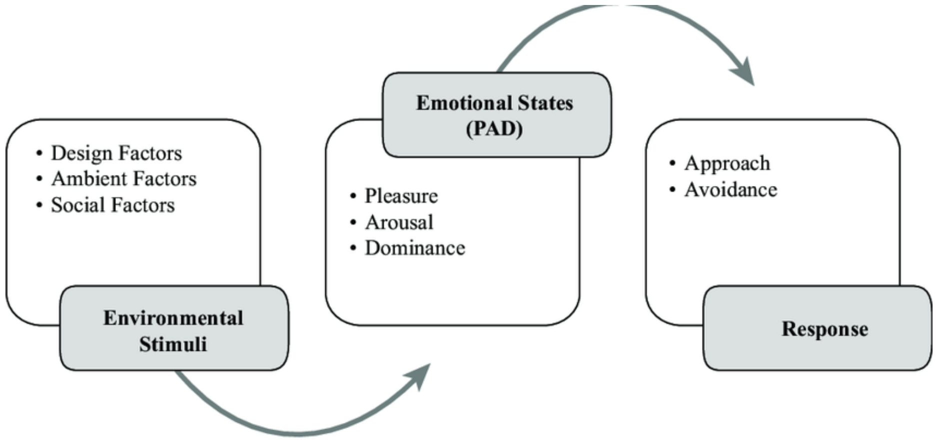


Figure 15. Mehrabian and Russell's S-O-R model (Mehrabian & Russell, 1974)

Emotional States. The original M-R model includes three dimensions of emotional states for individuals' perception of the physical environment: pleasure, arousal, and dominance. Pleasure represents how pleasant or unpleasant one feels about something, and arousal is how energized or soporific one feels. Dominance represents control and refers to how controlled or submissive one feels. Dominance, however, has been shown to have a non-significant effect on behavior whereas pleasure and arousal had significant effects on all behavior measures (Bellizzi & Hite, 1992; Donovan & Rossiter, 1982; Donovan, Rossiter, Marcoolyn, & Nesdale, 1994; Russell & Pratt, 1980). As such, two-dimensional pleasure-arousal emotional states are often used in studies.

Pleasure-displeasure is a feeling state that can be easily evaluated with behavioral metrics, such as a semantic differential scale, smile, laughter, and generally positive or negative facial expressions. Mehrabian and Russell (1974) employed the semantic differential method to measure pleasure. They used emotional adjective pairs to measure pleasure-unpleasure, happy-unhappy, pleased-annoyed, satisfied-unsatisfied, contented-melancholic, hopeful-despairing, and relaxed-bored. Mehrabian and Russell (1974) stated that arousal is conceptualized as a feeling state that varies along a single dimension ranging from sleep to frantic excitement. The semantic differential method was also employed to measure arousal. The emotional adjective pairs expressing arousal were stimulated-relaxed, excited-calm, frenzied-sluggish, jittery-dull, wide awake-sleepy, and aroused-unaroused.

Russell (1980) further conceptualized emotional states by developing a circumplex model of emotion, which is a two-dimensional circular space containing arousal on the vertical axis and pleasure on the horizontal axis (see Figure 16). In Russell's circumplex model of emotion (1980), emotional states can be identified at varying degrees of positive/negative pleasure and positive/negative arousal. Twenty-eight English words of feelings were placed on the circular form. Words that were thought to have the opposite meaning were placed on the opposite side of the circle. Russell (1980) explained that emotional states become moderate towards the middle of the space and strong towards the outside.

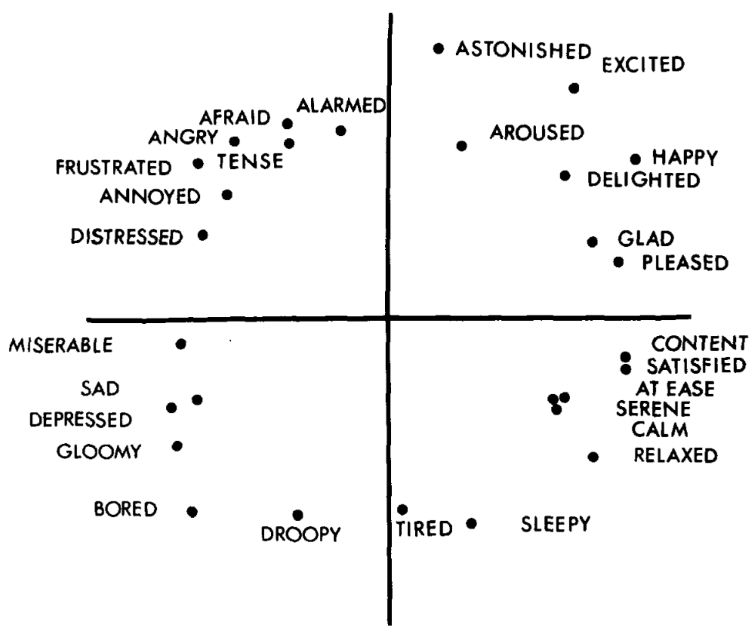


Figure 16. Russell's circumplex model of emotions (Russell, 1980)

Researchers adapted his circumplex model to represent the structure of emotion (Nardelli, Valenza, Greco, Lanata, & Scilingo, 2015; Posner, Russell, & Peterson, 2005; Russell, Lewicka, & Niit, 1989). Figure 17 presents the circumplex model of emotions for acoustic stimuli developed by Nardelli et al. (2015) based on Russell's model (1980). The model divides the space into four quadrants that represent different emotions based on the levels of pleasure and arousal. The upper left quadrant with high arousal and low pleasure represents "angry;" the upper right quadrant with high pleasure and high arousal represents "happy;" the lower left quadrant with low pleasure and low arousal represent "sad;" and the lower right quadrant with high pleasure and low arousal represents "relaxed."

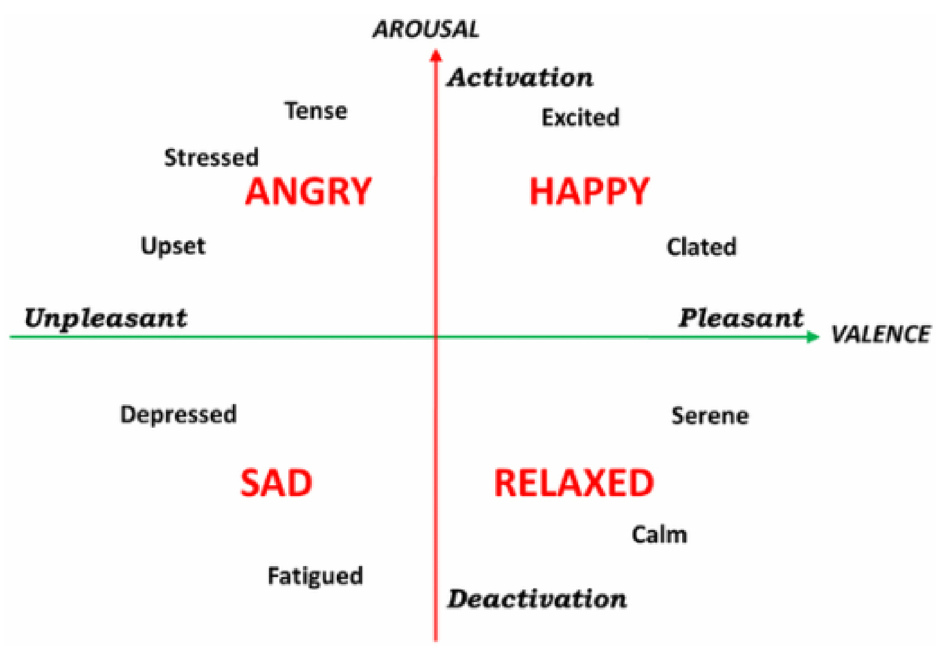


Figure 17. Circumplex model of emotions for acoustic stimuli (Nardelli et al., 2015)

Behavioral Response. The M-R model (1974) indicated that people's behavior is influenced by their emotional states. The behavior can be either approach or avoidance. Approach behavior explains the desire for staying, exploring, and affiliating with others in the environment (Booms & Bitner, 1980), whereas avoidance behavior is the desire to escape from the environment and to ignore communication from others (Donovan & Rossiter, 1982). Mehrabian and Russell used the concept of approach-avoidance in a broad sense to include the physical movement toward or away from an environmental stimulus, a degree of attention, exploration, and favorable attitudes. Verbally or nonverbally expressed liking, the level of performance (approach to a task), and affiliation (approach to another person) were examples of favorable attitudes.

In addition, the M-R model proposes that effects of environmental stimuli on approach-avoidance behavior are mediated by emotional states (i.e., pleasure and arousal). According to Mehrabian and Russell (1974), pleasure is not necessary, but it is a sufficient condition for positive reinforcement and the elicitation of approach. The approach is not limited to the pleasant stimulus itself, but it also applies to other temporally and spatially associated aspects of the pleasant stimulus. For example, task performance and affiliation can be increased or decreased by simply making the surrounding environment more pleasant or unpleasant. Arousal also mediates the effects of environmental stimuli on approach-avoidance behavior. A physical approach, preference, positive attitudes, exploration, performance, and affiliation are all maximized at a moderate level of arousal.

Applications of M-R Model

The M-R model (1974) has been extensively employed as a theoretical framework in various research to measure the effects of physical environments on people's emotional and behavioral responses. Because of its limitation to explain diverse stimuli, many scholars have extended the M-R model to suit their own research in the fields of marketing, retail, consumer services, hospitality management, and urban design (Ang, Leong, & Lim, 1997; Chen, Peng, & Hung, 2014; Demoulin, 2011; De Nisco & Warnaby, 2014; Gaur, Herjanto, & Makkar, 2014; Siamionava et al., 2018). Some of these studies observed fragmented effects from the M-R model: the effects of environmental stimuli on the emotional states or the effects of environmental stimuli on the behavioral response (Heung & Gu, 2012; Magnini & Kim, 2016; Park & Farr, 2007; Quartier et al., 2014). Other studies examined more complex effects such as mediating effects (Chang, 2016; Ha & Jang, 2010; Hyun, Meng, & Choi, 2017; Jani & Han, 2015; Kim & Lee, 2011; Morrison, Gan, Dubelaar, & Oppewal, 2011). Some studies extended the M-R model to explore the effects of environmental stimuli on impression, satisfaction, perceived value or quality of a space (Countryman & Jang, 2006; Tantanatewin & Inkarojrit, 2018; Wu & Wang, 2015).

Many studies focused on the effects of the indoor environment on customer behavior in restaurants, hotels, or retail stores. In previous studies, researchers adapted or extended the M-R model to evaluate the influence of servicescape and atmospherics created by interior design, decoration, spatial layout, music, scent, color, and light on customers' emotion and behavior (Jang & Namkung, 2009; Ladhari, Souiden, & Dufour, 2017; Park & Farr, 2007; Quarier et al., 2014).

The overall servicescape and atmospherics of dining, hotels, and stores were found to be significantly related to consumers' emotions and behavior (Kim et al., 2009; Ladhari et al., 2017). Studies proved that the servicescape of restaurants and dining atmospherics had a significant impact on customers' emotions and satisfaction, which influenced behavioral intention (Heung& Gu, 2012; Kim et al., 2009; Liu & Jang, 2009; Meng & Choi, 2017).

Kim and Moon (2009) proved that physical servicescape in a theme restaurant positively affected customers' feelings of pleasure. The emotion of pleasure was found to be positively related to revisit intention. Furthermore, the findings revealed a moderation effect of the theme restaurant type between pleasure and revisiting intention. Similarly, Meng and Choi (2017) investigated the relationships between the servicescape of theme restaurants, customers' emotions, satisfaction, and quality of life. The physical servicescape including background music, atmosphere, attractiveness, decoration, and facilities had a positive effect on customers' emotions. In addition, customer emotion was found to be significantly related to satisfaction.

According to Liu and Jang (2009), dining atmospherics had a positive effect on a positive emotion and a negative effect on a negative emotion. Both positive and negative emotions were found to be the key determinants of behavioral intentions of customers. Store atmosphere also had a positive effect on shoppers' emotions and purchase behavior. Heung & Gu (2012) found that restaurant atmospherics had a significant effect on customers' dining satisfaction and behavioral intention to return. They also proved that dining satisfaction had a significant positive effect on customers' behavioral intentions. Ha and Jang (2010) verified that service and food quality had significant effects on customer satisfaction and loyalty, which was moderated by restaurant atmospherics.

When these studies looked at the overall elements of the servicescape and atmospherics as environmental stimuli, some studies focused on only one or two of these elements. Hun et al. (2011) found that advertising factors including relevant news, stimulation, empathy, and familiarity significantly encourage emotional responses of customers in restaurants.

The effects of music were also explored in previous studies but were found to be inconsistent. Morris et al. (2011) revealed that music had a significant impact on shoppers' emotions and behavior. Additionally, the emotional state of pleasure was found to be the mediator of music and behavior. However, Andersson, Kristensson, Wästlund, & Gustafsson (2012) discovered that music had no significant effect on both pleasure and arousal.

Jani and Han (2015) tested moderation effects of personality including neuroticism, extraversion, openness, agreeableness, and conscientiousness on the relationship between hotel ambiance, guests' emotions, and hotel guest loyalty. The results of the study demonstrated a significant effect of hotel ambiance on guests' emotions, with those emotions having significant effects on loyalty.

Researchers also examined the effects of color and lighting based on the M-R model (Magnini & Kim, 2016; Park & Farr, 2007; Quartier et al., 2014). Magnini and Kim (2016) explored the effects of the background color of a restaurant on consumers' perceptions but found no significant effects. Park and Farr (2007) discovered significant lighting effects on consumers' pleasure and arousal in a retail environment. However, in another lighting study Quartier et al. (2014) found no significant lighting effects on consumers' behavior. Tantanatewin and Inkarojrit (2018) explored the influence of emotional response to interior color on restaurant entry decisions. The colors used on the computer simulated space were white, light pink, cream, light blue, orange, green yellow, green blue, red, brown, blue, and dark grey. The restaurant scenes of warm color with the high value received a higher score for pleasure. The results found the most powerful predictor for the behavioral response was pleasure.

Conceptual Framework and Research Questions

Based on the M-R model (1974) and the findings of the extant literature, the conceptual framework of the present study was developed (see Figure 18). The independent variable of the conceptual framework was six colors of LED lighting: three primary colors (i.e., red, green and blue) and three secondary colors (i.e., yellow, orange and violet). A review of the literature showed that colors used in colored lighting studies were often limited to less than three colors, mostly primary colors, whereas various colors of primary, secondary, achromatic colors, and more were used in color studies. To fill this gap, both primary and secondary colors of LED lighting were used in this study.

