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Aging-In-Place Home Modification: LED Lamp Color Temperature Preference Among Adults

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LED LAMP COLOR TEMPERATURE
PREFERENCE AMONG ADULTS

By

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ABSTRACT

This study evaluated LED color temperature preference and effectiveness in a task light setting for older adults with a comparison to younger adults. Test subjects included visually active adults, male and female, from 19 years to 96 years of age. The researcher tested one hundred participants from several test sites. The researcher ascertained conclusions based on the correlations of age, gender, visual acuity, time of day, and visual medical conditions to LED preference. A tunable lamp with four correlated color temperatures (CCT/K), 2700K, 3500K, 4100K, and 5000K was analyzed using timed and graded, reading and number comparison tasks. Lumen output between the correlated color temperatures was adjusted for consistency to prevent illuminance (lumens) from effecting the outcome. Test subjects choose a preferred correlated color temperature and completed a subjective survey accessing the preferred comfort level. Results indicated the test subjects performed better with the 4100K correlated color temperature. Regarding personal preference of correlated color temperature by test subjects on average: the 4100K correlated color temperature was preferred first (36%), the 3500K correlated color temperature was preferred second (28%), the 5000K was preferred third (24%), and the 2700K was preferred least (12%). A significant difference was discovered between men and

women with men, on average, taking longer to complete the reading and number matching tasks than women.

DEDICATION

Dedicated to Dr. Mitzi R. Perritt and Dr. Ray L. Darville. I could not have accomplished this endeavor without their understanding, encouragement, assistance, advice, and perseverance. Their observed pedagogy is the emulated model for my own teaching methods.

Also dedicated to my husband, Richard, for his unwavering support throughout a difficult and complicated process. We have loved and sustained each other since we were 16 years of age.

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This thesis has allowed me to utilize over 30 years of experience as an interior designer and general contractor with the knowledge obtained from Stephen F. Austin's graduate healthcare interior design program. I can utilize the collective knowledge to the benefit of my own design clients, incorporate healthcare design trends, and evidence based design into class instruction at the University of Akron's interior design undergraduate curriculum as an adjunct instructor.

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CHAPTER 1

Introduction

“Aging-in-place” represents the concept of remaining in one’s place of residence independently for life. It is calling that place of residence home, giving that place personal and social meaning, and giving the person residing there a sense of self-efficacy, connection, and wellbeing (Tanner, Tilse, & de Jonge, 2008). The Center for Disease Control and Prevention (CDC) terminology defines aging-in-place as "the ability to live in one's own home and community safely, independently, and comfortably, regardless of age, income, or ability level" (Centers for Disease Control and Prevention, 2013). The National Association of Home Builders (NAHB) further states: “It means the pleasure of living in a familiar environment throughout one’s maturing years and of enjoying the familiar daily rituals and the special events that enrich all lives. It means the reassurance of being able to call a house a home for a lifetime” (National Association of Home Builders, 2015).

Statement of the Problem

The aging of the United States population is well publicized. People of advanced years want to and tend to age in place because of a trusted sense of connection and familiarity to a specific environment providing a sense of identity and independence (Wiles, Leibing, Guberman, Reeve, & Allen, 2011). A vast amount of information is available on how to accomplish successful “aging-in-place” through the application of various home modifications (National Association of Home Builders, 2015; US Department of Health and Human Services, 2003), universal design principles (Albritton, 2014), adaptability and accessibility features (US Department of Health and Human Services, 2003), assistive technology or gerontechnology support (Bezaitis, 2008; Wilson, Mitchell, Kemp, Adkins & Mann, 2009; Young, 2012), appropriate community services, healthcare assistance organizations, government sponsored programs, positive aging programs, financial planning programs (Timmermann, 2014), age friendly community components, family support, and person-centered care support for older adults (Benefield & Holtzclaw, 2014). In addition, successful aging-in-place requires a lower probability of disease and disability, a high level of physical functioning, a high level of cognitive functioning, and a social and productive active engagement in life (Carr, Weir, Azar, & Azar, 2013). It is apparent after reviewing research literature on aging-in-place that one cannot age-in-place alone.

Research from the National Association of Realtors (National Association of Realtors, 2014) reveals most older adults stay in their own homes into their 70s and 80s. When they do move, they relocate close to home into smaller houses, apartments, condominiums, congregate, or healthcare settings (National Association of Realtors SRES®, 2014). American Association of Retired Persons

(AARP, 2010) survey indicates the trend to age in place is growing in demand among the aging because of personal preference. They enjoy their community and being near friends, family, community services, church, social organizations, and transportation (Keenan, 2010). Also, the prospect of aging-in-place is preferred over costly institutional options (Lawlor & Thomas, 2008). Communities, healthcare organizations, and governmental agencies recognize the benefits of encouraging and assisting older adults to age in place due to the impending rising cost of caring for them (Wiles, Leibing, Guberman, Reeve, & Allen, 2011).

One can find numerous statistics germane to the desire to age in place from various credible sources. They all send a similar message—the U.S. median age is increasing.

- One in three Americans is now 50 or older (American Association of Retired Persons, 2014).
- By 2030, one out of every five people in the United States will be 65+ and is projected to be twice as large in 2030 as in 2010, growing from 35 million to 72 million and representing nearly 20% of the total U.S. population (Federal Interagency Forum on Aging-Related Statistics, 2012).
- In 2012, the U.S. population was comprised of 43.1 million person 65 years or older increasing 21% from 35.5 million in 2002. They

represented 13.7% of the U.S. population, about one in every seven Americans. The 85+ population is projected to triple from 5.9 million in 2012 to 14.1 million in 2040 (US Department of Health and Human Services, 2013).

- 84% of Baby Boomers agree with the statement: “I want to stay in my home because I like what my community has to offer me” (American Association of Retired Persons, 2012).
- 88% of survey respondents (age 50+) reported that it is extremely or very important to have long-term-care services that allow aging-in-place (American Association of Retired Persons, 2011)
- 87% of adults age 65+ want to stay in their current home and community as they age. Among people age 50 to 64, 71% of people want to age in place (American Association of Retired Persons, 2014).
- Seniors Real Estate Specialist Council (SRES) research indicates older Americans include 76.5 million people born between 1946 and 1964 known as the Baby Boomers are 24.6% of the population and growing (National Association of Realtors SRES®, 2014).

Innumerable complications affect the individual’s ability to manage one’s personal environment and thwart successful aging-in-place. There are nine specific, age-related ailments associated with aging that affect the built environment in various ways. If designers are to assist the older population, they need to comprehend the characteristics associated with each aging ailment to be able to develop an ailment-specific living space (Ankerson & Gabb, 2009).

The nine age-related ailments are:

1. arthritis
2. cardiovascular diseases
3. diabetes
4. hearing impairments
5. mental disorders
6. muscular loss
7. neurological diseases
8. osteoporosis
9. vision impairments

Age-related ailments may cause some degree of general physical limitation in the following areas (Ankerson & Gabb, 2009):

- bending or reaching for objects
- climbing and descending stairs
- decreasing general mobility and flexibility
- getting into and out of furniture and fixtures such as showers and toilets
- getting up or down into a squat or floor position
- gripping, pinching, twisting, and squeezing (hands)

- lifting feet when walking versus shuffling
- lifting objects above shoulders or from below knees
- negotiating slippery surfaces (falls)
- resting required even while doing stationary tasks

Normal age-related changes in the eye and pathological transformations in the visual system can cause varying degrees of general physical limitation in vision impairment. Examples of age related vision impairment include the following (Shikder, Mourshed & Price, 2012; Figueiro, 2001):

- A gradual decrease in accommodation or loss of ability to see details or focus (presbyopia) caused by the hardening of the crystalline lens.
- Reduced retinal illuminance or the need for more light to see caused by senile miosis (loss of pupil size) and the thickening of the crystalline lens.
- Reduced contrast or the loss of ability to discern between shadows caused when the crystalline lens becomes less clear scattering light, or from "floaters" in the eye scattering light.
- Reduced color saturation also caused as the crystalline lens becomes less clear adding a luminous veil over colored images on the retina reducing their vividness. For example, reds look like pinks.

- Decreased color perception and reduced ability to discriminate blue colors as the eye loses sensitivity to the short wavelengths of blue light caused by the progressive yellowing of the crystalline lens.
- Poor night vision caused by reduced retinal illuminance.
- The need for more time to adapt to decreases or increases in light (dark adaptation).
- A loss of visual field due to cataracts, glaucoma, age related macular degeneration, diabetic retinopathy, or retinal detachment.

Addressing these visual impairments using home modification and low vision assistive technology positively affects aging-in-place. People who have physical modifications performed on their homes are likely to stay longer in their existing housing than those who do not. Creating a supportive environment can make it possible for older adults to stay in their own homes safely and independently for many years (Hwang, Cummings, Sixsmith, & Sixsmith, 2011).

The goal is to create a unique environment that is centered on the older adult’s capabilities. Their home must be able to accommodate natural changes and needs that come with getting older so they can age in place, stay healthy, and engage in meaningful activities which is an important component of successful aging (Surendranath, 2013). The ability to see clearly affects every aspect of aging-in-place from the recreational reading activity to the necessity of reading the label on a bottle of prescription drugs. In addition, falling and breaking a hip is a common and valid fear of the older adult. Without extensive physical therapy, nearly half of adults recover only partially and die within a year or two of a fall injury (National Association of Realtors SRES®, 2014). The simple home modification of improved lighting (as well as appropriately placed railings and grab bars) can help prevent this life-changing injury.

The scientific field of lighting has advanced rapidly. New and more effective lamp types such as light emitting diodes (LEDs) are continuing to be developed and refined (Eaton Cooper Lighting Business, 2015). More research is needed to understand if LED lamps can positively affect the visual acuity of older adults facilitating activity. Most past research has been performed with other lamp types such as fluorescent and halogen. The goal of this study is to determine which correlated color temperature (CCT/K) of LED lamps may be preferred by older adults for task lighting and which correlated color temperature is more effective in the accomplishment of task activities such as recreational reading, or functional reading such as labels on medication bottles.