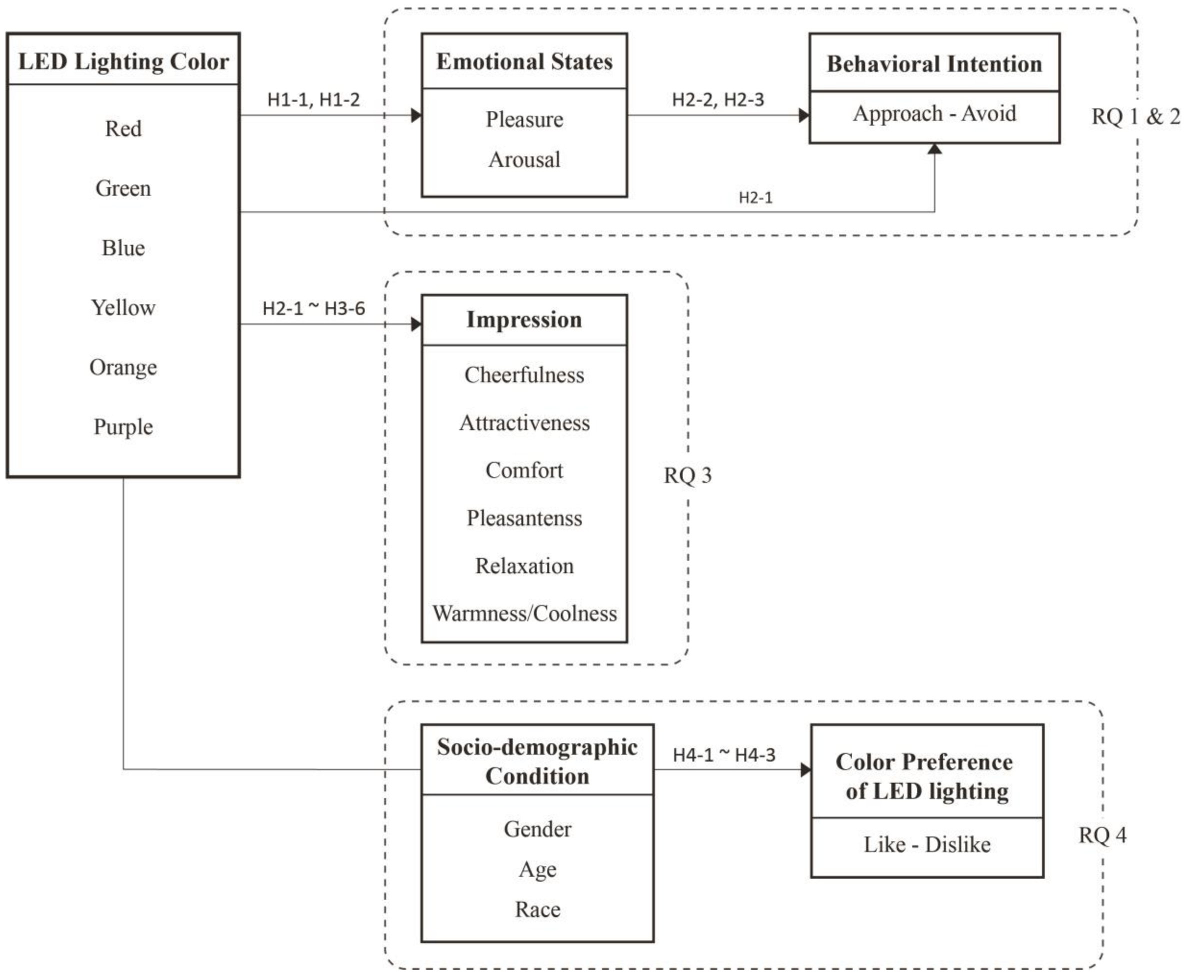


Figure 18. Conceptual model of the study

The conceptual framework first hypothesized the effects of six colors of LED lighting (i.e., red, green, blue, yellow, orange and violet) on emotional states (i.e., pleasure and arousal) and behavioral intention (i.e., approach or avoidance) based on the M-R model (1974): RQ1 and RQ2 in Figure 18. Emotional states of pleasure and arousal are used as a mediating variable and behavioral intention of approach or avoidance is used as a dependent variable. Second, referring to the literature on extended M-R models, the effects of six LED lighting colors on spatial impression (i.e., cheerfulness, attractiveness, comfort, pleasantness, relaxation, and warmness/coolness) was hypothesized in the conceptual framework: RQ3 in Figure 18. Finally, the influence of socio-demographic conditions (i.e., gender, age, and cultural group) on LED color preference was hypothesized based on findings of previous studies: RQ4 in Figure 18.

Based on the conceptual framework in Figure 18, the specific research questions and the related hypotheses are developed as follows:

RQ1. Does emotional response significantly differ by light color?

H1-1. There are significant differences in pleasure among six colors of LED lightings.

H1-2. There are significant differences in arousal among six colors of LED lightings.

RQ2. Does behavioral intention significantly differ by light color?

H2-1. There are significant differences in behavioral intention among six colors of LED lighting.

H2-2. There are significant indirect effects of six colors of LED lighting on behavioral intention mediated by pleasure.

. H2-3. There are significant indirect effects of six colors of LED lighting on behavioral intention mediated by arousal.

RQ3. Does spatial impression significantly differ among six colors of LED lighting?

H3-1. There are significant differences in cheerfulness of space among different colors of LED lighting.

H3-2. There are significant differences in attractiveness of space among different colors of LED lighting.

H3-3. There are significant differences in comfort of space among different colors of LED lighting.

H3-4. There are significant differences in pleasantness of space among different colors of LED lighting.

H3-5. There are significant differences in relaxation of space among different colors of LED lighting

H3-6. There are significant differences in warmness/coolness of space among different colors of LED lighting.

RQ4. Do socio-demographic conditions affect preferences of LED lighting?

H4-1. There are significant differences in color preferences of LED lighting between men and women.

H4-2. There are significant differences in color preferences of LED lighting among different age groups.

H4-3. There are significant differences in color preferences of LED lighting among different cultural groups.

CHAPTER 3

RESEARCH METHODS

In this chapter, the details of the research methodology are described. They are: (1) experimental research design, (2) experiment procedure, (3) study instrument, and (4) data analysis plan and preparation.

Experimental Research Design

Research Design

This study employed a quantitative research method. An experimental research design was conducted to test hypotheses. Experimental research design is an approach that examines the causal relationships and investigate the relationship between variables. In the experimental research, the independent variable is the treatment variable or the cause to be manipulated to test hypothesis and the dependent variable is the outcome variable or effect (Cresswell, 2013). The results of the experimental study will support or disprove the hypothesis.

Among many experimental designs, a crossover design is a study in which individual subjects receive a series of treatments over time (Johnson, 2010). This method is often used for clinical trials with two or more treatments for each subject. The present study selected the procedure from the crossover experimental design because of the similarity that different colors of LED lighting are given to each subject. The treatments or independent variables in this study were light colors: six colors of LED lighting including red, green, blue, yellow, orange, and purple. The experiment was designed to measure the effects of six colors of LED lighting on dependent variables: emotional states, behavioral intention, impression of space, and color preferences. Crossover experimental designs in clinical trials are usually longitudinal studies which take over a long period of time while the present study is a short version of it. In crossover design, a carryover effect between treatments can be an issue. To avoid the carryover effects, sufficiently long washout period between treatments is given. In the present study, interval time between treatments were given because various lighting colors exposed to the subjects can also cause carryover effects.

Sample

This study employed a voluntary sampling method using the online research tool at Michigan State University (MSU), which allows researchers to advertise their studies to potential participants. This system not only recruits research participants but also arranges the schedule for participants to visit the experiment room (McAlister, 2012). When the study was posted on the website by the researcher, email notifications were automatically sent to all users who were registered as online members. Those interested in participating in the experiment signed up for an available date and time if they met the requirement that they were not color blind. The recruitment started on May 12, 2018, and all entries were filled within a day.

Considering any possible overrepresentation of one gender in the research pool, the same number of male and female subjects were recruited to obtain balanced samples. The sample size was based on previous researchers' suggestions. In previous experimental studies on colors and lighting the number of participants widely varied and ranged from 25 to 920 participants (Tantanatewin & Inkarojrit, 2016; Wu & Wang, 2015; Al-Ayash et al., 2015; Barli et al., 2012;

Odabaşioğlu & Olguntürk, 2009). Different researchers suggested various approaches to decide the appropriate sample size. Some researchers suggested a minimum sample size of 100 to 150 (Anderson & Gerbing, 1988), but some researchers such as Bentler and Chau (1987) offered a ratio of sample size to number of observed variables (e.g., 1:5). When applying the suggested ratio 1:5 (Bentler & Chau, 1987) to this study, the required minimum sample size would be 85 (17x5) because this study used 17 items to measure emotional states, behavioral intention, impression of space, and color preference. Based on the minimum threshold of 85 subjects, 101 subjects were recruited for the research pool.

Experiment Room Settings

Laboratory setting. The experiment was conducted in the Food Sensory Laboratory in the Food Science Department at Michigan State University. The laboratory contains seven individual booths that are 26 inches by 27 inches and 35 inches high (see Figure 19). The entire room was painted in white and window blinds blocked the sunlight. Each booth was painted in a grey color to evaluate the colors in the most neutral situation. The LED lighting fixtures with color changing systems were installed on the top of each booth.

Figure 19. Individual sensory booth

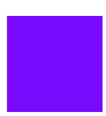
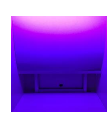
LED fixture and color setting. Advanced LED lighting technology can produce a variety of colors and different illuminance levels from one lighting fixture with a simple control.

For the experiment, a surface-mounted Philips Hue Light Strip Plus fixture with LED bulbs (see Figure 20) was installed in each individual booth to produce six different colors of lighting (i.e., red, green, blue, yellow, orange, and purple).

Figure 20. Philips Hue lightstrip. (Source: https://www.usa.philips.com)

The six colors of LED lightings were accurately converted from six primary and secondary colors of the NCS color system. Table 2 presents NCS color notation and RGB values for the six selected colors and Yxy values of six lighting colors converted from the RGB values.

Table 2. *Six Colors of LED Lighting Converted from Six Colors of NCS Color System*

Color	**NCS (RGB)**		**Yxy**		**fc**
Red	1085-Y80R (245.7.3)		19.578/0.63764/0.33066		11
Green	1075-G20Y (60.172.60)		30.790/0.30304/0.53530		15
Blue	1565-B (0.137.191)		21.650/0.19836/0.23409		18
Yellow	0580-Y (255.210.0)		67.357/0.45511/0.47682		19
Orange	0585-Y40R (254.127.0)		36.256/0.54355/0.40660		16
Purple	3055-R50B (119.10.255)		11.358/0.19436/0.08569		5

The level of brightness of the six lighting conditions was confirmed based on the recommendations of the Illuminating Engineering Society (IES) handbook. The unit of illuminance measurement is foot-candle (fc) or Lux. According to IES handbook (2011), when visual performance is important, the level of illuminance should be between 30-100fc depending on the contrast and size of the tasks. In any space where visual performances are not important and reading or visual inspections only occasionally occur, the recommended illuminance ranges from 3fc to 10fc (IESNA Handbook, 2000). Table 3 shows more specific illuminance level recommendations for different commercial spaces. Considering that colored lightings are generally used in spaces for relaxation, conversation, or entertainment such as hospitality, retail, healthcare, or recreation facilities, the level of illuminance for the experiment was selected based on the recommended illuminance level of a dining area (5-20fc), hotel lobby or corridor (10-20fc), cocktail lounge (5-20fc), recovery room (10-20fc), and reception area (10-20fc).

Table 3. *IES Foot-candle Recommendations*

Building Area	Recommended Foot-candle
Food Service Facilities	
Dining areas	5-20 fc
Cashier	20-50 fc
Hotels	
Lobby and general lighting	10-20 fc
Corridors, elevators, and stairs	10-20 fc
Reading and working areas	20-50 fc
Recreation Areas	
Cocktail lounges	5-20 fc
Swimming pools	5-20 fc
Theatre	5-10 fc
Auditoriums	
Assembly	10-20 fc
Exhibition halls	10-20 fc
Healthcare Facilities	
Recovery room	10-20 fc
Corridors and nursing areas	5-20 fc

The illuminance levels of six colors of lightings for the experiment are shown in Table 2: (1) 11fc for red, (2) 15fc for green, (3) 18fc for blue, (4) 19fc for yellow, (5) 16c for orange, and (6) 5fc for purple. The illuminance of the purple lighting was lower than other lightings because of the different range of intensity that each colored lighting can express. As shown on the Figure 21 which demonstrates the relative intensity of different colors, the intensity of purple is very low compared to other colors. This characteristic of color intensity caused lower illuminance of purple lighting.

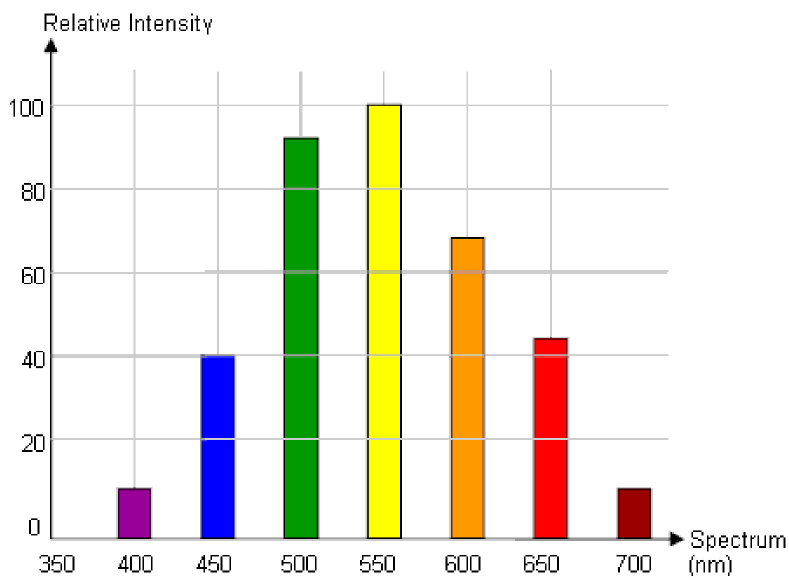


Figure 21. Relative intensity of colors (Halliday, 1994)

Experiment Procedure

Pilot Study

A pilot test was conducted in early May 2018 to test the design of the main experiment and identify any design issues to be adjusted in the main experiment. Seven MSU students participated in the pilot test. In the pilot study, the six experiment sessions were conducted with six different colored LED lightings for each participant. The participants were exposed to each color of lighting for 4 minutes with a 1-minute interval between sessions to reduce carryover effects from an afterimage.

The results of the pilot test revealed that participant fatigue was evident as each participant was tested in all six lighting conditions in a row. Participants expressed eye strain, boredom, tiredness, and inattention over time toward the end of the experiment. Participants also thought the overall experiment (40 minutes) and 1-minute interval time between sessions was too long. To minimize participant distraction and fatigue effects, the experimental sessions needed to be adjusted. In previous studies, some experiments were conducted for simply two colors (e.g., Yildirim et al., 2007) while Tantanatewin and Inkarojrit (2018) examined 11 different colors in their experiment. Yildirim et al. (2007) conducted experiments in a real restaurant while Tantanatewin and Inkarogrit (2018) used computer simulator for the experiment, which explains the number of colors provided in their experiments. In the most similar study by Odabaşioğlu and Olguntürk (2015), three different lighting colors, red, green and white, were provided. This study conducted experiments under a real-size room. Considering that many previous experiments were conducted for three conditions, the present study modified main experiment design to conduct three experiment sessions for each participant by providing three randomly selected colors from six lighting colors. The interval time between sessions was also adjusted to 40 seconds instead of 1 minute. The average of the total experiment time was reduced to 20 minutes for the main experiment.

Main Experiment Procedure

The experiment was conducted from 10 a.m. to 4 p.m. from May 16, 2018 to May 23, 2018. The participants scheduled an appointment to come to the experimental lab when they signed up for the experiment online. Maximum of three participants were tested at the same time in the same experiment sessions. When participants arrived at the lab, they were instructed to write their name on the sign-in form and sit in one of the sensory booths. They were then asked to read and sign the consent form. Ishihara's color-blind test (Ishihara, 1975) was performed on each participant and none of the participants were color blind. After participants passed the color-blind test, they were informed about the experiment. The purpose of the study, expectations, cautions and the procedures were explained. When all the participants understood the experiment procedure, the experiment began.

The experiment was designed to have three sessions per participant. In the first session, a randomly selected lighting color from the six colored LED lightings was turned on in each booth for 3 minutes (Figure 22). During these 3 minutes, participants were asked to complete the test instrument. When all the participants finished the questionnaire, or the 3 minutes have passed, they were asked to close their eyes and rest them for 40 seconds. After 40 seconds, the second session began and another randomly selected lighting color was turned on for 3 minutes. The same procedure that was done in the first session was performed. After the second session, the procedure was repeated once more with another lighting color.

When the participants completed all three sessions, each was given $10 as an expression of a gratitude and asked to sign a confirmation form before they left.

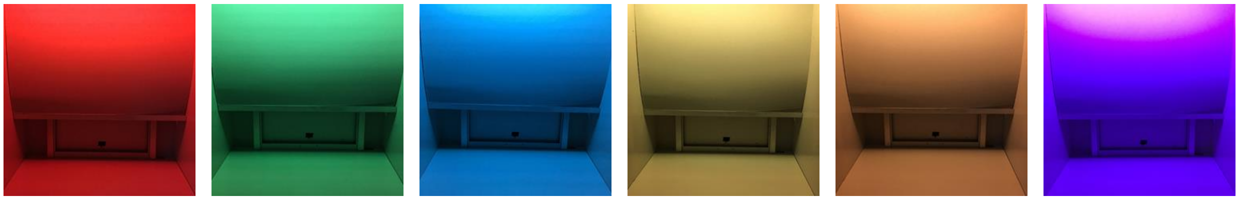


Figure 22. Six lighting color settings (from left: red, green, blue, yellow, orange and purple)

Study Instrument

The test instrument was developed based on the M-R model's (1974) measurement and related color and lighting studies (Magnini & Kim, 2016; Naz & Epps., 2004; Odabaşioğlu & Olguntürk, 2015; Siamionava et al., 2018; Tantanatewin & Inkarojrit, 2018; Wu & Wang, 2015; Yildirim et al., 2007; Yildirim et al., 2015). The questions were modified for the purposes of the study.

The questionnaire consists of three sections. In the first section, participants were asked about basic demographic information including their gender, age, and ethnicity. The second section measured (1) participants' behavioral intentions, (2) emotional states, (3) spatial impressions, and (4) color preference for each lighting condition. First, behavioral intention was measured using a single question asking overall intention of approach to or avoidance from the space in a given lighting condition based on the M-R model (1974). The original M-R model suggested four questions to measure behavioral intension: (1) desire to stay in the situation, (2) desire to explore the situation, (3) desire to work in the situation, and (4) desire to affiliate in the situation. But because subsequent studies used single question (Park, 2003; Park & Farr, 2007) and participants of this study were completing the same question repeatedly for three different experiment sessions, this study used a single question for behavioral intention. The original M-R model (1974) used a nine-point semantic differential scale to rate the emotional states and behavioral intentions of participants, but based on previous studies which applied M-R model (Jang & Namkung, 2009; Liu & Jang, 2009; Magnini & Kim, 2016; Morrison et al., 2011; Park & Farr, 2007), this study applied a seven-point semantic differential scale to rate how much they would be more likely to avoid (-3) or approach (3) the space in the given lighting condition.

Next, to measure the emotional states, participants were asked to rate their level of emotional state in the given lighting condition. Eight pairs of emotional words were used: pleasant-unpleasant, happy-unhappy, excited-calm, aroused-unaroused, satisfied-dissatisfied, side awake-sleepy, comfortable-uncomfortable, and stimulated-relaxed. These words were also adapted from the M-R model (1974) with minor changes in the expression of the words. For example, pleasant-unpleasant was used in this study instead of pleased-annoyed as developed by Mehrabian and Russell (1974). A seven-point semantic differential scale ranged from 1 (most negative) to 7 (most positive), but some items were reverse-scored to reduce response biases related to multi-item measurement scales such as acquiescence or straight-line responding when the wordings are in a single direction.

Similarly, to measure participants' spatial impressions in the given lighting condition, a seven-point semantic differential scale ranging from 1 to 7 on seven pairs of impression words was used. The impression words were: warm-cool, dull-bright, impressive-unimpressive, beautiful-ugly, attractive-unattractive, cheerful-gloomy, and appealing-unappealing. Some items were reverse-scored. The impression words used in this study were adapted from previous studies of lighting impressions and the extended M-R model (Countryman & Jang, 2006; Flynn, 1977; Flynn et al., 1973; Tantanatewin & Inkarojrit, 2016).

Finally, the preference level of the given colored LED lighting was measured with a seven-point semantic differential scale ranging from -3 (dislike) to 3 (like).

Data Analysis Plan and Preparation

Data Cleaning

Data was collected from a total of 101 subjects. Among the 101 participants, 88 participants completed three session experiments with three lighting color conditions, and 13 participants volunteered to complete six session experiments with six lighting color conditions. So, 342 data points were collected with 264 points coming from the three session experiments (88x3) and 78 from six session experiments (13 x 6). Among the 342 collected data points, three uncompleted data were dropped prior to analysis. As a result, a total of 339 data points were used for the analysis. All reverse-scored items for emotional states and impression measurements were recoded for further analysis.

Data Analysis

Data obtained from the experiments were analyzed using statistical analysis tools to test the research hypotheses and describe the results of the experiments. First, descriptive statistics were obtained to determine the distributional characteristics of each variable. Frequencies, mean, standard deviation, and percent were used.

Two types of factor analysis were used to measure the validity of the scale. Exploratory factor analysis was used to ensure that the factors were reduced as intended, and then a confirmatory factor analysis (CFA) was conducted to verify the construct validity. Reliability tests were performed to explain the internal consistency of the variables using Cronbach’s alpha value. A coefficient score of 0.7 or higher demonstrates an acceptable level of reliability coefficient (Nunnally, 1978).

Finally, one-way analysis of variance (ANOVA), regression, and path analysis were conducted to test the hypotheses. The assumptions of a one-way ANOVA are the followings: 1) Each sample is taken from a normally distributed population, 2) each sample has been drawn independently of other samples, and 3) there needs to be homogeneity of variances (One-way ANOVA, 2018). All these three assumptions were met, resulting in further analysis using one-way ANOVA. One-way ANOVA was used to test hypotheses 1, 2-1, 3, and 4 by finding differences in means among the six lighting colors in terms of emotional states (H1), behavioral intention (H2-1), and spatial impression (H3), as well as socio-demographic differences of color preference of LED lighting (H4). To test hypotheses 2-2 and 2-3 for the mediating effects of emotional states between colored LED lightings and behavioral intention, regression analysis, and path analysis were used. Then mediation analysis was conducted.

Mplus version 7 was used for the regression and path analysis, and Statistical Package of the Social Sciences (SPSS) version 24 for Windows was used for other methods including descriptive statistics and one-way ANOVA. The hypotheses of the study and applied statistic method with the computer program used for the data analysis are presented in Table 4.

Table 4. *Hypotheses and Applied Statistical Methods*

Hypothesis	Statistical Method	Program
Hypothesis 1		
There are significant differences in emotional states among six colors of LED lighting.	One-way ANOVA	SPSS 24
Hypothesis 2		
1. There is a significant difference in behavioral intention among six colors of LED lighting.	One-way ANOVA	SPSS 24
2-3. There is a significant indirect effect of six colors of LED lighting on behavioral intention mediated by emotional states.	Regression analysis Path Analysis (Mediation Analysis)	Mplus 7
Hypothesis 3		
There are differences among different colors of LED lighting in the impression of the interior space.	One-way ANOVA	SPSS 24
Hypothesis 4		
Socio-demographic features have significant effects on the color preference of LED lighting.	One-way ANOVA	SPSS 24

CHAPTER 4

RESULTS

This chapter presents the findings of statistical analyses on the effects of colored-LED lighting on emotional states, behavioral intentions, impression of space, and color preference. In the first section, the preliminary analyses including participant profile, factor analysis, and reliability test are presented. Then, findings from one-way ANOVAs, regression analysis, and path analysis for the hypothesis testing are reported.

Preliminary Analyses

Participant Profile

Table 5 presents the frequencies and percentage distribution for participant age, gender, and cultural background. A total of 101 subjects participated in the experiment. About half of the participants were men (n=50, 49.5%) and half were women (n=51, 50.5%). The majority of the participants were in their 20s. About 36.6% (n=37) of participants were between 21 and 25 years old, and 23.8% (n=24) were between 26 and 30 years old. So, more than 60% of the participants were aged between 21 and 30. About 14.9% (n=15) were between 31 and 35 years old, and 21.8% (n=22) were more than 35 years old. Participants from various races took part in the experiment. Nearly half of the participants were Caucasian (n=48, 47.5%), followed by Asian (n=34, 33.7%), African/Black (n=9, 8.9%), and others (10%). More than 80% of the participants were Caucasian or Asian. Among Caucasian participants, 56.3% were men and 43.7% were women; among Asian participants 41.2% were men and 58.8% were women.

Table 5. *Socio-demographic Characteristics of Study Participants*

Variable	**Frequency**	**Percent (%)**
Age		
-21	3	3.0
21 – 25	37	36.6
26 -30	24	23.8
31 – 35	15	14.9
35 -	22	21.8
Gender		
Male	50	49.5
Female	51	50.5
Cultural background		
Asian	34	33.7
African/Black	9	8.9
Caucasian	48	47.5
Hispanic/Latino	2	2.0
Pacific Islander	1	1.0
Mixed Race	5	5.0
Other	1	1.0
Prefer not to answer	1	1.0

Note. N=101

Factor Analysis and Reliability

Factor analysis is a statistical method to identify the underlying factor structure by reducing many interrelated items into a smaller set of latent variables (i.e., exploratory factor analysis [EFA]) and specify factor structure to test hypotheses (i.e., confirmatory factor analysis [CFA]). Principle component analysis (PCA) or factor analysis is a common method in studying people's perception (e.g., Liu, 2008; Yang, 2015) or dimensions in planning and design (e.g., Burley et al., 2009; Xu et al., 2015, Xu et al., 2017). This study used factor analysis for emotional state variables as emotional states were measured with multiple interrelated items from Mehrabian and Russell's (1974) measurement scale. First, EFA using Varimax rotation was carried out for deriving the factors. Two factors with an Eigenvalue greater than 1 were identified from the emotional state items. The first factor accounted for 47.16% of variance and the second factor accounted for 26.10% of variance, explaining 73.27% of the cumulative variance (Table 6).

EFA was followed by CFA to test if the two factors are significant and to determine construct validity by testing how well the measured items represent the number of constructs.

The results of CFA showed the factor loadings on items 1-4 of the pleasure variable were .848 or above and the factor loadings on items 1-3 of the arousal variable were .547 or above. All the items in this analysis had factor loadings greater than 0.50 and satisfy the convergent validity (Table 6). The EFA and CFA indicated that pleasure and arousal were distinct factors to the emotional state items. To test internal consistency of two factors, pleasure and arousal, reliability analysis using Cronbach's alpha was conducted. Pleasure indicated a high degree of internal consistency among the items with the coefficient alpha of 0.92. The coefficient alpha of arousal was 0.70, which is the minimum required value of Cronbach's alpha (Nunnally, 1978). As Cronbach's alpha values were above the acceptable level, two factors were utilized to test hypotheses.

Table 6. *Factor Analysis and Reliability*

	EFA			CFA			
	Factor loading	**Eigen-value**	**Variance explained**	**Factor loading**	**SE**	**p**	**Cronbach's α**
Pleasure		3.301	47.161				0.92
PLS1	.917			.921	0.011	.000	
PLS2	.869			.850	0.017	.000	
PLS3	.836			.850	0.017	.000	
PLS4	.854			.848	0.017	.000	
Arousal		1.827	26.106				0.70
ARS1	.759			.650	0.061	.000	
ARS2	.618			.690	0.061	.000	
ARS3	.555			.547	0.061	.000	
Cumulative Variance			73.267				

Note. Each factor is 7-point semantic differential word pair reflecting pleasure and arousal. One factor (Stimulated-Relaxed) was eliminated because of the low Cronbach's alpha value. [a]PLS1 = Pleasant-Unpleasant. [b]PLS2 = Happy-Unhappy. [c]PLS3 = Satisfied-Dissatisfied. [d]PLS4 = Comfortable-Uncomfortable. [e]ARS1 = Excited-Calm. [f]ARS2 = Aroused-Unaroused. [g]ARS3 = Wide awake-Sleepy.

Table 7 presents the results of Pearson correlation coefficients for emotional state items. Correlation coefficients indicated that four items of pleasure (i.e., PLS1, PLS2, PLS3, and PLS4) were strongly correlated ranging from 0.709 to 0.799 and three dimensions of arousal (i.e., ARS1, ARS2, and ARS3) were moderately correlated ranging from 0.333 to 0.444 ($p<.01$).

Table 7. *Pearson Correlations*

		1	2	3	4	5	6	7
1	PLS1	1						
2	PLS2	.799**	1					
3	PLS3	.771**	.709**	1				
4	PLS4	.775**	.731**	.728**	1			
5	ARS1	-.147	-.022	-.068	-.208	1		
6	ARS2	.118	.232	.123	.055	.444**	1	
7	ARS3	-.013	.072	.069	-.085	.414**	.333**	1

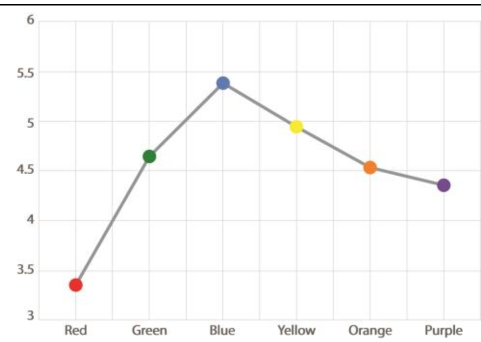
n=339. [a]1 = Pleasant-Unpleasant. [b]2 = Happy-Unhappy. [c]3 = Satisfied-Dissatisfied. [d]4 =. [e]5 = Comfortable-Uncomfortable. [f]6 = Aroused-Unaroused. [g]7 = Wide Awake-Sleepy.
*p<.05, **p<.01

Effects of LED lighting Colors on Emotional States

Pleasure. Table 8 presents the means and standard deviations for pleasure for six colors of lighting. The mean value was the highest for the blue lighting (M = 5.39, SD = 1.29) and the lowest for the red lighting (M = 3.35, SD = 1.54). The mean value for other lighting colors ranged from 4.35 (purple) to 4.93 (yellow). Levene's test for equality of variances found that the assumption of homogeneity of variance was met, F (5, 333) = 1.800, p = .112.