Research by the Seniors Real Estate Specialist Council (National Association of Realtors SRES®, 2014) reports the 55+ market or Baby Boomers are not thinking about aging; they are focusing more on maintaining an active lifestyle. A general attitude among Baby Boomers exists where they do not see themselves as old, and anything labeled as “senior” is rejected. According to SRES®, marketing to the older adult Baby Boomer should be age targeted not age restricted. SRES® recommends selling to Baby Boomers by appealing to their active lifestyle which helps the Baby Boomers feel empowered.

Despite the older Baby Boomers' denial of the eventual loss of their abilities, becoming more accepting of home modification and how to prepare now for later life would benefit them. A substantial number of adults in the age group of 41-49 and 50-59 expect to move to a new home for retirement by buying a second home or a new home which will later become a retirement residence (National Association of Realtors SRES® 2014). Thus, making a home more age friendly and accessible while they are still working and can afford to pay for renovations would be advisable. SRES® indicates Baby Boomers tend to hate rules and do not want information they can find themselves. They value convenience and customization as well as expert service and advice. Despite their using technology as a tool for communications and work, they still prefer to interact in person or by telephone. (National Association of Realtors SRES®, 2014). Because interior designers work one-on-one, a well-informed designer is in a good position to recommend more effective lighting as a first step in home modification for the older adult. Specific lamp types which aid visual acuity and are preferred by older adults could assist them in keeping the active lifestyle they so cherish.

Age-related lighting studies have researched luminance (LUX or FC) differences (Fotios & Cheal, 2009), color rendering index (CRI) differences

(O’Conner & Davis, 2005), correlated color temperature (CCT or K) differences, and dynamic lighting effects (Izso, Laufer, & Suplicz, 2009). In one study, older adults did find blue light more activating and red light more relaxing, and changes in light throughout the day was found to be energizing (Laufer, Lang, Izso, & Nemeth, 2009). Except for definite preferences in luminance most past study conclusions indicated very little difference in color discrimination or lamp source type preference (O’Conner & Davis, 2005; Esperjesi, Fernandez & Barlett, 2007).

There is more recent color preference research for LED. A recent study conducted with younger subjects studying color preference for a pair of 3000 K LED lamps indicated a preference for a YD-LED spectral power distribution (higher red and green), over a BP-LED spectral power distribution (more blue-yellow) when viewing rooms with matching brightness containing chromatic objects and still life arrangements. Red, green, orange, and wood objects were preferred in the YD-LED light. No preference was found then observing neutral, yellow, or blue objects (Wei, Houser, Allen, and Beers, 2014). Another study tested subjects from 18 to over 60 years of age for LED correlated color temperature (CCT) from 2855K to 6507K in a work environment (Dikel, Burns, Veitch, Mancini & Newsham, 2013). The test subjects preferred the middle range correlated color temperatures (Ks). Least preferred was the highest and lowest correlated color temperatures. An older study utilizing younger and older subjects performed three experiments analyzing several light sources including LED to evaluate legibility, visual clarity, perceptual whiteness, and perceptual brightness. The results showed that the whitest LED is the best light source for older people (Yamagishi, M., Kawasaki, F., Yamaba, K., & Nagatam, M. (2006).

Little research is found on LED lamp type preference testing for correlated color temperature (K) while maintaining the same lumens or illuminance levels for the older eye. Typically, when using a LED Lamp the lumens per watt (lm/W) decrease when lowering correlated color temperature to the warmer hues such as 2700K. Inversely, when raising the typical LED lamp to a higher correlated color temperature the lumens or illuminance increase with the bluer white light (Willmorth, 2016). Older adults require more illuminance to see clearly and therefore will select a higher correlated color temperature light source when tested. A study conducted in 2011 researched the effects of LED lighting on six older people aged 55-65 years for color discrimination and preference using two correlated color temperatures: 2800K and 6000K at 30 lux (3 fc), 200 lux (20 fc), and 1000 lux (100 fc). They evaluated color discrimination with the Farnsworth-Munsell 100 Hue Test and evaluated the test subject’s preference with a 7-scale, 6-item preference evaluation test. They concluded that older people perform better in correlated color temperature discrimination with the higher correlated color temperature LED light source which had the higher illumination. They also discovered the test subjects preferred higher illuminance levels when reading but still had different preferences regarding correlated color temperature of the light source when surveyed (Cheng, Ju, Sun, & Lin, 2011).

Once significantly more expensive, newer lamp types such as LEDs are becoming more economical and available for purchase through big box stores rather than only through lighting specialists. This access allows consumers to easily purchase them. Today great emphasis is placed on energy efficient lamps although often they do not provide appropriate light for the older adult. For example, compact fluorescents (CFLs), the most commonly available, residential, energy efficient, replacement lamp for a typical light fixture does not provide enough ambient light compared to the previously specified incandescent. Providing readily available yet energy efficient lamps which are beneficial, preferred, and easily purchased by Baby Boomers' can support the goal of aging-in-place.

Purpose of the Study

LED lamps and light fixtures are currently rigorously researched and developed because they are proving to be more versatile and energy efficient than other types of lamps, according to Tyson Swank, lecturer, during the LED Solutions Seminar conducted at The Source, Eaton Cooper Lighting Business education center at the corporate headquarters in Peachtree City, Georgia (personal communication, March 23, 2015). The developing popularity and increasing availability of LED lamps merits studying lamp preferences. The purpose of this study is to determine which of four LED correlated color temperatures levels (2700K, 3500K, 4100K, and 5000K) are preferred by older adults in a reading task-light setting while maintaining the same lumen levels. Available LED lamps lose lumens as the correlated color temperature is raised. Because the older adult eye requires higher illuminance levels to see more clearly test subjects would naturally prefer the higher correlated color temperature because of the higher lumens. Keeping the lumens constant will allow for a more accurate test of correlated color temperature preference. In addition, a preference evaluation will be presented to respondents for evaluation of their preferred correlated color temperature. Today lamp packaging includes lumen output and correlated color temperature data allowing purchasers more specific selections. Tunable lamps have become available in national retail stores such as Home Depot, Best Buy, Lowe’s, Target, and online allowing consumers to select them for their own dwellings. This information might assist manufactures, designers, and the older adult consumer.

Research Objectives

The study will include the following research objectives:

1. To determine older and younger adult preference in LED correlated color temperature (CCT) or Kelvin (K) levels in LED lamps while maintaining constant lumen levels.

2. To determine older and younger adult preference in LED correlated color temperature (CCT) or Kelvin (K) levels in LED lamps based on performance while maintaining constant lumen levels.
3. To determine the effect of age, gender, visual acuity, and visual medical conditions on LED correlated color temperature (CCT) or Kelvin (K) lamps while maintaining constant lumen levels.

Delimitations

The study will be delimited in the following areas:

1. The sample of older and younger adults will not be randomized but will rely on volunteers. Therefore, the results will not be generalized to the entire population of adults.
2. Residents of independent living facilities, senior citizen community group members, and other groups may be included in the study. Because independent living residents will be solicited as respondents it is possible that the sample may represent older adults from higher socioeconomic and educational levels.
3. The sample will be derived from adults residing in Ohio, age 18 or older.
4. Four correlated color temperatures 2700K, 3500K, 4100K, and 5000K will be used for the MNReading Acuity Chart Test and the Numerical Verification Test (NVT).

5. A tunable LED lamp with an adaptive control will be utilized to determine CCT/K, CRI, and lumens. Compact fluorescent, halogen, ceramic metal halide, and incandescent lamps will not be studied.
6. Respondents will self-report health conditions.

Definition of Terms

The researcher has identified certain terms that may be unfamiliar to the reader. See Appendix A for the definitions of these terms.

CHAPTER 2

Review of Literature

The aging population continues to increase throughout the world. As individuals age, even healthy eyes lose visual acuity, are more sensitive to glare, and need greater amounts of light to see well. Meeting the needs of an aging population's visual system is paramount for physical convenience, safety, comfort, and wellbeing. Therefore, the role of quality lighting becomes an important issue in everyday life for everyone and is particularly important for the older adult. This review of literature will provide an overview of lighting allied to home modification for the older adult, and an overview of the emergent area of LED lighting and its potential benefit for aging-in-place lighting applications.

Aging-in-Place

Older adults face barriers to independent living. Many older persons face limitations on independence in their homes only because the design and arrangement of their residence no longer meets their needs. The three most often reported difficulties related to getting around the home are negotiating stairs, using the bathroom, and getting in and out of the house (Benefield & Holtzclaw 2014; Bezaitis, 2008). Properly specified lighting can enhance function and safety in all three areas.

Older adult concerns. Some older adults are concerned about home visitability, which is having accessible features for friends or family who have trouble using stairs or those using walkers or wheelchairs. They may want to entertain disabled guests or may wish to plan a head start on changes they will need later in life when they require extra help getting around their home. For example, installing a ramp to a door of the dwelling and remodeling the hallways, doorways, and rooms to allow wheelchair access (US Department of Health and Human Services, 2003; Pynoos, Caraviello, & Cicero, 2009).

Older adults also worry about being forced into a nursing home because of difficulties moving around their personal residence. Many older adults are concerned about conserving financial resources for themselves, their spouses, their children, or being able to afford home modifications. Others have little experience with current costs and fear being overcharged for materials and services or worry about safety threats dealing with unreliable service providers. Some older adults refrain from modifying their homes because they lack the expertise to do it themselves, do not have anyone such as a family member who can afford to do the job for them, or are unable to find a good contractor. Some refuse to spend because they want to leave money to their children, or believe they are losing their independence by accepting changes (AOTA, 2014).

Family influence. Sometimes, family members meet with resistance from their parents to make changes. One increase in resistance to change occurs when individuals face losses in other areas of their life. A way to approach a parent is by making suggestions for change around “I” messages. “I worry about you falling on those stairs. As a gift, I am going to make sure your stairs are safe and well-lighted.” Demonstrating a caring attitude toward the older adult, can help counter some of their emotional and physical loses. Be sure to introduce changes at a slow pace to cause as little disruption as possible, or introduce the idea of change through small, less intrusive modifications in the guise of services when a need is identified. For example, when replacing their hard-to-reach light bulbs, upgrade the wattage or lumens for improved brightness at the same time (AOTA, 2014).