Table 8. *Means and Standard Deviations of Pleasure for LED Lighting Colors*

	n	*M*	*SD*
Red	50	3.35	1.54
Green	55	4.64	1.29
Blue	61	5.38	1.29
Yellow	58	4.93	1.35
Orange	53	4.52	1.42
Purple	62	4.35	1.65



Note. Means ranged from 1 to 7, with higher numbers representing more positive responses. [a]M = mean. [b]SD = Standard Deviation.

Table 9 presents the results of a one-way ANOVA on pleasure for six colors of lighting. The results of one-way ANOVA show that the differences among LED lighting colors were statistically significant, F (5, 333) = 12.325, p = .000. Thus, Hypothesis 1-1 is supported. Post-hoc analyses using Tukey's HSD indicate that level of pleasure in response to red lighting (M = 3.35, SD = 1.54) was significantly lower than to all other lighting colors. On the other hand, level of pleasure in response to blue lighting (M = 5.39, SD = 1.29) was significantly higher than orange (M = 4.53, SD = 1.42) and purple (M = 4.35, SD = 1.65) lightings as well as red (M = 3.35, SD = 1.54) lighting.

Table 9. *One-way ANOVA of the Influence of LED Lighting Colors on Pleasure*

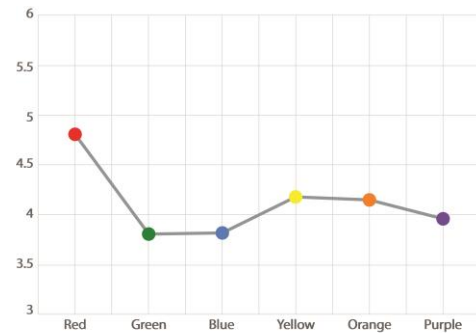
Source		***df***	***SS***	***MS***	***F***	***p***
Between groups		5	126.226	25.245	12.325	.000***
Within groups		333	682.096	2.048		
Total		338	808.322			
Post Hoc Test (Tukey)		**Mean Difference**		**Std. Error**		***p***
Red	Green	-1.291		.280		.000***
	Blue	-2.035		.273		.000***
	Yellow	-1.590		.276		.000***
	Orange	-1.178		.282		.001**
	Purple	-1.001		.272		.004**
Blue	Orange	.857		.269		.019*
	Purple	1.034		.258		.001**

[a]df = degrees of freedom. [b]SS = Sum of Squares. [c]MS = Mean Square.
*p<.05, **p<.01, ***p<.001

Arousal. Table 10 presents the means and standard deviations for arousal for the six lighting colors. The mean value of arousal for the red lighting (M = 4.80, SD = 1.05) was the highest while the green lighting (M = 3.80, SD = 1.07) showed the lowest mean for arousal. The mean values for warm colored lights (i.e., red, yellow, and orange) ranged from 4.14 to 4.8 while the mean values for cool colored lights (i.e., green, blue, and purple) ranged from 3.80 to 3.95. The overall means for warm colored lights were higher than for cool colored lights. Levene's test for equality of variances found that the assumption of homogeneity of variance was met, F (5, 333) = 1.772, p= .118.

Table 10. *Means and Standard Deviations of Arousal for LED Lighting Colors*

	n	***M***	***SD***
Red	50	4.80	1.05
Green	55	3.80	1.07
Blue	61	3.80	1.46
Yellow	58	4.17	1.27
Orange	53	4.14	1.22
Purple	62	3.95	1.27



Note. Means ranged from 1 to 7, with higher numbers representing more positive responses. [a]M = mean. [b]SD = Standard Deviation.

Table 11 presents the results of a one-way ANOVA for arousal for the six colors of lighting. The differences were statistically significant, F (5, 333) = 4.757, p = .000. Hypothesis 1-2 was supported. Post-hoc analyses using Tukey's HSD indicate that the arousal level for red lighting (M = 4.80, SD = 1.05) was significantly higher than for green (M = 3.80, SD = 1.07), blue (M = 3.81, SD = 1.46) or purple (M = 3.95, SD = 1.27) lighting. The results suggest that people tend to get more excited/stimulated under red lighting but feel more relaxed under cool colored lighting (i.e., green, blue, or purple lights).

Table 11. *One-way ANOVA of the Influence of LED Lighting Colors on Arousal*

Source		***df***	***SS***	***MS***	***F***	***p***
Between groups		5	36.389	7.278	4.757	.000***
Within groups		333	509.479	1.530		
Total		338	545.868			
Post Hoc Test (Tukey)		**Mean Difference**		**Std. Error**		***p***
Red	Green	1.000		.242		.001**
	Blue	.991		.236		.000***
	Purple	.848		.235		.005**

[a]df = degrees of freedom. [b]SS = Sum of Squares. [c]MS = Mean Square.
*p<.05, **p<.01, ***p<.001

Circumplex model of emotion. Figure 23 presents the placement of the six colors of LED lighting on the Russell's circumplex model of emotion based on the mean values of pleasure and arousal. The red lighting was located on "tense" emotion in the "angry" quadrant. The blue, green and purple lighting was place on "relaxed". Yellow and orange lights were placed in the "happy" quadrant. Red and blue lights were placed away from the center of the model meaning high strengths, while green, yellow, orange and purple lights were placed relatively close to the center of the model, meaning relatively low strength.

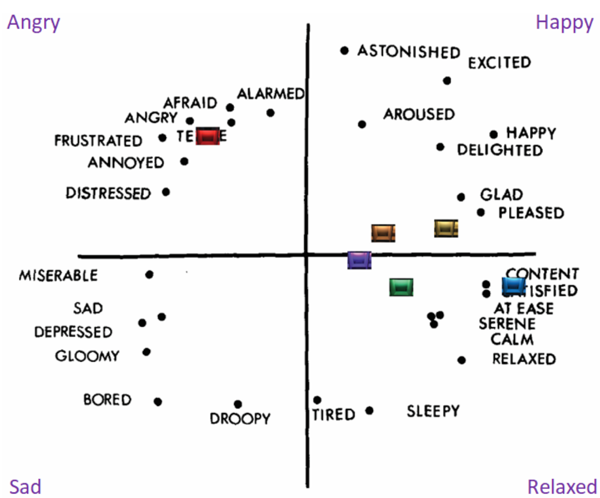


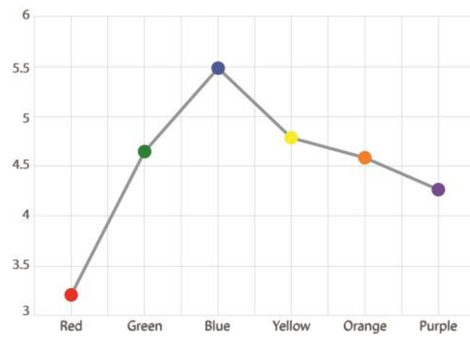
Figure 23. Six colors of LED lighting on Circumplex model of emotions

Effects of LED lighting Colors on Behavioral Intentions

Table 12 presents the means and standard deviations for behavioral intentions for six colors of lighting**.** The highest mean score was for blue lighting (*M* = 5.48, *SD* = 1.49), showing the highest desire to approach, while the red lighting (*M* = 3.20, *SD* = 1.93) was rated the lowest, showing the highest desire to avoid. The mean values for other colors ranged from 4.26 (purple) to 4.78 (yellow). Levene's test for equality of variances found that the assumption of homogeneity of variance was met, *F* (5, 333) = 1.620, *p* = .154.

Table 12. *Means and Standard Deviations of Behavioral Intentions for LED Lighting Colors*

	n	***M***	***SD***
Red	50	3.20	1.93
Green	55	4.64	1.42
Blue	61	5.48	1.49
Yellow	58	4.78	1.56
Orange	53	4.58	1.60
Purple	62	4.26	2.09



Note. Means ranged from 1 to 7, with higher numbers representing approach. [a]M = mean. [b]SD = Standard Deviation.

Table 13 indicates the one-way ANOVA results for behavioral intentions. There were statistically significant differences in behavioral intentions among the six colored LED lights, *F* (5, 333) =10.524, *p* = .000. Hypothesis 2-1 is supported. Post-hoc analyses using Tukey's HSD indicate that the mean score for behavioral intentions under the red lighting (*M* = 3.20, *SD* = 1.93) was significantly lower than for all the others. This can be interpreted to mean that people tend to avoid a space with red lighting. Blue lighting (*M* = 5.48, *SD* = 1.49) appears to be significantly approachable compared to red (*M* = 3.20, *SD* = 1.93) and purple (*M* = 4.26, *SD* = 1.09) lighting. The results of the analysis of behavioral intentions for each color bear a strong resemblance to those for pleasure, which makes it necessary to further test the mediation effect of emotional states theoretically supported by Mehrabian and Russell's Stimulus-Organism-Response model.

Table 13. *One-way ANOVA of the Influence of LED Colors on Behavioral Intentions*

Source		***df***	***SS***	***MS***	***F***	***p***
Between groups		5	151.819	30.364	10.524	.000***
Within groups		333	960.765	2.885		
Total		338	1112.584			
Post Hoc Test (Tukey)		**Mean Difference**		**Std. Error**		***p***
Red	Green	-1.436		.332		.000***
	Blue	-2.275		.324		.000***
	Yellow	-1.576		.328		.000***
	Orange	-1.385		.335		.001**
	Purple	-1.058		.323		.015*
Blue	Purple	1.217**		.306		.001

[a]df = degrees of freedom. [b]SS = Sum of Squares. [c]MS = Mean Square.
*p<.05, **p<.01, ***p<.001

Indirect effects of emotional states. Mediation analysis was conducted to explore the indirect effects of LED lighting colors on behavioral intentions mediated by emotional states. According to Baron and Kenny (1986), a variable functions as a mediator when four conditions are satisfied: (1) The independent variable significantly affects the mediator; (2) The independent variable significantly affects the dependent variable; (3) The mediator significantly affects the dependent variable; (4) The strength of the relationship between the independent and the dependent variable is significantly reduced when the mediator is added to the model. The first two conditions were met according to the results of hypothesis tests 1 and 2. To test the remaining two conditions, a regression analysis and path analysis were conducted using Mplus version 7.

To conduct regression analysis, the normality assumption was examined first in terms of skewness and kurtosis. Variables within skewness of -1 to 1 and kurtosis of -1 to 2 are considered acceptable (Huck, 2004). All variables used in this section were determined to be within the acceptable ranges, confirming that the assumption of normality was met and that it was permissible to proceed with the regression analysis. Table 14 presents the results of the regression analysis of emotional states on behavioral intentions. It indicates that arousal (β = .096, *SE* = .066, *p* = .145) does not have a significant impact on behavioral intentions, and therefore no further mediation analysis was required for mediating effects of arousal. Pleasure (β = 0.929, *SE* = 0.035, *p* = 0.000), on the other hand, was found to significantly influence behavioral intentions.

Table 14. *Regression Analysis of Emotional States on Behavioral Intentions*

Effects of	**Dependent variable**	$\boldsymbol{\beta}$	**S.E.**	**Est. / S.E.**	***p* -value**
Pleasure	Behavioral intentions	.929	.035	26.822	.000***
Arousal	Behavioral intentions	.096	.066	1.458	.145

Note. β = beta weights. S.E. = standard error. Est./S.E. = beta weights divided by standard error.
*p<.05, **p<.01, ***p<.001

Table 15 shows the results of path analysis to find the mediation effect pleasure. As the lighting colors are categorical variables, dummy variables were obtained with red lighting designated as a reference variable. The indirect effects of lighting colors on behavioral intention via emotional states were estimated using maximum likelihood. Model fit was evaluated with a chi-square test of model fit and the RMSEA. For the maximum likelihood method, cutoff value for the model fit test is over .90 for CFI and TLI, and below .06 for RMSEA (Hu & Bentler, 1999). The model fit test met all the criteria (χ^2= 148.09, $p < .001$; CFI =.942, TLI = .910, RMSEA < .001). The result of path analysis indicates that there were significant indirect effects of lighting colors on behavioral intention mediated by pleasure. Compared to the red LED lighting, green (β = 1.171, *SE* = .301, *p* = 0.000), blue (β = 1.964, *SE* = 0.300, *p* = 0.000), yellow (β = 1.478, *SE* = 0.297, *p* = 0.000), orange (β = 1.026, *SE* = 0.314, *p* = 0.001) and purple (β

= .688, *SE* = 0.338, *p* = 0.042) lights had significant indirect effects on behavioral intentions mediated by pleasure. In other words, these five colors of lightings are approachable compared to the red lighting because people feel more pleasant under all these lightings than red lighting. The result supports the mediating effects predicted by Mehrabian and Russell's Stimulus-Organism-Response theory.

Table 15. *Path Analysis of Emotional States Between LED Lighting Colors and Behavioral Intentions*

Dependent variable	Effects of	Via	β	S.E.	Est. / S.E.	*p* -value
Behavioral Intention	Green	→ Pleasure	1.171	0.301	3.888	.000***
	Blue		1.964	0.300	6.538	.000***
	Yellow		1.478	0.297	4.984	.000***
	Orange		1.026	0.314	3.272	.001**
	Purple		0.688	0.338	2.034	.042*
Model Fit: χ^2= 148.09, ***p*** < .001; **CFI** =.942, **TLI** = .910, **RMSEA** < .001						

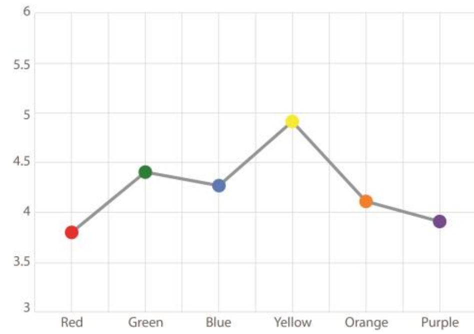
Note. Dummy variables were used for LED lighting colors. β = beta weights. S.E. = standard error. Est./S.E. = beta weights divided by standard error. [a]LED color = Color of LED lighting which affects behavioral intention. [b]χ^2 = chi square goodness of fit statistic. [c]CFI = Comparative Fit Index. [d]TLI = Tucker Lewis Index. [e]RMSEA = Root Mean Square Error of Approximation. *p<.05, **p<.01, ***p<.001

Effects of LED lighting Colors on Spatial Impressions

Cheerfulness. Table 16 presents the means and standard deviations for cheerfulness for six LED lighting colors. The mean value of the yellow lighting (*M* = 4.98, *SD* = 1.68) was the highest in terms of cheerfulness while the red lighting (*M* = 3.88, *SD* = 1.65) was rated the lowest, followed by purple lighting (*M* = 3.95, *SD* = 1.54). Levene's test for equality of variances found that the assumption of homogeneity of variance was met, *F* (5, 333) = 1.882, *p* = .097.

Table 16. *Means and Standard Deviations of Cheerfulness for LED Lighting Colors*

	n	*M*	*SD*
Red	50	3.88	1.65
Green	55	4.47	1.32
Blue	61	4.33	1.69
Yellow	58	4.98	1.68
Orange	53	4.15	1.94
Purple	62	3.95	1.54



Note. Means ranged from 1 to 7, with higher numbers representing more positive impression. [a]M = mean. [b]SD = Standard Deviation.

Table 17 shows the results of the one-way ANOVA for cheerfulness for six LED lighting colors. The one-way ANOVA results show that the differences in cheerfulness of the space among the LED lighting colors were statistically significant, F (5, 333) = 3.426, p = .005. Hypothesis 3-1 was supported. Post-hoc analyses using Tukey's HSD indicates that yellow lighting (M = 4.98, SD = 1.68) was rated as significantly more cheerful than red lighting (M = 3.88, SD = 1.65) or purple lighting (M = 3.95, SD = 1.54). These results suggest that people tend to see yellow lighting as the most cheerful lighting while red and purple lightings seem rather gloomy.

Table 17. *One-way ANOVA of the Influence of LED Lighting Colors on Cheerfulness*

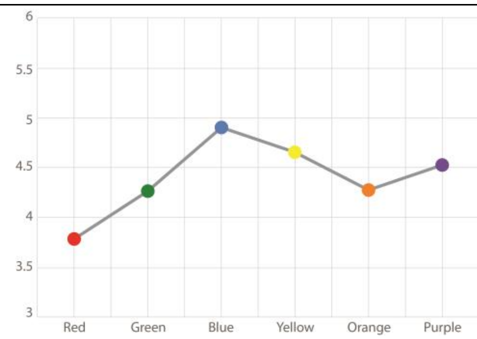
Source		***df***	***SS***	***MS***	***F***	***p***
Between groups		5	46.248	9.250	3.426	.005**
Within groups		333	899.062	2.700		
Total		338	945.310			
Post Hoc Test (Tukey)		**Mean Difference**		**Std. Error**		***p***
Yellow	Red	-1.103		.317		.008**
	Purple	1.031		.300		.009**

[a]df = degrees of freedom. [b]SS = Sum of Squares. [c]MS = Mean Square.
*p<.05, **p<.01, ***p<.001

Attractiveness. Table 18 presents the means and standard deviations of attractiveness for six lighting colors. The mean value of attractiveness was the highest under the blue lighting (*M* = 5.00, *SD* = 1.54) and the lowest under the red lighting (*M* = 3.72, *SD* = 1.69). The mean values of other lighting colors ranged from 4.47 (green) to 4.81 (yellow). Levene's test for equality of variances found that the assumption of homogeneity of variance was met, *F* (5, 333) = 1.384, *p* = .230.

Table 18. *Means and Standard Deviations of Attractiveness for LED Lighting Colors*

	n	***M***	***SD***
Red	50	3.72	1.69
Green	55	4.47	1.35
Blue	61	5.00	1.54
Yellow	58	4.81	1.62
Orange	53	4.53	1.54
Purple	62	4.61	1.75



Note. Means ranged from 1 to 7, with higher numbers representing a more positive impression. [a]M = mean. [b]SD = Standard Deviation.

Table 19 indicates the one-way ANOVA results on attractiveness for six lighting colors. The differences in attractiveness of the space among the LED lighting colors were statistically significant, *F* (5, 333) = 4.076, *p* = .001. Hypothesis 3-2 was supported. Post-hoc analyses using Tukey's HSD indicate that the red lighting (*M* = 3.72, *SD* = 1.69) was rated significantly less than blue (*M* = 5.00, *SD* = 1.54), yellow (*M* = 4.81, *SD* = 1.62), or purple (*M* = 4.61, *SD* = 1.75) lighting.

Table 19. *One-way ANOVA of the Influence of LED Lighting Colors on Attractiveness*

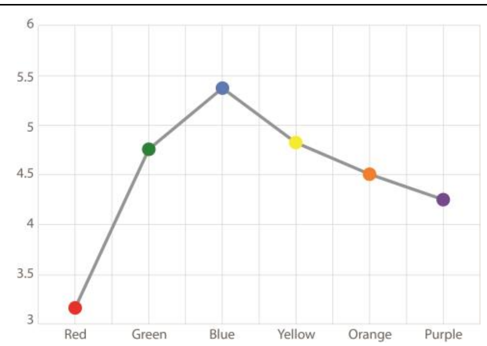
Source		***df***	***SS***	***MS***	***F***	***p***
Between groups		5	51.327	10.265	4.076	.001**
Within groups		333	838.620	2.518		
Total		338	889.947			
Post Hoc Test (Tukey)		**Mean Difference**		**Std. Error**		***p***
Red	Blue	-1.280		.303		.000***
	Yellow	-1.090		.306		.006**
	Purple	-.893		.302		.038*

[a]df = degrees of freedom. [b]SS = Sum of Squares. [c]MS = Mean Square.
*p<.05, **p<.01, ***p<.001

Comfort. Table 20 presents the means and standard deviations of comfort for six LED lighting colors. The mean value for the blue lighting (M = 5.43, SD = 1.51) was highest while that for the red lighting (M = 3.26, SD = 1.66) was lowest (Table 18). The mean ratings of other lighting colors ranged from 4.29 (purple) to 4.88 (yellow). Levene's test for equality of variances found that the assumption of homogeneity of variance was met, F (5, 333) = 2.224, p = .052.

Table 20. *Means and Standard Deviations of Comfort for LED Lighting Colors*

	n	***M***	***SD***
Red	50	3.26	1.66
Green	55	4.75	1.64
Blue	61	5.43	1.51
Yellow	58	4.88	1.69
Orange	53	4.51	1.75
Purple	62	4.29	1.92



Note. Means ranged from 1 to 7, with higher numbers representing a more positive impression.
[a]M = mean. [b]SD = Standard Deviation.

Table 21 presents the results of the one-way ANOVA on comfort for six colors of LED lighting. The differences in how comfortable people feel under different colors of LED lighting were statistically significant, F (5, 333) = 9.867, p = .000. Hypothesis 3-3 was supported. Post-hoc analyses using Tukey's HSD indicate that red lighting (M = 3.26, SD = 1.66) felt significantly less comfortable than all other lighting colors. The blue lighting (M = 5.43, SD = 1.51) was rated significantly more comfortable than orange (M = 4.51, SD = 1.75) or purple lighting (M = 4.29, SD = 1.92).

Table 21. *One-way ANOVA of the influence of LED Lighting Colors on Comfort*

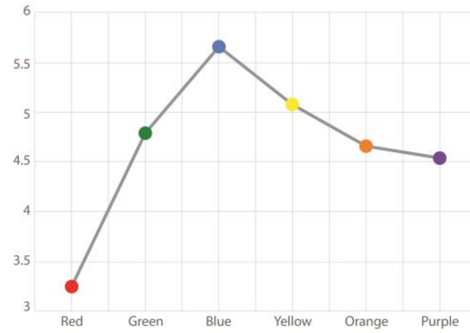
Source		***df***	***SS***	***MS***	***F***	***p***
Between groups		5	142.698	28.540	9.867	.000***
Within groups		333	963.149	2.892		
Total		338	1105.847			
Post Hoc Test (Tukey)		**Mean Difference**		**Std. Error**		***p***
Red	Green	-1.485		.332		.000***
	Blue	-2.166		.324		.000***
	Yellow	-1.619		.328		.000***
	Orange	-1.249		.335		.003**
	Purple	-1.030		.323		.019*
Blue	Orange	.917		.319		.049*
	Purple	1.136		.307		.003**

[a]df = degrees of freedom. [b]SS = Sum of Squares. [c]MS = Mean Square.
*p<.05, **p<.01, ***p<.001

Pleasantness. Table 22 shows the means and standard deviations of pleasantness for six colors of LED lighting. The mean value of pleasantness was the highest under the blue lighting (M = 5.67, SD = 1.54) and the lowest under the red lighting (M = 3.34, SD = 1.79). The mean values of other lighting colors ranged from 4.58 (purple) to 5.10 (yellow). Levene's test for equality of variances found that the assumption of homogeneity of variance was met, F (5, 333) = 1.502, p = .189.

Table 22. *Means and Standard Deviations of Pleasantness for LED Lighting Colors*

	n	*M*	*SD*
Red	50	3.34	1.79
Green	55	4.75	1.54
Blue	61	5.67	1.54
Yellow	58	5.10	1.63
Orange	53	4.66	1.61
Purple	62	4.58	2.02



Note. Means ranged from 1 to 7, with higher numbers representing a more positive impression.
[a]M = mean. [b]SD = Standard Deviation.

Table 23 presents the results of one-way ANOVA on pleasantness for six colors of LED lightings. The results of one-way ANOVA show that there were statistically significant differences in the pleasantness of the space among different colors of LED lighting, F (5, 333) = 10.116, p = .000. Hypothesis 3-4 was supported. Post-hoc analyses using Tukey's HSD indicate that red lighting (M = 3.34, SD = 1.79) was rated significantly less pleasant than all other lighting colors. The blue lighting (M = 5.67, SD = 1.54) was rated significantly more pleasant than other lighting colors except the yellow lighting (M = 5.10, SD = 1.63).

Table 23. *One-way ANOVA of the influence of LED Lighting Colors on Pleasantness*

Source	*df*	*SS*	*MS*	*F*	*p*
Between groups	5	160.473	32.095	11.116	.000***
Within groups	333	961.462	2.887		
Total	338	1121.935			

Post Hoc Test (Tukey)		**Mean Difference**	**Std. Error**	***p***
Red	Green	-1.405*	.332	.000***
	Blue	-2.332*	.324	.000***
	Yellow	-1.763*	.328	.000***
	Orange	-1.320*	.335	.001**
	Purple	-1.241*	.323	.002**

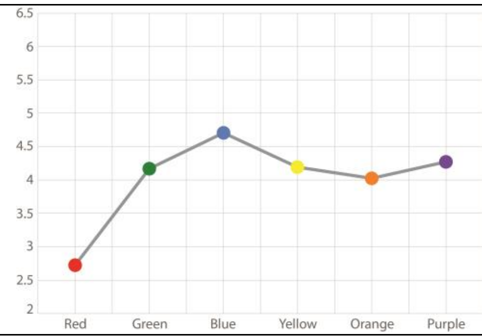
Table 23. (cont'd)				
Blue	Green	.927	.316	.041*
	Orange	1.012	.319	.020*
	Purple	1.091	.306	.006**

[a]df = degrees of freedom. [b]SS = Sum of Squares. [c]MS = Mean Square.
*p<.05, **p<.01, ***p<.001

Relaxation. Table 24 presents means and standard deviations of relaxation for six colors of LED lighting. The mean value for the blue lighting (M = 4.72, SD = 1.86) was the highest in terms of relaxation while the value for the red lighting was the lowest, with very low mean scores (M = 2.74, SD = 1.58). The mean ratings of other lighting colors ranged from 4.04 (orange) to 4.31 (purple). Levene's test for equality of variances found that the assumption of homogeneity of variance was met, F (5, 333) = 1.627, p = .152.

Table 24. *Means and Standard Deviations of Relaxation for LED Lighting Colors*

	n	***M***	***SD***
Red	50	2.74	1.58
Green	55	4.18	1.83
Blue	61	4.72	1.86
Yellow	58	4.24	1.98
Orange	53	4.04	1.70
Purple	62	4.31	1.80



Note. Means ranged from 1 to 7, with higher numbers representing a more positive impression.
[a]M = mean. [b]SD = Standard Deviation.

Table 25 shows the one-way ANOVA results for relaxation. There were statistically significant differences in relaxation ratings among the LED lighting colors, F (5, 333) = 3.035, p = .011. Hypothesis 3-5 was supported. Post-hoc analyses using Tukey's HSD indicate that relaxation score for the red lighting (M = 2.74, SD = 1.58) was significantly lower than that for all the other colors. The mean score for red was considerably below the midpoint of the scale, whereas all the other scores were above the midpoint.

Table 25. *One-way ANOVA of the influence of LED Lighting Colors on Relaxation*

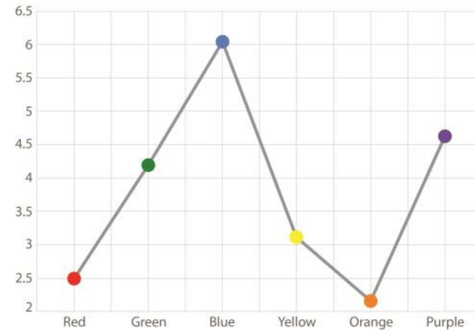
Source		***Df***	***SS***	***MS***	***F***	***p***
Between groups		5	50.896	10.179	3.035	.011*
Within groups		333	966.019	3.354		
Total		338	1016.915			
Post Hoc Test (Tukey)		**Mean Difference**		**Std. Error**		***p***
Red	Green	1.442		.352		.001***
	Blue	1.981		.344		.000***
	Yellow	1.501		.348		.000***
	Orange	1.298		.355		.004**
	Purple	1.566		.342		.000***

[a]df = degrees of freedom. [b]SS = Sum of Squares. [c]MS = Mean Square.
*p<.05, **p<.01, ***p<.001

Warmness/Coolness. Table 26 presents the means and standard deviations of rated warmness/coolness of six colors of lighting. The mean value for the blue lighting (*M* = 6.03, *SD* = 1.34) was the highest (coolest) and the red lighting (*M* = 2.50, *SD* = 1.56) showed the lowest (warmest) mean rating. Red (*M* = 2.50, *SD* = 1.56), orange (*M* = 2.17, *SD* = 1.11), and yellow (*M* = 3.16, *SD* = 1.76) lighting were all rated warmer than (below) the midpoint of the scale (4). On the other hand, the means for the blue (*M* = 6.03, *SD* = 1.34), green (*M* = 4.25, *SD* = 1.47), and purple (*M* = 4.61, *SD* = 1.81) lighting were all above (i.e., cooler than) the neutral point. Levene's test for equality of variances found that the assumption of homogeneity of variance was met, *F* (5, 333) = 1.972, *p* = .082.

Table 26. *Means and Standard Deviations of Warmness/Coolness for LED Lighting Colors*

	n	***M***	***SD***
Red	50	2.50	1.56
Green	55	4.25	1.47
Blue	61	6.03	1.34
Yellow	58	3.16	1.76
Orange	53	2.17	1.12
Purple	62	4.61	1.81



Note. Means ranged from 1 to 7, with higher numbers representing cooler lighting colors. [a]M = mean. [b]SD = Standard Deviation.