Even when an older adult is in an older home and on a limited budget, he or she can implement universal design and barrier free features to make their home more livable as they age and more marketable when it is time to sell (Albritton, 2014). Identify design features that will promote security, comfort, and facilitate ease of mobility throughout the home. Look for potential trip hazards and ways to improve the lighting to make the home a safer, more comfortable place in which to live before a fall and subsequent broken hip. Introduce changes to their personal living environment, redesigning parts of the house for accessibility, or consider moving them to more accessible housing. It is best to approach this subject long before safety issues become paramount. Analyze their lifestyle to ascertain what tasks they need or want to continue to perform each day and help problem solve a solution to ensure comfort, safety, and enjoyment. Find the fit between them and their environment by taking a good look at the physical environment while they are engaged in the routines and daily activities that make life meaningful for that individual. Then assist them in making the modifications to the home environment that enables them to maintain maximum independence and promote overall health and well-being. It is not just about safety and independence but quality of life and social connections (AOTA, 2014; Surendranath, 2013).

Families and other caregivers must be the ones to help the older person obtain the assistance needed to maintain independence. They should offer to help the individual make choices and deal with contractors. Investigate and suggest resources such as bill paying services, meals on wheels, lawn care, house cleaning and window washing companies. Some older adults prefer professional assistance over dependence upon family members (AOTA, 2014).

People often assume home modification means major structural changes, but there are numerous lessor ways to create an accessible home. Make the bathroom space safer and more accessible by increasing the illumination, adding nightlights, freeing the bathroom floor of clutter, rearranging furnishings to improve the flow of the room, and adding grab bars to the shower placed at the appropriate height (Brachtesende, 2015).

Interrelationships among illness, injury, and aging. Individuals may experience subtle decreases in vision, hearing, balance, and coordination as they age. Pronounced changes such as severe arthritis or ocular diseases such as age-related macular degeneration or diabetic retinopathy can interfere with their ability to perform daily tasks and decrease independence. People with illnesses or those who are recovering from injuries may find that their condition has altered their ability to perform daily routines and roles, as well. They may feel limited in such activities as cooking, cleaning, bathing, dressing, and social participation. Physical changes can make older adults more susceptible to falls in the home. Appropriate home modifications may help improve these situations (AOTA, 2003).

Lighting Effects on Health, Wellbeing, and Alertness

Designers benefit from understanding what the human eye and brain require for performing competently in the built environment. Designers need to be aware of the biological and psychological effects, and to understand that the visual quality of the light can have a positive influence on alertness, health, and wellbeing. It can enhance the visual experience and maintain productivity and engagement in occupation (Laufer et al., 2009, Izso et al., 2009).

Physical effects. There are several components of the eye that detect and translate light. Rods are photoreceptors that operate in scotopic light situations, not permitting color vision, but translate value information of bright or dark. They are sensitive to subtle light changes and motion and are responsible for our peripheral vision (Russell, S. 2012). Decreasing rod density as a person ages is one reason older adults have difficulty with low light situations. Cones are responsible for detail, sharpness, and color vision. They are decisive in indoor lighting situations. The sensitivity of rod and cone photoreceptors varies for different wavelengths of light. The maximum visual sensitivity is in the yellow-green region of the light spectrum and the maximum biological sensitivity is in the shorter blue wavelength region. The biological effect of the blue wavelength light is the suppression of the hormone melatonin which allows for sleep. A recent study found that green wavelength light also contributes to melatonin suppression (Gooley et al. 2010). Age-related pupillary miosis and reduced crystalline lens transmission due to lens yellowing blocks more of the short (blue) wavelengths which affects circadian photoreception for the circadian rhythms sleep-wake timing (Turner & Mainster, 2008).

There is a third ocular photoreceptor in the eye beside rods and cones. The third photosensory neuron is also thought to contribute to the control of the biochemical processes in the human body involved with the biological clock and the regulation of hormones related to light/dark rhythms or day-night cycles affecting the internal 24-hour circadian clock (Foster, 2008). The human eye and brain not only utilizes light to see images but also facilitates photoentrainment (circadian entrainment) which adjusts the circadian clock affecting sleep quality, and according to research may affect long-term decline in physiological function, neurobehavioral performance, and may increase risk for diabetes, cardiovascular disease, and specific types of cancer (Figueiro et al., 2016: Foster, 2008; Turner, & Mainster, 2008).

Psychological effects. Daylight or natural light has a dynamic character in intensity and wavelength. It has a positive influence on mood, atmosphere, and the visual impression of a space. It is stimulating and energizing. Studies have shown that people prefer to utilize a combination of artificial light and daylight in a space for its mood lifting effects (van Bommel & van den Beld, 2004). Older adults may keep indoor light levels low for various reasons such as saving money, conserving electricity, or from habit (Bakker, Iofel, & Lachs, 2004). They may have little access to bright natural light, staying indoors for various reasons such as difficulty with mobility. Disruption of darkness at night can occur when they wake to use the bathroom. Limited bright light during the day and disrupted darkness at night can interfere with the circadian rhythms and the dark-induced functions such as melatonin secretion. Depression, insomnia, confusion, and loss of cognitive ability can result. Evidence indicates that architectural manipulation of environmental light and darkness can diminish these symptoms (Royer et al., 2012; Shikder et al., 2012; White, Ancoli-Israle, & Wilson, 2013).

Lighting Improvements

There are countless ways a building can contribute to the lives of those aging-in-place with a more productive, comfortable, and safe environment. Falls are the leading cause of injury and accidental death in adults over the age of 65. Reasons are new or unfamiliar surroundings, improper footwear, cumbersome furniture arrangements, and distractions (AOTA 2003). Low light situations, glare situations, and dramatic light level changes can also cause a person to stumble and fall accidentally, causing a serious injury, even death. Proper lighting is necessary to assist adding adults with poor depth perception which can also contribute to falling (Shikder et al., 2012). One method to enhance depth perception is to have light project 18 to 20 feet into a space (Eaton Cooper Lighting Business, 2015).

The Illuminating Engineering Society's (IES) recommendations for senior residences are 300 lux or 30 footcandles (fc) for ambient lighting, 750 lux or 75 fc for task lighting such as reading, and 600 lux or 60 fc for grooming. Designers can apply general lighting principles when making lighting more effective for older adults. They can be sure to increase ambient light levels to a minimum of 300 lux or 30 fc, and increase task area light levels to at least 1000 lux or 100 fc. They can minimize glare, increase contrast, balance illuminance levels in hallways and foyers with those of adjacent spaces, and improve color perception (Figuerio, 2001; IESNA, 2007).

Specific changes which can make lighting more effective and improve vision include the following (US Department of Health and Human Services, 2003; Figueiro, 2001; Figueiro & Rea, 2005; IESNA, 2007, 2009; Lawlor & Thomas, 2008; National Association of Home Builders, 2015):

- Add automatic controls such as occupancy/motion sensors to turn lights on and off, and photocells to turn lights on at the onset of darkness in appropriate areas of the home.
- Choose appliances with easy to reach and read controls.
- Create high color/texture contrast between adjacent surfaces and changes in surface levels. The best contrast for older adults is black and white. Unsaturated blues and green are often the most difficult for the maturing eye to discriminate.
- Dust the light fixtures and clean windows to make a home brighter.
- Eliminate glare spots by providing surface materials with a matte finish.
- Install a sensor light at an exterior no-step entry focusing on the door lock.
- Install a mirror in the bathroom without a counter in front to stand closer and with lighting on each side to balance illumination to the face.
- Install a pre-programmed thermostat that is easy to see and read.
- Install a wet location or code correct light source over the tub or shower stall.

- Install motion-sensor flood lights or increase lighting on exterior pathways, porches, and doorways.
- Install under cabinet lighting with light rail valance to shield or block direct view of the light source preventing glare.
- Install windows that are taller, or lower with lower sill heights to provide more natural light.
- Keep a magnifying glass available in places where it may be needed such as the living room, or bedroom for reading small print and provide a lighted magnifying mirror in the bathroom.
- Keep room finishes simple avoiding complex decorative patterns to minimize confusion with objects on floors and furnishings.
- Locate floor lamps slightly behind and to the side so light is delivered over the reader's shoulder.
- Locate TV or computer monitors so they do not reflected light from windows or light fixtures.
- Locate wall mounted swing arm lamps to the side of the bed below eye level for reading to prevent glare. Task lighting beside the bed should be adjustable and easy to reach with easily accessible controls such as touch-activated, sensor based or easy-to-feel button.
- Locate light switches, thermostats, and other environmental controls no higher than 48 inches from the floor.

- Make house numbers easy to read by using large, white, lighted numbers against a dark background on the front of the house.
- Monitor lighting as well as heating, and air conditioning from any TV in the house with a monitored high-tech security/intercom system.
- Move a favorite reading chair next to a window.
- Paint or stain door frames a dark color to contrast with lighter walls to improve their visibility.
- Place a contrast strip on top and bottom stairs to increase the visibility of stairs and use color contrast between treads and risers. Rope-lights installed under a lower rail provide light on the stair tread, while concealing the light from the eyes and can be used on interior and exterior stairs. Solar powered or electrically powered step lights can provide additional light on stair tread.
- Place an accented strip or contrasting color on edge of countertops to provide visual orientation to the workspace.
- Place lighting over the sink, stove, and other work areas.
- Prevent glare from exposed lamps with semi-transparent or opaque reflector and use semi-specular or matte finishes for visible reflectors.
- Provide an audible and visual strobe light system to indicate when the doorbell, telephone, smoke, or CO_2 detectors have been activated.

- Provide automatic, light-sensor night-lights in hallways between the bedroom and bathroom, and in the bathroom with amber or red color lamps to prevent disrupting circadian (light/dark) sleep cycles.
- Provide clear access space of 30-inches by 48-inches in front of switches and controls.
- Provide intermediate illuminance levels in transitional spaces so older adult eyes can adapt more easily as they move from bright outdoor areas to dim indoor spaces during the day, or from bright indoor spaces to dark outdoor spaces at night by utilizing adjustable lighting controls such as dimmers.
- Provide lighting in closets.
- Provide plenty of windows for natural light using energy efficient windows with Low-E glass or other energy saving types. Increase daylight levels in the space with windows and skylights to improve color discrimination and provide blinds, shades, or curtains to minimize glare from windows.
- Rearrange furniture to increase natural light, unblocking windows.
- Relocate some electrical outlets from the typical height to 27" above finished floor to prevent bending down to reach them, and outlets may need to be closer than 12 feet apart.
- Relocate light switches if they aren't properly located. Each room should have at least one light that can be turned on from an easy to reach switch

at the doorway before one enters the room. Locate light switches outside the bathroom door as well as inside for entering a potentially dark space.

- Replace heavy draperies which block daylight with woven shades or sheer curtains to reduce glare and diffuse. Add separate window coverings for privacy.
- Replace lamps with higher wattage or higher lumen energy efficient lamps.
- Replace small light switches with rocker or touch style switches that have lighted or glow-in-the dark surfaces to aid visibility at night.
- Select luminaires that use baffles, lenses, or louvers. Shield direct views of lamps by using architectural features, such as valances, soffits, and coves and paint the insides a matte white to help diffuse light.
- Take advantage of reflected light to increase uniformity and reduce glare by using light colors on walls and ceilings. A suggested light reflective value (LRV) of paint color is an LRV of 75-90 on ceilings and 60-80 on walls.
- Use adjustable light fixtures with switches and dimmers for task lighting.
- Use dark baseboards to help define floors and walls.
- Use full-spectrum lamps that simulate daylight to enhance visual acuity and provide better light for reading and writing.

- Verify there are enough outlets to avoid the need to use extension cords which can lead to tripping.

Lighting Types and Usage

To clarify, luminaires are light fixtures, and lamps are the lightbulbs inside the light fixtures. There are several types of luminaires utilized in residential lighting such as architectural or structural, ceiling-mounted, track, recessed, wall-mounted, suspended pendant or chandeliers, furniture-integrated, and portable. Major types of structural luminaires include cove lighting, valance lighting, cornice lighting, soffit, and wall bracket lighting. Portable, plug-in luminaires include desk lamps, table lamps, floor lamps, under cabinet, and night lights. Lamp types used most often in residential include incandescent—common and halogen, and parabolic aluminized reflector lamps (PAR), fluorescent—linear, and compact, and more recently, light-emitting diode (LED) and organic light emitting diode (OLED) lamps. Categories of lighting techniques include general illumination or ambient lighting, task lighting, and accent or decorative lighting (Winchip 2011),

Balanced light. Ambient lighting should be balanced providing uniform lighting to a space. This can be accomplished by adding skylights and windows sourcing natural daylight and adding electric lighting by bouncing light off ceilings and walls using direct/indirect fixtures such as pendants, valances, and wall washers, and by installing surface mounted ceiling fixtures. Balance daylight by providing it from more than one direction such as from opposing walls or skylights with the addition of electric lighting. Recessed fixtures can provide ambient light with a flood lamp or accent lighting with a narrow intense beam lamp. Recessed lighting is not recommended for task lighting. It is important to conceal all lamps from view or use a diffuser to control glare (Winchip, 2011).

Residential lighting. Traditionally, incandescent lamps have been used in residential and admittedly most closely resembles warm natural daylight with a CRI rating (how true colors appear) of 100 and a correlated color temperature of 2700K. Unfortunately, they are not energy efficient, releasing the major part of their energy in the form of heat (90%) and have poor lamp life. Even fluorescent lamps, utilized more in commercial residential applications, release about 80% of their energy as heat (Winchip, 2011). Considering the world consumption of energy with rising energy prices, heightened environmental awareness, and the implementation of energy codes and standards, the need to conserve with more energy efficient, longer life lamps is required. Researchers have analyzed lamp types such as fluorescent and halogen to find more energy efficient lamps which can work as well for older adults as incandescent (Davis & Garza, 2002); (O'Conner & Davis, 2005). Although natural lighting is preferred in senior housing, appropriately selected artificial lighting can provide a positive alternative. LED holds promise for both a decorative and functional enhancement to natural lighting for a senior-friendly environment. Recent LED retrofits of residential older adult facilities have proved successful and elicited positive responses from residents and caregivers (Elia, 2013).

Light Emitting Diode Lamps (LED)

Referred to as solid state lighting (SSL), LED is a newer lamp type which may be a better alternative to incandescent and CFLs when retrofitting lighting for older adults still in their homes. LED stands for light-emitting diode producing light-emitting photons also known as electroluminescence. LEDs produce these photons at different wavelengths which appear as different colors. It is a semi-conductor device consisting of a chemical chip embedded in a plastic capsule that emits visible light. Chemicals contained in the chip determine the color of the light. The light is focused or scattered by lenses, diffusers, or a reflector cup. A minimal amount of heat is produced and is emitted to the bottom of the luminaire which acts as a heat sink (Philips Lighting, 2017). They use direct current and require a driver or transformer. Several chips are required in one fixture to produce enough illumination to light a room area or a large surface. LEDs are suitable for ambient lighting, directional accent applications, small and medium scale diffuse applications, continuous linear sources for coves and slots, and for colored or color-changing applications. They are available as complete lighting systems or luminaires, dedicated modules, continuous arrays, and as retrofit lamps for existing fixtures (Karlen, 2012; Russel, 2012; Winchip, 2011).

LED advantages. LEDs are durable, made of solid-state electronics which run on low voltage direct current LED drivers. They can reach 80-98 color rendering index (CRI) which is close to the incandescent lamp's 100 CRI (ability of the lamp to render objects as they would be seen in outdoor sunlight—a CRI of 100 is near perfect), without producing excessive heat and energy waste. They release only 10% of their energy as heat. LED light is directional so less usable light is lost in the fixture compared to other lamp types. It is a light source that has a long-rated life (30,000 to 100,000 lumens), is extremely compact, and needs little maintenance. They have less lumen depreciation or light loss factor (LLF), a feature which continues to improve. For example, the same LED lamps that had a 70% loss at 50,000 hours, now maintains 90% lumens at 70,000 hours (Eaton Cooper Lighting Business, 2015; General Electric Company, 2014).

LEDs are safer to use because they are cooler to the touch, which can be a safety benefit when installed in residential settings. For example, when utilized as under cabinet lighting LEDs won't burn skin if accidently touched. LED lamps aren't damaged by hand oils as are other lamp types such as halogen. LED has a flexible correlated color temperature range from 1500K to 9000K (warmer to cooler in color) and can be used in color tunable applications giving users personal control (Dikel et al., 2013). They operate without emitting ultraviolet or infra-red radiation and produce vivid saturated colors (Illuminating Engineering Society of North America, 2006). They can be utilized in almost a limitless range of lighting effects. The bluish tint of the white LED has a high biological efficacy for the circadian system (Figueiro et al., 2016). In addition, there are tax benefits and rebates for using energy saving lamps which LED lamps fulfill (Eaton Cooper Lighting Business, 2015; Winchip, 2011).

Advantages over incandescent and CFL's include lower energy consumption, longer life span, improved physical robustness, smaller size, and faster switching. They can be used for daylight harvesting and can be dimmed without the costly ballast of a CFL (Elia, 2013; Leviton Manufacturing Company, 2007). LED light output is measured in lumens not energy consumption. Because of their beneficial attributes and energy savings, LED is the most widely researched lighting source used today. LED is replacing virtually all lamp types in every conceivable commercial application and is swiftly progressing to residential settings (Eaton Cooper Lighting Business, 2015).

In addition, LEDs do not contain mercury and do not have filaments or glass that can break. LEDs low heat also helps to reduce the quantity of energy required to cool a building (Winchip, 2011).

LED disadvantages. LEDs still have higher first or initial costs. Manufacturers cannot consistently make each LED the same. Differences can occur even in the same produced batch. Since the differences are significant, the LEDs are sorted in groups or bins. A bin may contain LEDs of similar light emittance within a range of wavelength (color), luminous flux, and voltage.

Heat does have a negative effect on a LED system although this applies to all lamp types. A heat sink (Philips Lighting, 2017) required to prevent heat from decreasing the lamp life. The driver is the weakest part of the system. If the LED lamp fixture fails the problem is usually with the driver (Eaton Cooper Lighting Business, 2015). A high glare potential is possible as in any lamp type so lenses and diffusers are required. The white LEDs have poor color rendering of flesh tones which would not be useful in diagnostic settings although this too is improving. The higher the CRI the lower the lumens per watt (lpW) output due to the addition of specific phosphors (USAI Lighting, 2012).

Organic light emitting diodes (OLEDs). OLEDs, the lighting technology of the future, consist of a semi-conducting organic material which generates light from the composition of planar sheets. The emissive electroluminescent layer is an organic compound film which emits light in response to an electric current. They distribute light evenly providing a soft light and can be used as wall coverings, ceilings, displays, and lighting panels. Presently they are too inefficient and expensive to manufacturer for regular use (Karlen, 2012).

Polymer light emitting diodes (PLEDs). PLEDs use large plastic molecules called polymers as the semiconductor material in LEDs. These molecules are printed onto plastic rather than on glass. They are thinner, stronger, and more flexible (Rey-Barreau, J. A. 2015).

Tunable LEDs. Tunable LED white light is a recent concept technology that enables users to adjust the correlated color temperature of a lamp in real time. Users modify the correlated color temperature (CCT) and intensity of the source with an input, such as a slider control or intelligent lighting management system. The range of attainable correlated color temperatures varies by product and manufacturer. A typical range may lie somewhere between 1600K and 6500K. Manufacturers offering tunable lamps provide a spectrum with an effective range that covers both warm and cool temperatures. Tunable LEDS can be used to develop a 24-hour lighting environment where light can be adjusted in the home to mimic the variation of natural daylight cycles or merely adjusted for preference. Individuals can control the quality, color, and quantity of light to suit the types of activities they're performing using either standard dimmers or programmable control systems adjusting the correlated color temperature, intensity, and lumens (USAI Lighting, 2013).