Table 27 shows the one-way ANOVA results for the warmness versus coolness of the lighting colors. There were statistically significant differences in warmness/coolness among the different LED lighting colors, F (5, 333) = 51.429, p = .000. The hypothesis 3-6 was supported. Post-hoc analyses using Tukey's HSD indicated that the red lighting (M = 2.50, SD = 1.56) was rated significantly warmer than green (M = 4.25, SD = 1.47), blue (M = 6.03, SD = 1.34), or purple (M = 4.61, SD = 1.81) lighting. The blue lighting (M = 6.03, SD = 1.34) was rated significantly cooler than all the others. The green lighting (M = 4.25, SD = 1.47) was also rated significant cooler than red (M = 2.50, SD = 1.56), yellow (M = 3.16, SD = 1.75), or orange (M = 2.17, SD = 1.10). Orange lighting (M = 2.17, SD = 1.10) was rated significantly warmer than all other lighting except the red lighting (M = 2.50, SD = 1.56). Purple lighting (M = 4.61, SD = 1.81) was significantly different from the other lighting except for green (M = 4.25, SD = 1.47).

Table 27. *One-way ANOVA of the influence of LED Lighting Colors on Warmness/Coolness*

Source	***df***	***SS***	***MS***	***F***	***p***
Between groups	5	604.371	120.874	51.429	.000***
Within groups	333	782.656	2.350		
Total	338	1387.027			

Table 27. (cont'd)				
Post Hoc Test (Tukey)		**Mean Difference**	**Std. Error**	***p***
Red	Green	-1.755	.300	.000***
	Blue	-3.533	.292	.000***
	Purple	-2.113	.291	.000***
Green	Blue	-1.778	.285	.000***
	Yellow	1.099	.289	.002**
	Orange	2.085	.295	.000***
Blue	Yellow	2.878	.281	.000***
	Orange	3.863	.288	.000***
	Purple	1.420	.276	.000***
Yellow	Orange	.985	.291	.010*
	Purple	-1.458	.280	.000***
Orange	Purple	-2.443	.287	.000***

[a]df = degrees of freedom. [b]SS = Sum of Squares. [c]MS = Mean Square.
*p<.05, **p<.01, ***p<.001

Lighting color image scale. Based on the results for warmness/coolness and cheerfulness for six colors of LED lighting, the lighting color image scale was developed. Adapting Kobayashi's color image scale, six colors of LED lighting were placed in the two-dimensional scale diagram with warm-cool on the horizontal axis and cheerful-gloomy on the vertical axis. Figure 24 shows the comparison of the color image scale for the six LED lighting colors and the comparable six colors on Kobayashi's color image scale. Comparison of the two color image scales reveals a strong resemblance for impressions of warmness and coolness of colors. It can be predicted that, just like pigment colors, people tend to perceive red, orange and yellow lighting as warm and green, blue and purple lighting as cool.

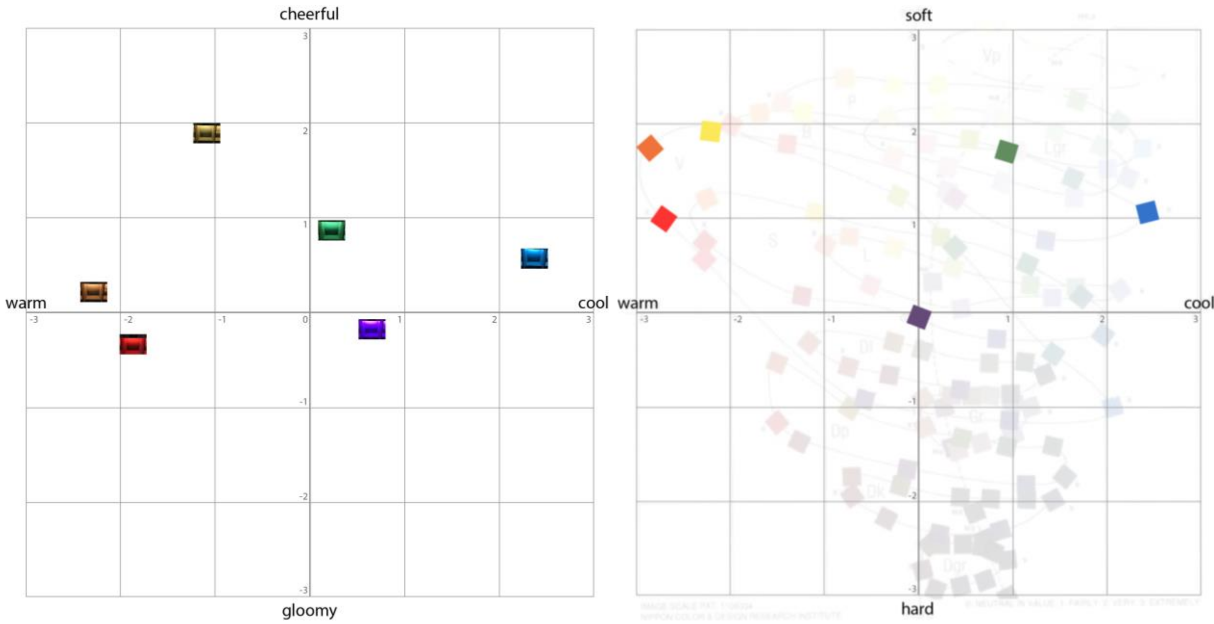


Figure 24. Color image scale of LED lighting vs. Kobayashi's color image scale

Color Preference by Gender, Age, and Cultural Background

Color preference by gender. Table 26 presents the means and standard deviations of color preference ratings for male and female participants. The least preferred color of LED lighting was red for both male (M = 3.67, SD = 1.92) and female (M = 2.83, SD = 1.90) participants. The blue lighting was rated the highest by both male (M = 5.70, SD = 1.41) and female (M = 5.31, SD = 1.73) participants. The overall mean value of color preference for each LED lighting color was very similar between male and female groups.

Table 28. *Means and Standard Deviations of the Color Preference for LED Lighting by Gender*

	Red		Green		Blue		Yellow		Orange		Purple	
Gender	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
Male	3.67	1.92	4.62	1.75	5.70	1.41	5.04	1.80	4.89	1.55	4.17	2.09
Female	2.83	1.90	4.72	1.62	5.41	1.73	4.88	1.79	4.04	1.88	4.76	1.95

n = 339. [a]M = Mean. [b]SD = Standard Deviation. [c]GEN = Gender.

Table 29 presents the one-way ANOVA results for color preference by gender. A Levene test found that the assumption of homogeneity of variance was met, one-way ANOVA was carried out. Gender differences in LED color preference were not significant. Hypothesis 4-1 was not supported.

Table 29. *One-way ANOVA of Color Preference of LED Lighting by Gender*

Source		***df***	***SS***	***MS***	***F***	***p***
Between groups	Red	1	8.776	8.776	2.403	.128
	Green	1	.162	.162	.057	.812
	Blue	1	1.283	1.283	.505	.480
	Yellow	1	.383	.383	.119	.731
	Orange	1	9.607	9.607	3.274	.076
	Purple	1	5.285	5.285	1.299	.259

[a]df = degrees of freedom. [b]SS = Sum of Squares. [c]MS = Mean Square.
*p<.05, **p<.01, ***p<.001

Color preference by age group. Table 30 presents the means and standard deviations of color preference by age group. The average color preference for blue lighting was highest in two groups under 36. People in groups over 36 preferred green lighting the most. Red lighting had the lowest mean value for color preference for all age groups except those under 21.

Table 30. *Means and Standard Deviations of the Color Preference for LED Lighting by Age*

	Red		Green		Blue		Yellow		Orange		Purple	
Age	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
-25	3.80	1.82	4.88	1.80	5.71	1.37	4.91	1.69	5.00	1.24	4.64	1.81
26-35	2.83	1.85	4.24	1.59	5.69	1.52	4.50	1.96	4.33	1.65	4.27	2.07
36-	3.50	2.20	5.67	0.82	4.82	2.09	5.56	1.59	4.07	2.34	4.56	2.28

n = 339. [a]M = Mean. [b]SD = Standard Deviation.

As shown in Table 31, there were no significant age differences in preferred color of LED lighting. Hypothesis 4-2 was not supported.

Table 31. *One-way ANOVA of Color Preference of LED Lighting by Age*

Source		***df***	***SS***	***MS***	***F***	***p***
Between groups	Red	2	9.376	4.688	1.261	.293
	Green	2	11.591	5.795	2.176	.124
	Blue	2	7.014	3.507	1.411	.252
	Yellow	2	10.089	5.045	1.625	.206
	Orange	2	7.650	3.825	1.262	.292
	Purple	2	1.585	.792	.189	.829

[a]df = degrees of freedom. [b]SS = Sum of Squares. [c]MS = Mean Square.
*p<.05, **p<.01, ***p<.001

Color preference by cultural background. In terms of cultural differences, due to the low number of participants in the cultural group of African/Black, Hispanic/Latino, Pacific Islander, Mixed race, and other, the analysis was conducted between Asian and Caucasian which in sum were more than 80% of all participants (Table 32). The mean value of preference for red lighting was lower in the Asian group (*M* = 2.53, *SD* = 1.81) compared to the Caucasian (*M* = 4.04, *SD* = 1.78) groups. The mean preference for blue lighting was high in both cultural groups. The mean preference for orange lighting was higher in the Caucasian group (*M* = 5.21, *SD* = 1.36) than Asian group (*M* = 4.32, *SD* = 1.91). The mean preference for purple lighting was low in the Asian group (*M* = 3.50, *SD* = 2.03) and high in the Caucasian group (*M* = 5.25, *SD* = 1.57) groups.

Table 32. *Means and Standard Deviations of the Color Preference of Lighting by Cultural Background*

	Red		Green		Blue		Yellow		Orange		Purple	
Cultural Group	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**
Asian	2.53	1.81	4.82	1.62	5.54	1.62	5.16	1.63	4.32	1.91	3.50	2.03
Caucasian	4.04	1.78	4.63	1.80	5.25	1.69	4.29	2.05	5.21	1.36	5.25	1.57

n = 82. [a]M = Mean. [b]SD = Standard Deviation.

Results of the one-way ANOVA showed that cultural differences in color preference of LED lighting were statistically significant (see Table 33). Hypothesis 4-3 was supported. Post-hoc analyses using Tukey's HSD indicate that Asians (*M* = 2.53, *SD* = 1.81) had a significantly greater aversion to red lighting than Caucasians (*M* = 4.04, *SD* = 1.78) group. Caucasians (*M* = 5.25, *SD* = 1.57) had a stronger preference for purple lighting than Asians (*M* = 3.50 *SD* = 2.03).

Table 33. *One-way ANOVA of Color Preference of LED Lighting by Cultural Background*

Source			***df***	***SS***	***MS***	***F***	***p***
Between groups		Red	2	35.457	12.728	3.757	.031*
		Purple	2	47.909	23.955	7.006	.002**
Post Hoc Test (Tukey)			**Mean Difference**		**Std. Error**		***p***
Red	Asian	Caucasian	-1.515*		.565		.027
Purple	Asian	Caucasian	-1.750**		.523		.004

[a]df = degrees of freedom. [b]SS = Sum of Squares. [c]MS = Mean Square.
*p<.05, **p<.01, ***p<.001

All of the hypotheses were tested and the results supported 12 out of 14 hypotheses. Table 34 summarizes the results of the hypothesis tests.

Table 34. *Results of Hypothesis Tests*

Hypotheses		Result
RQ1. Does emotional response significantly differ by light color?		
H1-1	There are significant differences in positive affect in response to the six colors of LED lighting.	Supported
H1-2	There are significant differences in arousal in response to the six colors of LED lighting.	Supported
RQ2. Does behavioral intention significantly differ by light color?		
H2-1	There are significant differences in behavioral intentions in response to the six colors of LED lighting.	Supported
H2-2	There are significant indirect effects of the six colors of LED lighting on behavioral intentions mediated by pleasantness of affect.	Supported
H2-3	There are significant indirect effects of six colors of LED lighting on behavioral intention mediated by arousal.	Supported

Table 34. (cont'd)

RQ3. Does spatial impression significantly differ by six colored LED lighting?		
H3-1	There are significant differences in cheerfulness of space in response to the different colors of LED lighting.	Supported
H3-2	There are significant differences in attractiveness in response to the different colors of LED lighting.	Supported
H3-3	There are significant differences in comfort in response to the different colors of LED lighting.	Supported
H3-4	There are significant differences in pleasantness in response to the different colors of LED lighting.	Supported
H3-5	There are significant differences in relaxation in response to the different colors of LED lighting.	Supported
H3-6	There are significant differences in warmness/coolness in response to the different colors of LED lighting.	Supported
RQ4. Do socio-demographic conditions affect preferences for LED lighting?		
H4-1	There are significant differences in preferences for LED lighting colors between males and females.	Not supported
H4-2	There are significant differences in preferences for LED lighting colors among the different age groups.	Not supported
H4-3	There are significant differences in preferences for LED lighting colors among the different cultural groups.	Supported

Note. RQ = Research Question, H = Hypothesis

CHAPTER 5

DISCUSSION AND CONCLUSION

This chapter presents four sections. The first section summarizes the study. The second section discusses the findings and theoretical contributions, and the third section discusses the implications of the study. Limitations and possible future research directions are reviewed in the final section.

Summary of the Study

The purpose of the study was threefold: (1) to explore the effects of six different colors of LED lighting on emotional states and behavioral intentions, (2) to explore the effects of six different colors of LED lighting on spatial impressions, and (3) to explore the effects of socio-demographics on color preferences for LED lighting. Based on Mehrabian and Russell's M-R model (1974) as a theoretical framework, four main research questions with 14 hypotheses were developed. An experimental research design was employed to answer the research questions by testing hypotheses. In an experimental lab equipped with color changing LED lighting systems, a total of 101 participants participated in the experiments and 342 data points were collected.

To test the hypotheses, this study conducted the one-way ANOVA for emotional states (i.e., pleasure and arousal), behavioral intentions (i.e., approach or avoidance), impressions of the space where the lights were installed (i.e., cheerfulness, attractiveness, comfort, pleasantness, relaxation and warmness/coolness), and color preferences (i.e., degree of liking or dislike) among six colors of LED lighting. Additionally, the study conducted regression analysis and path analysis for emotional states, and behavioral intentions and to analyze the mediating effects based on the M-R model. The results of the one-way ANOVA confirmed that there are significant differences among the six different colors of LED lighting in emotional states (H1), behavioral intentions (H2-1), and spatial impressions (H3). The regression and path analysis demonstrated that pleasure significantly mediates the relationship between LED lighting colors and behavioral intentions (H2-2). Finally, one-way ANOVA of color preference by socio-demographics showed that color preference was significantly different among different cultural groups (H4-3).

Discussion

Effects of LED lighting Colors on Emotional States and Behavioral Intentions

The findings reveal that lighting colors significantly impact people's feeling of pleasure and arousal as well as behavioral intention. Of the six lighting colors, blue and red in particular show dominant contrasting results for all variables. On the other hand, green, yellow, orange and purple lightings do not show much difference for most variables, unlike the prediction.