Conclusion

The challenge of aging-in-place is a multifaceted concern with wide-ranging solutions. Various societal issues affect the complex progression of aging. Research and refinement of the aging-in-place process will continue due to the sheer numbers of this growing segment of the worldwide population. Additional realistic housing solutions are needed as the aging population numbers increase. The cost to individuals, families, neighborhoods, and state and federal governments will continue to escalate. Individual aspects of aging-in-place can be researched to ameliorate even in marginal ways. The effect of lighting on the older person and their environment is only one of these. Advisement lighting research for healthcare settings and residential dwellings suited to the aging is obtainable for those enlightened and progressive. Lighting research on older lamp types is also available. Less research is available on how the correlated color temperature of LED lamps can affect the older eye and on the effectiveness of tunable LED, and very little is available on OLED and PLED lamp preference.

CHAPTER 3

Methodology

This chapter discusses research techniques to study LED lamp efficacy and correlated color temperature preference of older adults as compared to younger age groups in a task light setting. The researcher did not test lamp types such as incandescent, fluorescent, neon and cold cathode, induction, and high intensity discharge (HID) lamps, which include metal halide, sodium, and mercury vapor. A quasi-experimental research design was utilized for which a judgmental sampling (independent living facility residents) and convenience sampling (university faculty, staff, and students) techniques provided available subjects (Babbie, 2011).

Two studies regarding lighting for the older adult by Davis and Garza (2002) and O'Conner and Davis (2005) inspired the research. The first research paper documented "the effects of illuminance level, illuminance distribution, background reflectance on visual performance, and preference for a group of older individuals performing an achromatic visual task" (Davis & Garza, 2002). The second paper determined "the effects of source spectral content and illuminance level on color discrimination ability and preference of a group of older individuals from an independent living facility and a group of younger participants" (O'Conner & Davis, 2005). The studies investigated color discrimination and preference under different light sources. Both studies used halogen and compact fluorescent lamp types of varying spectral content or correlated color temperature (CCT), color rendering index (CRI), and illuminance levels. The first study tested older subjects; the second study tested older and younger subjects. Visual acuity eye tests determined subjects free of visual disease and those which were visually-active meaning they consistently performed visual tasks such as sewing, reading, or driving. Both studies concluded that older adults preferred higher luminance; however, they did not reach a definitive conclusion regarding correlated color temperature preference.

Purpose of the Study

This study investigated the effectiveness of four correlated color temperatures (CCT/K) for visual acuity in an achromatic task-light setting using a tunable LED lamp which maintained consistent lumen (fc/lux) levels. Further, this study explored which correlated color temperature (CCT/K) subjects preferred by using a tunable LED lamp with an adaptive control. The researcher determined conclusions on the correlations of age, gender, visual acuity, and visual medical conditions to LED preference. In addition, the researcher identified which correlated color temperature lamp was more comfortable to test subjects based on a subjective survey.

Sample

The researcher targeted a sample size of 100 subjects. Eligibility requirements at the independent living facilities limited residents to 55 years of age and over. Staff would participate as well. Test subjects could perform visual tasks such as sewing, reading, and driving. A subject who could not physically drive but was still visually active was included in the sample. The study accepted male and female individuals and all ethnicities. The researcher selected test subjects based on competency and voluntary participation—a non-probability convenience sampling technique (Babbie, 2011).

Sampling Sites

The researcher acquired study subjects through contact with facility managers and/or activity directors of independent living facilities or community centers in northern Ohio. A personal visit by the researcher with a letter of introduction (see Appendix D) about the study encouraged managers and directors to provide permission (see appendix E). The activity directors from participating facilities displayed a volunteer flyer (see Appendix U) and posted a sign-up sheet for volunteer participants (see Appendix F). The researcher obtained additional study subjects from volunteers of the local university student body, faculty, and staff which provided data for age comparison studies.

Independent living facilities. These facilities provide communal living for senior citizens and offers supportive services such as meals, housekeeping, laundry service, transportation, scheduled recreational activities, wellness programs, and a variety of concierge services. Independent living facilities typically offer adults ages 55 and older the opportunity to maintain a social and active lifestyle. The resident is assured that his/her specific needs will be met, allowing independence and enhanced quality of life. This type of living arrangement provides choice, dignity, privacy, respect, and socialization for older adults. It is a good option if minor assistance or no assistance is needed with activities of daily living. It is an option for those adults who want a place to live that requires little or no home maintenance and yard work, socialization with peers, broadened social network, and shared activities and meals with others (Facilities Guidelines Institute, 2014). Facilities with this level of senior housing provided subjects who were still visually active and thus, well suited to serve as study subjects.

List of sampling sites. Internet research identified significant number of potential independent living facilities available throughout the researcher's vicinity. Appendix C contains a list of organizations that provided a permission slip or letter agreeing to participate in the study (Appendix E).

***Independent living facility test sites*.** Residents of three private independent living apartment complexes agreed to participate. Marketing brochures described two independent living complexes as holiday retirement communities where residents may enjoy an independent retirement lifestyle.

Residents enjoy three meals per day, cleaning, and a full range of activities. Medical assistance is not provided. Activity directors of these facilities, called enrichment coordinators, assisted in soliciting participants for the study by posting and distributing a flyer supplied by the researcher (see Figure 16, Appendix U). The researcher also spoke to the residents in the dining room at mealtime explaining the study and walked around the dining room securing participants.

A life plan community also contributed respondents. It provides a variety of housing choices including independent living, assisted living, and nursing home care. There is a medical complex on the site which is also open to the community. Services to residents include two meals per day, cleaning, and activities. The researcher’s contact was the director of the independent living apartment complex.

University test site. The university provided the most test subjects for the study. Subjects consisted of current staff and faculty, students, and retired faculty.

Data Collection Materials

During the study the researcher utilized data collection forms, equipment, and measuring instruments. Of key interest was the Spectrophotometer and the custom fabricated testing apparatus (See Figure 9, Appendix M).

Visual acuity. The researcher decided to screen participants for visual acuity since the testing procedure involved reading an 8-point font. Visual acuity refers to the ability to discern shapes and details. It is just one factor in overall vision, alongside color vision, peripheral vision, and depth perception. A visual acuity test determines the smallest letters which can be read on a standardized chart. A Snellen test uses a chart of letters or symbols of different sizes, arranged in rows and columns, and is viewed from a specific distance, usually 14 to 20 feet away. The top number refers to the distance a person should stand from the chart, typically 20 feet. The bottom number indicates the distance at which a person with normal eyesight could read the same line. For example, 20/20 is considered normal, but 20/40 indicates that letters an individual can read correctly at the standard 20 feet distance can be read by a person with normal vision from 40 feet away. Even if one or two letters is missed on the smallest line, it is still considered to be vision equal to that line.

Since the researcher would collect data from various sites a chart (see Figure 10, Appendix N) from Konan Medical (KonanMedical.com, 2016) was selected. This acuity eye chart only required a 10-foot distance from the subject, allowing for the test to take place in smaller rooms.

Test subjects used an eye occluder (see Figure11, Appendix O) to test visual acuity in each eye by covering the non-tested eye. The occluder was cleaned with antiseptic cleaning wipes between test subjects.

Color blindness. The researcher screened participants for color deficiencies using a color plate test by Colomax.org (see Figure 12, Appendix P). It was important to note whether a subject was color blind as this issue could impact the person's lamp correlated color temperature preference.

Testing apparatus. The primary piece of equipment employed was a custom portable box resembling the one used by O'Conner and Davis (2005) (See Figure 1).

Figure 1. Example of the experimental light box device

The O'Conner and Davis (2005) experimental light box device. Adapted from O'Conner, D. A., & Davis, R. G. (2005). Lighting for the elderly: The effects of light source spectrum and illuminance on color discrimination and preference. *Leukos*, 2(2), 123-132. doi:10.1582/leukos.2005.02.02.004

AVID Labs built the experimental light box (see Figure 2) and provided the adaptable control and the Ketra 38 Spectrum LED tunable lamp (see Figure 7 &

8, Appendix K). The testing apparatus dimensions consisted of 36” wide, 36” tall, and 32” deep with the interior covered by a medium/dark neutral gray felt. A depth of 32 inches allowed the box to be transported through commercial doors. The tunable LED lamp with a 90+ CRI and 1000 lumen output was installed inside the top center of the light box (see Figure 8, Appendix K).

Figure 2. Actual light test box device at the university setting

The researcher programmed four correlated color temperature settings into the lamp’s adaptable control: 2700K, 3500K, 4100K, and 5000K. The lumen per square meter (lux) output of each setting was maintained between the correlated color temperatures by dimming the lamp settings of 3500K, 4100K, and 5000K by 4%. This strategy kept the lux range of the correlated color temperatures between 937 lx to 963 lx. Providing a close lux output for each correlated color temperature allowed the researcher to test preference for correlated color temperature (K), not illuminance (Alex Tollington, personal communication, LED Specifier Summit, November 17, 2015).

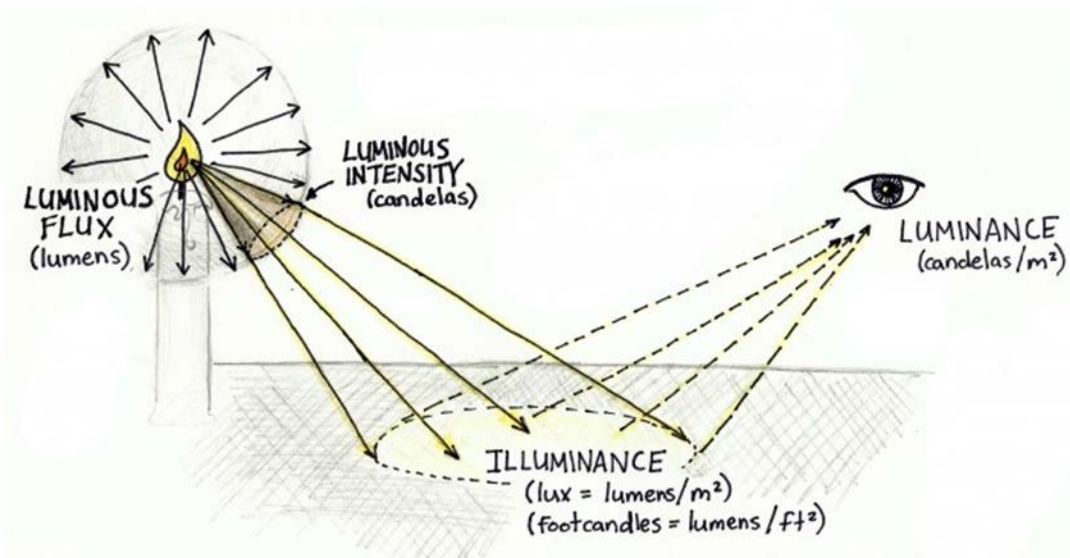
The inside of the test box featured a medium neutral-gray felt fabric to prevent glare during the testing. See Figure 2 for the test box and Appendix K for test lamp specifications). The LED light fixture plugged into a typical AC duplex outlet receptacle. The adaptable control communicated with the lamp wirelessly and was set using the Ketra Design Studio software obtained online (see Appendix L). The adaptable control adjusted the correlated color temperatures (Kelvins) and illuminance (footcandles/lux) levels used in the testing.

The researcher checked measurements with the CL-500A Illuminance Spectrophotometer which measured illuminance (footcandles/lux) and correlated color temperature (CCT/K). The measurement tool was selected for rapid ease of use (see Figure 9), in Appendix M for the spectrophotometer specifications). The researcher recorded ambient room lux measurements at each site location before each group of test subjects. Data recorded included the time of day and the length of time for each test to be completed.

The Language of Light

Regarding illuminance and luminance, the diagram in Figure 3 clarifies basic lighting metrics and the type of light reflectance quantified by the light meter. The researcher measured illuminance which is the amount of light that strikes the desk surface, not the amount of light that reflects into the subject's eyes. Most recommended footcandles/lux (illuminance) is the measurement used for optimizing visual comfort since building codes and standards use illuminance to specify the minimum light levels for specific tasks and environments (DiLaura, Houser, Mistrick, and Steffy 2011*).*

Figure 3. Basic lighting metrics



The amount of light emitted by a light source is called luminous flux (lumens). The amount of light that travels from the source and reaches the surface such as the desk or paper is illuminance. Luminance is the amount of light reflected off a surface into a subject's eyes. Retrieved from *Measuring Light Levels*. http://sustainabilityworkshop.autodesk.com/buildings/measuring-light-levels

Data Collection Procedure and Oversight

The researcher utilized research methods, personnel, and equipment for the collection of data. A pilot test confirmed the testing sequence.

IRB approval. The researcher requested approval for the use of human subjects by submitting an application to the Stephen F. Austin State University Institutional Review Board (IRB). The IRB approved the study (see Appendix B).

Research logistics. The researcher hired a research assistant to help solicit test sites. Afterward, the researcher conducted all interviews and tests to insure consistent test procedures. The researcher inputted all test data into the SPSS Graduate Student version 23 data analysis software program. The researcher's spouse assisted with the transport and setup of the test equipment.

Testing procedure. Each facility provided a space such as an activity room or chapel for the experiments. The researcher dimmed the ambient lighting in the space to minimize the subject's visual adaptation and used a spectrophotometer to record ambient light readings at each test site. Adjusting window treatments, electric lighting, and covering windows with cardboard minimized ambient footcandle/lux (lumens) readings.

The researcher introduced herself, welcomed the test subject, reviewed the consent form (see Appendix G), and explained the test procedure for the visual tasks (see Appendix F). The subject indicated they understood the tasks and then completed the "Informed Consent Form" (see Appendix G). The researcher recorded a control number on each test folder and all data sheets for confidentiality. The researcher interviewed each subject completing the Personal Data Form (see Appendix I) and the medical vision questionnaire (see Appendix

I). The researcher then commenced the visual acuity test (see Figure 10, Appendix N) using an eye occluder (see Figure 11, Appendix O) and the color blindness test (see Figure 12, Appendix P). The subject wore whatever eye glasses or contacts normally used for all reading and vision checks.

The test subject then proceeded to the reading tasks where he/she was seated at the test light box in an adjustable office chair. The chair was adjusted until the subject was comfortable. The researcher turned off the room lights and asked the test subject to close his/her eyes for approximately 30 seconds before beginning the first task to prevent a comparison of the room's ambient light with the first LED test setting. Three main reading tasks and one subjective survey was conducted. The test subject also was asked to close his/her eyes between each task to prevent visually recognizing the correlated color temperature changes between each light setting.

The reading tests then began. The first reading task was composed of four different MNRead chart pages (see Appendix R). Each MNRead chart page was read under a different correlated color temperature. One page was read under the 2500K and a different page with different sentences was read under the 3500K, 4100K, and 5000K. Each page consisted of five different sentences with five font sizes in Times New Roman: 16-point, 14-point, 12-point, 10-point, and ending with 8-point. Each of the four pages had different sentences obtained from a MNRead sentence chart for a total of 20 sentences (see Appendix Q).

The second reading test consisted of four separate NVT number match task pages (see Appendix S). A number match task was conducted under the 2500K, and a different number match task was conducted under each lamp: the 3100K, 4000K, and 5000K. The researcher used NVT number match tasks comparable to the original NVT number match tasks conducted by O'Conner and Davis (2005).

The third reading task consisted of reading a white instruction label on an orange pharmacy medication bottle with a 12 point, black, Arial font. The test subject chose the correlated color temperature setting he/she preferred by looking at the label under each of the correlated color temperatures. The researcher cycled through the correlated color temperatures using the adaptive control as many times as needed until the test subject felt comfortable with a choice. After choosing the preferred correlated color temperature, the test subject read the medication bottle instruction label. The researcher timed all nine tests with a stop watch to the 1/100th measurement. Finally, the test subject completed a written comfort survey. The researcher then thanked the participant and escorted him/her from the testing room.

Visual acuity test. The test subject wore their glasses or contact lenses and sat 10 feet from the Konan Medical eye chart for the visual acuity test. The subject covered one eye at a time using an eye occluder (see Figure 11, Appendix O), while he/she read aloud lines of letters on the Konan Medical eye chart. The test subjects could guess if unsure of the letter. The researcher recorded the results.

Color blindness test. After the visual acuity test, the researcher administered a color blindness test comparable to the Ishihara Color Plates. The test subject identified colored numbers in 13 colored circles. The researcher recorded the results.

Light quality preference test. After the MNReading tasks and Numerical Verification Reading Tasks (see Figure 13, Appendix Q and Figure 14, Appendix S), the subject performed a correlated color temperature preference test while reading the medication bottle label. The researcher cycled through the four correlated color temperatures until the test subject chose a preferred correlated color temperature. After choosing their preferred correlated color temperature, the test subject read the instructions on the label. The researcher recorded the time using a stop watch (see Figure 17, Appendix V) with a hundredth measurement. Afterwards, the test subject completed a comfort preference survey for the chosen correlated color temperature setting (see Appendix J).

Pilot Test

The researcher conducted a pilot study with eight volunteer subjects selected from the researcher's family, friends, co-workers, and university students; ages varied from 18 to 77 years. The pilot study subjects signed the consent form and completed the personal data form. First, they performed the visual acuity test and color blindness test followed by the correlated color temperature tasks, the preference test, and the comfort survey. The researcher used the spectrophotometer to measure ambient or general light levels (footcandles/lux) of the testing space. Ambient light in the subsequent testing rooms was kept as dark as feasibly possible. The pilot study revealed needed adjustments to the data collection process to produce an efficient and smooth sequence of testing.

Variables

The study examined multiple variables. The researcher identified nine independent variables and three dependent variables.

Specific physical attributes which may affect the subject's performance and preference include the following independent variables:

1. Age. The subject's age was recorded on the personal data form.
2. Gender. The subject's gender was recorded on the personal data form.
3. Visually Active. The subjects self-reported whether they considered themselves visually active on the personal data form.
4. Visual Acuity. Visual acuity was tested with the test subject's glasses or contacts and recorded.
5. Color Blindness. The subject self-reported color blindness on the personal data form, and a color blindness test was administered and recorded.

6. Visual Medical Conditions. The subject self-reported any visual (eye) medical conditions on the personal data form.
7. Public or Private Facility. The researcher indicated on the personal data form whether the test site location facility was a public or private facility.
8. Time of Day. The researcher recorded on the personal data form time of day when the test was administered.
9. Test Time. The researcher also recorded on the personal data form time required for each test completion.

The test subject's task error score, time score, and correlated color temperature preference was determined by measuring the following dependent variables with the CL-500A Illuminance Spectrophotometer light meter, the Ketra adaptable control tunable S38 tunable LED lamp, and stop watch:

1. Correlated Color Temperatures (CCTs). CCT of the light source was measured in the Kelvin scale. The selection scale was 2700K (warm or red/yellow color), 3500K (less warm or red/yellow color), 4100K (whiter or bluer in color), and 5000K (coolest or bluest color).
2. Ambient Room Luminance Level. Ambient Room Luminance is measured in lux, within a range of .1 for a windowless room to 8.1 lux for a windowed room.

3. The researcher recorded test score errors and task performance time for all four correlated color temperatures.

Hypotheses to Test

The study procedure tested ten hypotheses.

1. There will be a significant mean difference on performance scores based on correlated color temperature.
2. There will be a significant mean difference on performance scores based on correlated color temperature participant preference.
3. Males and females will have a significant mean difference on their correlated color temperature participant preference.
4. Males and females will have a significant mean difference on their performance scores (time and errors).
5. Age groups will have significant mean differences on their correlated color temperature participant preferences.
6. Age groups will have significant mean differences on their performance scores (time and errors).
7. There will be significant mean differences in performance scores (time and errors) based on visual acuity.
8. There will be significant mean differences in correlated color temperature participant preference based on visual acuity.