First, it is found that there are significant differences in pleasure among six lighting colors examined in this study. Blue lighting showed the highest scores for pleasure among the six lighting colors and had a significantly higher pleasure level than warm lighting colors: red and orange. Given that many previous color studies have demonstrated that blue was a highly pleasant and preferred color (Al-Ayash et al., 2016; Jalil et al., 2013; Madden et al., 2000; Yildirim et al., 2015), these findings provide empirical evidence in support of previous color studies that noted a high level of pleasure in blue. On the other hand, the red lighting received the lowest mean score for pleasure and the mean scores were significantly lower than all other five colors. This finding indicates that people can feel unpleasant when they are in a space illuminated with red lighting. In line with Al-Ayash et al. (2016) and Bellizzi and Hite (1992), the result supports the findings of previous color studies showing that red is not a pleasantly perceived color, but effects of red lighting on pleasure showed mixed results in some previous studies. For example, the lighting study of Odabaşioğlu et al. (2015) found that there was no significant difference in the pleasure level between red lighting and green lighting. In addition, considering that people feel less pleasant in blueish cool white lighting with high color temperature than in reddish warm white lighting with low color temperature (Park et al., 2007; Wu et al., 2015), the result of this study indicates the effects of cool or warm colored lighting on pleasure are different from cool or warm white lighting, which are more consistent with findings of pigment color studies by Jalil et al. (2013), Madden et al. (2000) and Yildirim et al. (2015).

Second, the findings revealed that the red lighting received the highest mean ratings for arousal and this level was significantly higher than all cool colored lightings such as blue, green, and purple. Many previous color studies reported that red is physiologically arousing in terms of heart rate, respiration, and skin response (Gerard, 1958; Jacobs & Hustmyer, 1974; Kaufman, 2003; Siamionava et al., 2018; Wilson, 1966). This study provides empirical evidence that emotional arousing effects of red lighting is significantly higher than cool colored lighting. The mean ratings of arousal on yellow and orange lighting were also higher than the mean arousal scores of green, blue, and purple lighting. This result supported Kaufman (2003) and Wilson (1966)'s previous findings of color studies that warm colors such as red, orange, and yellow have more arousal effects while cool colors such as green and blue have more calming effects.

Third, the findings reveal that people's behavior can be affected by different lighting colors. The mean ratings for behavioral intention were the highest for blue lighting while the lowest for red lighting. This result indicates that people might want (or try) to avoid or leave a space when they are exposed to red lighting while they might want (or try) to approach or stay longer in a space when they are exposed to blue lighting. This result is consistent with previous pigment color studies which showed negative impact of red and positive impact of blue on behaviors (Al-Ayash et al., 2016; Siamionava et al., 2018; Yildirim et al., 2015).

The findings also revealed that effects of yellow and green lighting on pleasure and behavioral intension were very similar. The mean ratings of yellow were the second highest and green the third highest in both pleasure levels and approach/avoid behavioral intentions. In the color study of Tantanatewin et al., (2016), yellow showed higher pleasure levels than purple while pleasant levels of purple were significantly higher than yellow in Yildirim et al. (2007). Considering that previous studies rarely focused on the effects of secondary colors: yellow, orange, and purple lightings; although pigment colors of the secondary colors were examined (Tantanatewin et al., 2016; Tantanatewin et al., 2018; Yildirim et al., 2007); the present study illuminates the effects of secondary colors of lighting on emotions and behaviors.

Moreover, this study confirmed the mediating effects of emotional states between LED lighting colors and behavioral intentions. The path analysis proves that there are indirect effects of LED lighting colors on behavioral intention mediated by pleasure. In line with previous studies which demonstrated the mediating effects of emotional states (e.g., Ha et al., 2010; Jani et al., 2015; Kim et al., 2009; Morris et al, 2011) on behavioral intention, this study supports Mehrabian and Russell's M-R model (1974). Although contrary to the M-R model, this study does not find any significant mediation effects of arousal, this result is also consistent with previous studies which demonstrated a weak relationship of arousal with environmental stimuli as well behaviors (Ryu & Jang, 2007).

Furthermore, this study applied the circumplex model of emotions proposed by Russell (1980) and Nardelli et al., (2015), and developed the two-dimensional visual matrix of lighting emotions for six colors of lighting based on pleasure and arousal. Six lighting colors were placed on the circumplex model of emotion to visually present how each lighting color is associated with various emotions. The circumplex model of emotions for six lighting relevantly explains the color emotions derived from the results of pleasure and arousal levels in this study. The findings demonstrate that red lighting was related to unpleasant or upset emotions while blue lighting was associated with serene and calm emotions. Along with blue lighting, although not as strong, yellow, green, and orange lightings were more related to relaxed emotions while purple lighting was slightly associated with the emotion of depression and fatigue. The findings indicate that the circumplex model of emotions is an effective visual tool to present relevant emotions associated with each lighting color. Circumplex model can be a very effective tool for easy recognition of how each lighting color relates to people's feelings. Thus, it is expected that anyone including professionals to use this model to easily apply the lighting colors based on the purpose.

Effects of LED lighting Colors on Spatial Impression

This study measures the impact of lighting colors on six spatial impressions including cheerfulness, attractiveness, comfort, pleasantness, relaxation, and warmness/coolness based on the previous studies (Countryman & Jang, 2006; Flynn, 1977; Tantanatewin et al., 2018; Wu et al., 2015). One of the main findings is that warmness and coolness of lighting colors are very similar to that of pigment colors. Other findings reveal that lighting colors influence people's impression of a space in terms of attractiveness, comfort, pleasantness and relaxation, supporting Countryman et al. (2006), Tantanatewin et al. (2016) and Wu et al. (2015). Similar to the results of lighting color effects on the emotional states, blue and red lightings show dominant contrasting results in terms of lighting color effects on spatial impressions.

The results of this study demonstrate that the mean ratings for blue lighting are the highest for four impressions: attractiveness, comfort, pleasantness, and relaxation whereas red lighting shows the lowest mean ratings for the same four impressions. These results are consistent with previous color studies in the color psychology literature (Bellizzi et al., 1992; Siamionava et al., 2018; Yildirim et al., 2015). As in the results of pleasure and behavioral intentions, significant differences are observed in red and blue lightings across the four impressions. In terms of other lighting colors, the mean ratings of green, yellow, orange, and purple lightings for attractiveness, comfort, pleasantness, and relaxation showed that all these lighting colors are positively perceived by people. However, in the study of color and lighting effects on retail impression conducted by Tantanatewin et al. (2016), yellow background was found to be more positively perceived than blue and purple backgrounds. Further studies with various colors with different lighting colors are recommended because only a few studies explore lighting colors other than primary colors and the results were inconsistent.

Meanwhile, the yellow lighting was found to be the most cheerful lighting color in this study. This finding offers an explanation that people perceive yellow as a cheerful color in both pigment and lighting. The result of this study also showed that red, yellow, and orange lightings were related to the impression of warmness while green, blue, and purple lightings were related to impressions of coolness. Along with the common impressions that red, yellow, and orange are warm colors and that green, blue, and purple are cool colors, it was proved that people feel the same about lighting colors in terms of warmness and coolness.

Similar to the circumplex model of emotion mentioned earlier, this study develops the lighting color image scale by referring to the Kobayashi's color image scale, where the x-axis represents warm-cool and the y-axis represents cheerful-gloomy. Although the y-axis represents a different impression compared to Kobayashi's color image scale, it is demonstrated that the possibility of lighting color image scales is as useful as Kobayashi's color image scale. With more lighting colors applied to it, this initial lighting color image scale showed some potential for further development in future studies.

Color Preference by Gender, Age, and Cultural Background

This study examines color preferences by three socio-demographics, gender, age, and cultural background. The findings reveal that cultural differences are an influencing factor on the color preference of lighting. This result supports studies on the cultural difference of color preference (Madden et al., 2000; Park et al., 2010; Xin et al., 2004; Yi et al., 2015). Although the cultural background of participants and colors used in the experiments were different than in previous studies, this study confirms that there are cultural differences in the color preference of lighting. The findings indicated that Asians significantly do not prefer red and purple lighting compared to Caucasians. No difference is found on the color preference of lightings for green, blue, yellow, and orange lightings, but the mean values of preference in lighting color indicates that both Asians and Caucasians preferred blue lighting the most and red lighting the least. Green, yellow, and orange lightings are also preferred by both cultural groups. Previous studies found that blue appears to be the most preferred color by all cultural groups and green, white, and red were also preferred by all nationalities (Madden et al., 2000; Xin et al., 2004). Red color preference of pigment color and lighting color are different in cultural groups, but blue is the most preferred color both in pigment and lighting colors regardless of cultural background.

On the contrary, it was found that gender does not have any impact on the color preference of lighting. This result is in accordance with Odabaşioğlu and Olguntürk (2015) in that there were no differences between male and female under red lighting as well as green lighting. However, these results are not consistent with those of many other studies proving gender differences of pigment color preferences (Hurlbert et al., 2007; Jalil et al., 2013; Ou et al., 2004; Yildirim et al., 2007). It was also found that there is no significant age difference on the color preference of lighting. The age differences of color preference studies are limited, but the color perception of very young participants or very old participants are continuously explored. Laufer et al. (2009) and Beke et al. (2008) found that elderly groups averaging 65 years old preferred red color and high chroma colors. Similarly, Adams (1987) found that infants preferred warm colors over cool colors. These results contrast with the findings that adults tend to prefer blue (Al-Ayash et al., 2016; Jalil et al., 2013; Madden et al., 2000; Yildirim et al., 2015). Michaels (1924), and Suchman et al. (1966) discovered that there were differences in color preference between younger children and older children. It can be estimated from the literature that there are differences in the preference of lighting colors among an adult group, a very young group, and a very old group. Further studies on age difference of lighting color preference are suggested.

Implications

There are both theoretical and practical implications from the results of this study. This section discusses the theoretical contributions to the body of existing knowledge and the practical implications for design professionals and policy makers.

Theoretical Implications

Theoretically, the present study contributes to the current lighting and color literature. One important theoretical implication is the application of Mehrabian and Russell's M-R model of Stimulus-Organism-Response (SOR) paradigm to explain effects of lighting color on emotions and behaviors. The M-R model (Mehrabian & Russell, 1974) has been adapted as a theoretical framework by many researchers for more than four decades (e.g., Countryman et al., 2006; Heung et al., 2012; Magnini et al., 2016; Park et al., 2007; Quartier et al., 2014; Wu & Wang, 2015), but few studies have ever used the M-R model for effects of lighting colors. The present experimental study expands the application of the M-R model by testing it to examine effects of lighting color and enriches the knowledge in lighting color literature. Furthermore, this study identifies mediating effects of emotional states between environmental stimuli and behavioral intention by conducting path analysis. Given that very few color studies have explored the mediating effect in the M-R model and most of previous studies just focused on the effects of color on emotional states (NAz & Epps, 2004; Siamionava et al., 2018; Yildirim et al., 2007), this study goes a step further to validate the mediating effects associated with color by analyzing the mediating effects of pleasure between LED lighting colors and behavioral intention.

A second theoretical implication is its timely focus on colored lighting. Color and lighting have been studied separately by various researchers in different disciplines for a long time but colored lighting has just begun to get the attention of researchers. As it is expected that there will be an increase in studies on colored lighting due to significant growth in the use of color changing LED lighting (DOE, 2014), this study provides insights into directions of future colored lighting studies. In addition, given that previous color studies focused mostly on the effects of primary colors: red, green, and blue (e.g., Odabaşioğlu et al., 2015; Siamionava et al., 2018), the present study contributes to the existing literature on color by investigating effects of secondary colors (i.e., yellow, orange, and purple) in addition to the primary colors.

A third theoretical implication of this study is its methodological approach. Due to time , environmental, and economic condition limitations, most color or lighting studies (e.g., Siamionava et al., 2018; Tantanatewin et al., 2016, 2018) used photographic images or computer-simulated images to assess the effects of color or lighting instead of conducting an experiment under actual color and lighting conditions. This study conducts an experiment in the controlled sensory lab equipped with a color changing LED lighting system and each participant was exposed to six actual lighting colors randomly manipulated by the researcher. Compared to the studies that used photo or computer simulations, this study conducts a more rigorous methodological approach and illuminates a research method for future colored lighting studies.

Finally, the present study contributes to our current understanding of color emotions by presenting lighting colors emotions and impressions on the visual matrices (1) by applying pleasure-arousal levels on the circumplex model of emotion (Nardelli et al., 2015; Russell, 1980) and (2) by applying cheerfulness-warmness/coolness levels on the matrix of the lighting color image scale (Kobayashi, 1981). By identifying the possible application of these visual tools on lighting color emotions, this study is perhaps the first to develop the circumplex model and color image scale for colored lighting. These two models will be developed further with more colors of lighting in the near future.

Practical Implications

The results of this study not only contribute to the body of knowledge on color and lighting research but also provide practical guidelines for design practitioners who are interested in effective lighting design with colored lighting as well as individual users who want to design their own space with various colors of LED lighting.

First, the insights provided by this study can support design professionals such as interior designers, lighting designers, and architects. For instance, based on the results that people feel pleasant and comfortable the most under blue lighting followed by yellow and green lighting, it is recommended to use blue lighting to create pleasant and comfortable spaces such as break areas, reception areas in general, and in particular, waiting and reception areas for healthcare facilities. Yellow or green lighting can also be good options for those areas. Based on findings that yellow lighting was significantly more cheerful than other lighting colors, it is recommended to use yellow lighting for play areas for children, indoor recreation areas, and shopping malls. Based on findings that people feel more relaxed under blue lighting followed by purple lighting, it is suggested that designers choose blue or purple lighting for spas and massage shops. Based on the results that people can be stimulated, but also tensed or stressed under red lighting, it is suggested that designers should be very careful in using red lighting. Red lighting might be a good choice for entertaining area such as a club or bar, but caution should be practiced when employing such a color.

In addition, considering that many previous lighting studies have found that warm white lighting is more preferred and feels more pleasant than cool white lighting (Park, 2003; Wu & Wang, 2015) contrary to results of this study, care should be taken when using colored lighting for the entire space. Designers should be aware that the effect of warm and cool white lighting is different from that of warm and cool colored lighting. The experiment in this study was conducted in a small booth rather than in the whole room and the effects of lighting colors may vary when applied to the entire room. Therefore, the use of colored lighting for interior spaces would be more effective when used as an accent lighting.

Additionally, designers should also consider the cultural background of the users when choosing the color of LED lighting. The results suggest using purple and orange lightings for Caucasians but to avoid these colors for Asians. Asian users are not fond of red lighting while Caucasian users perceive all colors of lighting positively. Moreover, results of studies about the cultural difference in color preferences show differences over time which may be assumed by the changes in cultural flow and globalization. Because the world changes fast, continuous research on cultural difference in color preference is needed for the better indoor lives of people.

Any people who are interested in using colored lighting can also benefit from the results of this study. With the advancement of technology, it is now very easy to change colors of lighting with a simple manipulation from the application of a mobile device. LED lightings today are easily connected with the popular smart devices like Echo, Alexa, HomePod and Home. With huge smart speaker market growth, it is easy to find LED lightings used in the residents (Market

Research Report, 2018). It would be easier to change the mood and impression of interior by using the color changing LED lighting than changing the paint color. It is expected that more people will use the colored LED lighting for their interior spaces and the result of this study can provide evidence-based insights.

Limitations and Future Research

Although this study presents contributions to the body of knowledge on color and lighting research, several limitations exist. First, the voluntary sampling approach can limit the generalization of the results. As the participants were recruited via the online research pool at Michigan State University, only the people who were aware of this online pool were able to apply for the experiment. Although participants were randomly assigned to the experiment sessions, the results of this study should be applied with caution because only certain types of people could participate in the experiment. The sample may not be appropriately representative of the population. Future study is recommended to replicate this study using a more rigorous probability sampling and random assignment to validate the results of this study.