9. There will be significant mean difference in performance scores based on eye medical conditions.
10. There will be significant means differences in correlated color temperature participant preference based on eye medical conditions.

Data Analysis Tools

The researcher examined and analyzed the data from this study using the SPSS (Graduate Student version 23) data analysis software. Descriptive analysis procedures included frequency tables, measures of central tendency and dispersion, and crosstabulation with appropriate measures of association. The researcher recorded data by hand, graded performance tests, and input data into the SPSS data analysis software after testing was concluded.

Conclusion

The assessment of these hypotheses enabled the researcher to evaluate color temperature preferences of older and younger adults and color temperature effect on visual acuity using a tunable LED lamp in a task light setting. The researcher's careful preparation of key elements of the study such as the study sites, study participants, testing instruments, study-research questions, data collection documents, identification of variables, formulation of research hypotheses, and IRB approval made possible the success of this study and efficacy of the study findings. Because of the use of convenience sampling, the results of this study will not be generalizable to a larger population.

CHAPTER 4

Results

This study evaluated LED correlated color temperature preference (CCT/K) and effectiveness in a task light setting for older adults with a comparison to younger adults. The researcher based conclusions on the relationships of age, gender, visual acuity, and visual medical conditions to LED preference and test results. The researcher analyzed four correlated color temperatures (CCT/K), 2700K, 3500K, 4100K, and 5000K using timed and graded reading and number comparison tasks. The researcher adjusted the lumen output between the correlated color temperatures for consistency to prevent brightness from effecting the outcome. Test subjects chose a preferred correlated color temperature and completed a subjective survey accessing the comfort level.

Sample Demographics

The researcher obtained test subjects from two types of populations: residents and staff from independent living apartment complexes and faculty, staff, and students from a university. The researcher provided an incentive to 27% of participants, but 73% declined the incentive and participated voluntarily. A total of 106 interviews participated; six invalid tests were discarded. Therefore, the study contained a total of 100 usable test cases. Participants with macular degeneration in both eyes were unable to complete the tasks while participants with macular degeneration in one eye completed the tasks as were participants with mild dementia. A participant with multiple sclerosis was unable to see well enough to complete the tasks. Table 1 displays sample demographics.

The gender distribution was 77% female and 23% male; 42% of the test subjects were single, 29% were married or living together, 6% were divorced, and 23% were widowed. Other demographics included age, education, and employment. Age range was divided into three main groups: youngest adults from 18 to 22 years (34%), mid-range adults from 23 to 69 years (32%), and oldest adults from 70 to 100 years (34%).

The test subject education level indicated 7% attended high school or less, 63% received more than high school (meaning college), 23% received more than college (meaning graduate work), and 7% acquired doctorates. Employment status indicated 21% were full-time, 34% retired, 5% were employed part-time, 39% were full-time students, and 1 was a part time student. All test subjects at the university were working either as faculty, staff, or students and the independent living facility test subjects were retired or working full time staff.

Visual Characteristics of Test Subjects

All test subjects self-reported they were visually active meaning they regularly performed activities such as reading, sewing, or driving. Glasses or contacts were worn by 78% of the participants and 22% did not need glasses or contacts (see Table 2).

Table 1

Sample Demographics

Characteristic	Count	Percent	Cumulative Percent
Gender			
Male	23	23	23.0
Female	77	77	100.0
Age Range			
18 to 22 youngest adults	34	34	34.0
23 to 69 mid-range adults	32	32	66.0
70 to 100 oldest adults	34	32	100.0
Marital Status			
Married or living together	29	29	29.0
Single	42	42	71.0
Divorced	6	6	77.0
Widowed	23	23	100.0
Education Level			
High school or less	7	7	7.0
More than high school - college	63	63	70.0
More than undergraduate - Graduate	23	23	93.0
Doctorate	7	7	100.0
Employment			
Full employment	21	21	21.0
Retired	34	34	55.0
Part-time employment	5	5	60.0
Full-time student	39	39	99.0
Part-time student	1	1	100.0
Received incentive			
Yes, received an incentive	27	27	27.0
No, did not receive and incentive	73	73	100.0

Table 2

Test Subject Visual Characteristics

Visual Characteristic	Count	Percent	Cumulative Percent
Wears glasses/contacts or not			
Yes, glasses or contacts	78	78	78.0
No	22	22	100.0
Visual acuity test chart 10 feet away			
20/20	51	51	51.0
20/40	40	40	91.0
20/50	5	5	96.0
20/63	3	3	99.0
20/80 and up	1	1	100.0
Visual medical conditions- self-report			
None other than glasses/contacts	70	70	70.0
Yes, additional visual conditions	30	30	100.0
Glare sensitivity awareness self-report			
Never	29	29	29.0
Occasionally	61	61	90.0
A lot	10	10	100.0
Night vision difficulty self-report			
None	69	69	69.0
Yes	29	29	98.0
Don’t know	1	1	99.0
Inconclusive	1	1	100.0

The visual acuity test indicated 51% of participants had 20/20 vision, 40% had 20/40 vision, 5% had 20/50, 3% had 20/63 and one person scored 20/80. All participants complete the tasks. Participants reported sensitive to glare “a lot” (10%), occasional sensitivity (61%), and never being bothered by glare (29%).

Only two participants reported not having adequate depth perception; 95% reported no issues with depth perception and three were not certain. Only one participant reported not having adequate peripheral vision.

Table 3

Color Blind Aware vs. Color Blind Test

Color Blind	Count	Percent	Cumulative Percent
Color blind test results			
Not color blind	74	74.0	74.0
Some measure of color blind	26	26.0	100.0
Color blind test subject awareness			
Not color blind	95	95.0	95.0
Yes, color blind or unsure	5	5.0	100.0

Interestingly, 95% of participants reported not being color blind and 5% indicated colorblindness or uncertainty. Comparing their self-report to the color-blind test indicated otherwise. Only 74% tested not colorblind, 26% tested as having some measure of color blindness (see Table 3). The older age group comprised 70.6% of that 26%--those tested as having some measure of color blindness (see Table 5). The large incidence of partial color blindness occurring in the older age group could be due to age differences such as the yellowing of the older eye lens making it more difficult to discern between reds, oranges, yellows, yellow greens, and greens as indicated by the color blind test. Table 3 indicates test subject color blind awareness compared to the color-blind test results and Table 5 displays the percentage of the older age group.

Table 4

Preferred CCT/Kelvins to Color Blind Test Results

			Color blind test		
			Not Color Blind	Some Measure of Color Blind	Total
Preferred CCT/Kelvins reading medication bottle	2700K	Count	6	6	12
		% within color blind test	8.1%	23.1%	12.0%
	3500K	Count	23	5	28
		% within color blind test	31.1%	19.2%	28.0%
	4100K	Count	30	6	36
		% within color blind test	40.5%	23.1%	36.0%
	5000K	Count	15	9	24
		% within color blind test	20.3%	34.6%	24.0%
Total		Count	74	26	100

Comparing correlated color temperature preference with the result from the color-blind test indicated 34.6% of those with some measure of color blindness (26%) chose the 5000K correlated color temperature, 23.1% chose the

4100k, 19.2% chose the 3500K, and 23.1% chose the 2700K correlated color temperature as seen in the crosstabulation in Table 4.

Testing Room Characteristics

The university test site was considered a public test site with 61% of the test subjects versus the private independent living apartments with 39% of the test subjects. Test times were divided into three categories: 32% of test subjects performed the test in the morning from 7 a.m. to 12 noon, 52% performed in the afternoon from 12 noon to 5 p.m., and 16% performed in the evening from 5 p.m. to 9 p.m. (see Table 6). Two rooms were utilized for the tests at the university. One for the acuity and color blind tests and one for the light box tests. Both rooms were windowless. The lumen level in the university light box test room provided the darkest ambient light level of .1 lux—60% of the tests. The other testing rooms ranged from .2 lux to 8.1 lux ambient room light. Every effort was made to keep the ambient room light as low as possible by covering windows with cardboard and turning off electric lighting during the tests. Table 6 displays the ambient room light lux levels of each test site.

Table 5

Color Blind Test Result Compared to Age Range

Color Blind Test		Age Range: 18 to 22 Youngest Adults	Age Range: 23 to 69 Mid-range Adults	Age Range: 70-100 Oldest Adults	
Not color blind	Count	33	31	10	74
	% within age range	97.1%	96.9%	29.4%	74.0%
Some measure of color blindness	Count	1	1	24	26
	% within age range	2.9%	3.1%	70.6%	26.0%
Total	Count	34	32	34	100
	% within age range	100.0%	100.0%	100.0%	100.0%

Table 6

Testing Room Characteristics

Test Room Characteristics	Count	Percent	Cumulative Percent
Ambient room lumens (Lux)			
0.1	60	60	60.0
0.2	5	5	65.0
1.4	9	9	74.0
2.1	7	7	81.0
2.5	8	8	89.0
4.0	1	1	90.0
4.8	3	3	93.0
8.1	7	7	100.0
Time of day			
Morning 7 am to 12 noon	32	32	32.0
Afternoon 12 noon to 5 pm	52	52	84.0
Evening 5 pm to 9 pm	16	16	100.0

Table 7

Time Length of Tasks

Minutes	Participants	Percent	Cumulative Percent
12	1	1.0	1.0
13	5	5.0	6.0
14	6	6.0	12.0
15	8	8.0	20.0
16	7	7.0	27.0
17	11	11.0	38.0
18	8	8.0	46.0
19	7	7.0	53.0
20	9	9.0	62.0
21	5	5.0	67.0
22	6	6.0	73.0
23	3	3.0	76.0
24	4	4.0	80.0
25	7	7.0	87.0
26	4	4.0	91.0
27	1	1.0	92.0
28	3	3.0	95.0
29	2	2.0	97.0
30	3	3.0	100.0
Total	100	100.0	

Test times ranged from the shortest test time of 12 minutes to the longest test time of 30 minutes per person (M = 19.77, SD = 4.618). Test subjects at the university test site completed tasks every 20 minutes. The independent living facility test subjects required 30 minutes between tests (see Table 7).