Another limitation is related to the experiment room settings. The objective of this study is to examine the effects of LED lighting colors of interior space. Due to the limitation of the facilities, the experiment had to be conducted in a small booth instead of a large room. There might be differences in how people perceive the space with colored lighting in a booth compared to the entire room. A laboratory setting of an entire room with LED lighting is recommended in future studies.

The last limitation is that this study did not include a neutral colored lighting as a control variable. Some color studies in the past also used different colors as variables without any control variable (i.e., neutral color) but comparing colored lightings to a neutral lighting like a white lighting, can provide a better understanding of lighting color effects. It is recommended that future research should use a neutral color as a control group when comparing the effects of different colors.

This study explores the effects of three primary colors and three secondary colors of LED lighting. There has been extensive research on various pigment colors beyond primary and secondary colors over decades, but few studies have been conducted on lighting colors. To narrow this research gap, future studies are recommended to use more various colors of lightings. In addition, as the lighting colors can look differently according to the level of illumination, future studies are also recommended to test effects of different illumination levels for the same colors.

Conclusion

The findings from this study demonstrate that LED lighting colors have significant influence on emotional states (i.e., pleasure and arousal), behavioral intentions (i.e., approach or avoidance), and spatial impressions (i.e., cheerfulness, attractiveness, comfort, pleasantness, relaxation, and warmness/coolness). Furthermore, the pleasure is shown to have a mediating effect between LED lighting color and behavioral intentions. The results also indicate that color preference of the LED lighting is influence by cultural background.

The results of this study have theoretical value in that they fill the gaps in previous color and lighting research on emotion, behavioral intention, and impression of the space by exploring lighting color effects based on the Mehrabian and Russell's M-R model (1974). This study also contributes practically by providing useful insights into the use of colored lighting for design professionals and individual users.

Based on this study, future research should (1) use a more rigorous probability sampling, (2) conduct similar experiment in a setting of an entire room, (3) examine a neutral colored lighting as a control variable, and (4) extend this study by exploring the effects of more colors of lightings in various illumination levels.

APPENDICES

APPENDIX A: IRB Approval Letter

MICHIGAN STATE
UNIVERSITY

EXEMPT DETERMINATION

***Flexibility Initiative* - See Special Exclusions Below**

March 23, 2018

To: Eunsil Lee

Re: **MSU Study ID:** STUDY00000575
Principal Investigator: Eunsil Lee
Category: Exempt 98
Exempt Determination Date: 3/23/2018

Title: Exploring Effects of Colored Light-Emitting Diode (LED) Lighting on Human Emotion and Behavior

This project has been determined to be exempt under the Michigan State University (MSU) Flexibility Initiative Exemption Category 98.

Exemption Category: This project has qualified for the Flexibility Initiative Exemption Category 98: Research involving benign interventions in conjunction with the collection of data from an adult subject through verbal or written responses (including data entry) or video recording if the subject prospectively agrees to the intervention and data collection and at least one of the following criteria is met:

(A) The information obtained is recorded in such a manner that human subjects cannot be identified directly or through identifiers linked to the subjects; or

(B) Any disclosure of the human subjects' responses outside the research would not reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation.

See Human Research Protection Program (HRPP) Manual 8-8-B, Exemption Category 98, for the full text of Exemption Category 98.

Exclusions: To continue to qualify for Exemption Category 98, the project must not include:

- Federal funding or federal training grants
- FDA regulated
- Sponsor or other contractual restrictions
- Clinical interventions (including clinical behavioral interventions)
- Prisoners as subjects
- Receipt of an NIH issued certificate of confidentiality to protect identifiable research data
- Be a project for which MSU serves as the Institutional Review Board (IRB) of record

Office of Regulatory Affairs
Human Research Protection Program

4000 Collins Road
Suite 136
Lansing, MI 48910

517-355-2180
Fax: 517-432-4503
Email: irb@msu.edu
www.hrpp.msu.edu

MSU is an affirmative-action, equal-opportunity employer.

- Children as research subjects

If any of the above criteria become applicable to a project determined exempt under this flexibility initiative, the IRB office must be promptly notified prior to implementation of the criteria and the project must be reviewed and approved in accordance with the appropriate review level (e.g. expedited, full board).

Principal Investigator Responsibilities: The Principal Investigator assumes the responsibilities for the protection of human subjects in this project as outlined in HRPP Manual Section 8-1, Exemptions.

Continuing Review: Exempt projects do not need to be renewed.

Modifications: In general, investigators are not required to submit changes to the IRB once a research study is designated as exempt as long as those changes do not affect the exempt category or criteria for exempt determination (changing from exempt status to expedited or full review, changing exempt category) or that may substantially change the focus of the research study such as a change in hypothesis or study design. See HRPP Manual Section 8-1, Exemptions, for examples. If the project is modified to add additional sites for the research, please note that you may not begin the research at those sites until you receive the appropriate approvals/permissions from the sites.

Change in Funding: If new external funding is obtained for an active human research project that had been determined exempt, a new initial IRB submission will be required, with limited exceptions. Please see exclusions as funding changes may disqualify this project from this flexibility initiative.

Reportable Events: If issues should arise during the conduct of the research, such as unanticipated problems that may involve risks to subjects or others, or any problem that may increase the risk to the human subjects and change the category of review, notify the IRB office promptly. Any complaints from participants that may change the level of review from exempt to expedited or full review must be reported to the IRB. Please report new information through the project's workspace and contact the IRB office with any urgent events. Please visit the Human Research Protection Program (HRPP) website to obtain more information, including reporting timelines.

Personnel Changes: After determination of the exempt status, the PI is responsible for maintaining records of personnel changes and appropriate training. The PI is not required to notify the IRB of personnel changes on exempt research. However, he or she may wish to submit personnel changes to the IRB for recordkeeping purposes (e.g. communication with the Graduate School) and may submit such requests by submitting a Modification request. If there is a change in PI, the new PI must confirm acceptance of the PI Assurance form and the previous PI must submit the Supplemental Form to Change the Principal Investigator with the Modification request (http://hrpp.msu.edu/forms).

Closure: Investigators are not required to notify the IRB when the research study is complete. However, the PI can choose to notify the IRB when the project is complete and is especially recommended when the PI leaves the university.

For More Information: See HRPP Manual, including Sections 8-1, Exemptions and 8-8-B, Exemption Category 98 (available at https://hrpp.msu.edu/msu-hrpp-manual-table-contents-expanded).

Contact Information: If we can be of further assistance or if you have questions, please contact us at 517-355-2180 or via email at IRB@ora.msu.edu. Please visit hrpp.msu.edu to access the HRPP Manual, templates, etc.

APPENDIX B: Consent Form for Experiment

Research Participant Information and Consent Form

You are being asked to participate in a research study. Researchers are required to provide a consent form to inform you about the research study, to convey that participation is voluntary, to explain risks and benefits of participation, and to empower you to make an informed decision. You should feel free to ask the researchers any questions you may have.

Study Title: **Exploring Effects Of Colored Light-Emitting Diode (Led) Lighting On Human Emotion And Behavior**
Researcher and Title:
Eunsil Lee, associate professor, Michigan State University (Principal Investigator)
Heejin Lee, Ph.D. candidate, Michigan State University
Department and Institution: School of Planning, Design, and Construction
Address and Contact Information: 201L Human Ecology, East Lansing, MI 48824.
(517) 432-3249

1. PURPOSE OF RESEARCH

- You are being asked to participate in a research study of exploring effects of colored LED lighting on human emotion and behavior.
- From this study, the researchers hope to learn the effects of colored-LED lighting in interior spaces on occupants' emotional and behavioral responses using three colors of LED lighting (i.e., red, green, blue, yellow, orange, and purple) as environmental stimuli.
- Your participation in this study will take about 20minutes.

2. WHAT YOU WILL DO

- You will be asked to answer the questionnaire under different colored LED lightings. There are NO right or wrong answers. We need your honest opinion.
- Procedure: Before the experiment, you will be tested for color vision with Ishihara's Tests for color blindness and if you don't pass the test you will not be able to participate in the study. If you pass the color blind test, colored LED lighting will be turned out for 3 minutes and you will be asked to answer the questionnaire of emotional word pairs followed by behavioral intention. Then you will be asked to close your eyes and rest them for 40 seconds. The procedure will be repeated until all LED lighting colors are displayed.

3. POTENTIAL BENEFITS

- You will not directly benefit from your participation in this study. However, your participation in this study may contribute to the body of knowledge on color and lighting. This study will provide people with a better understanding of the effects of color, lighting, and colored lighting in interior spaces. This study also expects to help design professionals understand clients' perceptions toward colored lighting and predict what kind of behaviors they might see from their clients. The effective use of colored lighting in interior spaces such as restaurants, hotels, retail spaces, or other service facilities may enhance the occupants' pleasant experiences.

4. POTENTIAL RISKS

- There are no foreseeable risks associated with participation in this study

5. PRIVACY AND CONFIDENTIALITY

- The data for this project will be kept confidential.

- Although we will make every effort to keep your data confidential there are certain times, such as a court order, where we may have to disclose your data.
- The results of this study may be published or presented at professional meetings, but the identities of all research participants will remain anonymous.

6. YOUR RIGHTS TO PARTICIPATE, SAY NO, OR WITHDRAW

- Participation is voluntary. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled.
- You have the right to say no.
- You may change your mind at any time and withdraw.
- You may choose not to answer specific questions or to stop participating at any time.

7. COSTS AND COMPENSATION FOR BEING IN THE STUDY

- You will receive $10 cash for participating in the study.

8. CONTACT INFORMATION

If you have concerns or questions about this study, such as scientific issues, how to do any part of it, or to report an injury, please contact the researcher.
Eusil Lee, Associate Professor, by mail 201L Human Ecology, East Lansing, Mi 48824, phone: 517-432-3249, or e-mail: leeeunsi@msu.edu
Heejin Lee, Ph.D. Candidate, by mail 102 Human Ecology, East Lansing, MI 48824, phone: 517-402-0365, or email: leeheeji@msu.edu

If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at 4000 Collins Rd, Suite 136, Lansing, MI 48910.

9. DOCUMENTATION OF INFORMED CONSENT.

Your signature below means that you voluntarily agree to participate in this research study.

______________________________ __________________________

Signature Date

You will be given a copy of this form to keep.

APPENDIX C: Questionnaire Used for Experiment


Dear participant,

You are being asked to participate in an experimental research exploring how you feel about certain lighting color. We ask you to help us by participating in this experiment with your earnest response to this questionnaire. You will be asked to answer the questionnaire under 3 lighting colors. There are NO right or wrong answers. We need your honest opinion.

Before the experiment, you will be tested for color vision with Ishihara's Tests for color blindness. If you pass the color blind test, the experiment begins. One lighting color will be turned on for 3 minutes and you will be asked to answer the questionnaire of emotional word pairs followed by behavioral intention. Then you will be asked to close your eyes and rest them for 40 seconds. This procedure will be repeated until all 3 lighting colors are displayed.

Your participation in this experiment will take about 20 minutes including introduction of the experiment and the rest time during the experiment. Your responses will remain **strictly confidential** and your identity will not be linked to the data you provided.

Please direct any questions about the study to Dr. Eunsil Lee, Professor in The School of Planning, Design, and Construction at Michigan State University by phone: (517) 432-3249, e-mail: leeeunsi@msu.edu or Heejin Lee, doctoral student at Michigan State University by phone: (517) 402-0365, e-mail: leeheeji@msu.edu or regular mail: 201L Human Ecology, East Lansing, MI 48824.

THANK YOUR for your kind help in completing the research.

Sincerely,

Michigan State University Researchers

MICHIGAN STATE
UNIVERSITY

ABOUT YOU…

- **Please indicate your gender** *(Please check one).*
  - ☐ Male
  - ☐ Female
  - ☐ Prefer not to answer

- **What is your age?**
  - ☐ Less than 21
  - ☐ 21 - 25
  - ☐ 26 – 30
  - ☐ 31 – 35
  - ☐ More than 35

- **Please identify your ethnicity** *(Please check one).*
  - ☐ Asian
  - ☐ African/Black
  - ☐ Caucasian
  - ☐ Hispanic/Latino
  - ☐ Native American
  - ☐ Pacific Islander
  - ☐ Mixed Race
  - ☐ Other
  - ☐ Prefer not to answer

- **Do you have any visual impairments (example: color blindness) that cannot be corrected by your glasses or contact lenses?**
  - ☐ Yes
  - ☐ No

- **What are your three most favorite colors?**
  - ☐ Red
  - ☐ Orange
  - ☐ Yellow
  - ☐ Yellow-green
  - ☐ Green
  - ☐ Blue
  - ☐ Navy
  - ☐ Purple
  - ☐ Pink
  - ☐ Light blue
  - ☐ White
  - ☐ Black
  - ☐ Grey
  - ☐ Silver
  - ☐ Gold
  - ☐ Etc.______________

SECTION I: OVERALL EMOTION

❖ Please check the current color of the light setting.

☐ Red ☐ Green ☐ Blue ☐ Yellow ☐ Orange ☐ Purple

1. **Based on the lighting condition, I would be more likely to...**

Avoid	-3	-2	-1	0	+1	+2	+3	**Approach**

2. **What emotional response do you associate with this color of lighting?**

____

3. **Please rate how this color of lighting makes you feel.**

Pleasant	1	2	3	4	5	6	7	Unpleasant
Unhappy	1	2	3	4	5	6	7	Happy
Excited	1	2	3	4	5	6	7	Calm
Unaroused	1	2	3	4	5	6	7	Aroused
Satisfied	1	2	3	4	5	6	7	Dissatisfied
Wide Awake	1	2	3	4	5	6	7	Sleepy
Uncomfortable	1	2	3	4	5	6	7	Comfortable
Relaxed	1	2	3	4	5	6	7	Stimulated

4. **Please rate your overall impression of the lighting condition.**

Warm	1	2	3	4	5	6	7	Cool
Dull	1	2	3	4	5	6	7	Bright
Impressive	1	2	3	4	5	6	7	Unimpressive
Beautiful	1	2	3	4	5	6	7	Ugly
Unattractive	1	2	3	4	5	6	7	Attractive
Cheerful	1	2	3	4	5	6	7	Gloomy
Unappealing	1	2	3	4	5	6	7	Appealing

5. **Overall, how much do you like the lighting condition in this space?**

Dislike	-3	-2	-1	0	+1	+2	+3	**Like**

5-1. Please briefly explain why you chose the above response.

____

When you are finished, please raise your hand for a few second to let the researcher know you are done.
Then turn the page over and wait for all other participants are finished before moving on to the next lighting color.

OVERALL COMMENTS

- Please feel free to give any comments about this experiment.

____

____

____

THANK YOU FOR YOUR TIME IN COMPLETING THIS EXPERIMENT.

When you are finished, please raise your hand for a few second to let the researcher know you are done. Then turn your page over and wait for all other participants are finished before moving on to the next lighting color.
You may close your eyes and rest them.

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REFERENCES

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