Preferred Correlated Color Temperature (K)

After the achromatic reading and number matching tasks were completed, the test subjects selected the correlated color temperature they preferred from the 2700K, 3500K, 4100K, and 5000K correlated color temperatures lamp selections. The researcher cycled through the settings as the participant held an orange medication bottle with black text on a white label. The participants selected the most comfortable light setting or the one they thought made the text appear clearer. 36% selected the 4100K light setting, 28% selected 3500K, 24% selected 5000K, and 12% selected 2700K (see Table 8). Ironically, 2700K is what most individuals have had in their homes when they purchase the standard lightbulb whether incandescent or compact fluorescent.

Table 8

Test Subjects Preferred Correlated Color Temperature

Correlated Color Temperature	Count	Percent	Cumulative Percent
Preferred CCT/Kelvins			
2700K	12	12	12.0
3500K	28	28	40.0
4100K	36	36	76.0
5000K	24	24	100.0

Hypothesis Tested

The following hypotheses were tested:

1. There will be a significant mean difference on performance scores based on correlated color temperature.
    - A frequency analysis of the MNReading test times indicated that participants on average had the fastest reading time with the 4100K correlated color temperature, second fastest with the 3500K, third fastest with the 2700K, and 5000K was last.
        - 4100K (M = 20.87, SD = 6.77)
        - 3500K (M = 20.98, SD = 7.14)
        - 2700K (M = 21.90, SD = 7.83)
        - 5000K (M = 22.11, SD = 8.84)
    - A frequency analysis of the MNReading test errors indicated that participants had on average the fewest errors with the 4100K correlated color temperature, the 3500K was second, 2700K was third, and 5000K was last.
        - 4100K (M = .64, SD = .91)
        - 3500K (M = .65, SD = .82)
        - 2700K (M = .68, SD = .95)
        - 5000K (M = .93, SD = 1.09)

- A frequency analysis of the NVT number matching test time indicated that participants on average completed the number matching task the fastest with the 4100K correlated color temperature, the 5000K was second, the 3500K was third, and the 2700K was last.
    - 4100K (M = 54.16, SD = 21.65)
    - 5000K (M = 54.73, SD = 21.99)
    - 3500K (M = 60.26, SD = 23.29)
    - 2700K (M = 60.38, SD = 24.96)
- A frequency analysis of the NVT number matching task errors indicated that participants on average had the fewest errors with the 4100K correlated color temperature, the 5000K was second, the 2700K was third, and 3500K was last.
    - 4100K (M = .31, SD = .734
    - 5000K (M = .51, SD = .823)
    - 2700K (M = .72, SD = 1.055)
    - 3500K (M = 1.18, SD = 1.366)

Table 9 displays the summarization of the mean difference relationship between the correlated color temperature and participant performance.

Table 9

Achromatic Test Performance

Performance	MNRead Time	MNRead Errors	NVT Number Time	NVT Number Errors
1st	4100K	4100K	4100K	4100K
2nd	3500K	3500K	5000K	5000K
3rd	2700K	2700K	3500K	2700K
4th	5000K	5000K	2700K	3500K

2. There will be significant mean difference on performance scores based on correlated color temperature participant preference. A One-way ANOVA performed with the preferred correlated color temperatures as the independent factor variable against the dependent variables of test time and errors found an insignificant mean difference.

- 2700K MNReading task errors

  ($F = .065$, $df = 15$ and 84, $p = .978$)

- 2700K MNReading task time

  ($F = .668$, $df = 15$ and 84, $p = .573$)

- 3500K MNReading task errors

  ($F = 1.514$, $df = 15$ and 84, $p = .216$)

- 3500K MNReading task time

  ($F = .746$, $df = 15$ and 84, $p = .527$)

- 4100K MNReading task errors

  (F = .770, *df* = 15 and 84, *p* = .514)

- 4100K MNReading task time

  (F = .449, *df* = 15 and 84, *p* = .718)

- 5000K MNReading task errors

  (F = .721, *df* = 15 and 84, *p* = .542)

- 5000K MNReading task time

  (F = .472, *df* = 15 and 84, *p* = .702)

- 2700K NVT number matching task errors

  (F = .748, *df* = 15 and 84, *p* = .526)

- 2700K NVT number matching task time

  (F = .518, *df* = 15 and 84, *p* = .671)

- 3500K NVT number matching task errors

  (F = 1.108, *df* = 15 and 84, *p* = .350)

- 3500K NVT number matching task time

  (F = .911, *df* = 15 and 84, *p* = .349)

- 4100K NVT number matching task errors

  (F = .203, *df* = 15 and 84, *p* = .894)

- 4100K NVT number matching task time

  (F = .582, *df* = 15 and 84, *p* = .628)

- 5000K NVT number matching task errors
  ($F = .104$, *df* = 15 and 84, $p = .958$)
- 5000K NVT number matching task time
  ($F = .539$, *df* = 15 and 84, $p = .656$)

3. Males and females will have significant mean differences on their correlated color temperature preference. A One-way ANOVA difference indicated no significant mean difference between males and females in correlated color temperature preference with only a .9 difference between females ($M = 2.74$) and males ($M = 2.65$); ($F = .146$, *df* = 1 and 98, $p = .703$).
4. Males and females will have significant mean differences on their performance scores (time and errors).
   - A One-way ANOVA descriptive indicated that there was a significant mean difference between men and women on the following:
     - 3500K MNReading task time ($F = 3.951$; *df* = 1 and 98, $p = .050$) where men on average ($M = 23.54$) took 3.32 seconds longer to perform the reading task than women ($M = 20.22$).
     - 2700K NVT number matching task time ($F = 15.541$, *df* = 1 and 98, $p = .000$) where men ($M = 77.19$) on average took 21.83

seconds longer than women (M = 55.36) to perform the number matching task.

  - 3500K NVT number matching task time (F = 16.787, *df* = 1 and 98, *p* = .000) the 3500K where men (M = 76.47) on average took 21.05 seconds longer than women (M = 55.42) to perform the number matching task.
  - 4100K NVT number matching task time (F = 19.151, *df* = 1 and 98, *p* = .000) where men (M = 70.10) on average took 20.70 seconds longer than women (M = 49.40) to perform the number matching task.
  - 5000K NVT number matching task time (F = 14.108, *df* = 1 and 98, p = .000) where men (M = 68.92) on average took 18.44 seconds longer to complete the task than women (M = 50.48).

- There was no significant mean difference between men and women on number of errors related to correlated color temperature for the following:
  - 2700K MNRead task errors
    (F = 114, *df* = 1 and 98, *p* = .736)
  - 3500k MNRead task errors
    (F = .777, *df* = 1 and 98, *p* = .380)

- 4100K MNRead task errors

  (F = .198, *df* = 1 and 98, *p* = .658)

- 5000K MNRead task errors

  (F = .123, *df* = 1 and 98, *p* = .726)

- 2700K NVT number matching task errors

  (F = .598, *df* = 1 and 98, *p* = .441)

- 3500K NVT number matching task errors

  (F = .448, *df* = 1 and 98, *p* = .505)

- 4100K NVT number matching task errors

  (F = 2.521, *df* = 1 and 98, *p* = .116)

- 5000K NVT number matching errors

  (F = .428, *df* = 1 and 98, *p* = .515)

- There was no significant mean difference between men and women for the following MNRead reading task time:

  - 2700K MNReading task time

    (F = 1.162, *df* = 1 and 98, *p* = .284)

  - 4100K MNReading task time

    (F = 2.464, *df* = 1 and 98, *p* = .120)

  - 5000K MNReading task time

    (F = 1.932, *df* = 1 and 98, *p* = .168)

5. Age groups will have significant mean differences on their correlated color temperature preference. There was no significant mean difference on age groups effecting test subject's correlated color temperature preference according to the One-way ANOVA calculation (F = .883, *df* = 2 and 97, *p* =.417).
6. Age groups will have significant mean differences on their performance scores (time and errors). Refer to Table 1 for age group divisions. A One-way ANOVA and Post HocTukey multiple comparison indicated a significant mean difference for the following:
    - 2700K MNReading task errors (F = 4.496, *df* = 2 and 97, *p* = .014) where the midrange age group on average made .63 fewer reading errors, and the youngest age group made .09 fewer errors than the oldest age group.
        - Mid-range age group (M = .28)
        - Youngest age group (M = .82)
        - Oldest age group (M = .91)
    - 2700K MNReading time (F = 14.359, *df* = 2 and 97, *p* = .000) where the youngest age group on average read faster by 8.13 seconds, the mid-range age group by 7.55 seconds faster than the oldest adult age group.

    - Youngest age group (M = 18.95)
    - Mid-range age group (M = 19.53)
    - Oldest age group (M = 27.08)
- 3500K MNReading task time (F = 20.703, *df* = 2 and 97, *p* = .000) where the youngest age group on average read faster by 8.56 seconds, and the midrange age group by 7.77 seconds faster than the oldest age group.
    - Youngest age group (M = 17.82)
    - Mid-range age group (M = 18.61)
    - Oldest age group (M = 26.38)
- 4100K MNReading task time (F = 18.395, *df* = 2 and 97, *p* = .000) where on average the youngest age group read faster by 7.89 seconds, and the mid-range age group by 6.89 seconds faster than the oldest age group.
    - Youngest age group (M = 17.87)
    - Mid-range age group (M = 18.87)
    - Oldest age group (M = 25.76)
- 5000K MNReading task time (F = 16.864, *df* = 2 and 97, *p* = .000) where on average the youngest age group read faster by 10.3 seconds, and the mid-range age group by 8.12 seconds faster than the oldest age group.

- Youngest age group (M = 17.91)
- Mid-range age group (M = 20.09)
- Oldest age group (M = 28.21)

- 2700K NVT number matching task time (F = 47.449, *df* = 2 and 97, *p* = .000) where on average the youngest age group completed the number matching task faster by 39.44 seconds, the mid-range age group by 51.08 seconds faster than the oldest age group.
    - Youngest age group (M = 45.03)
    - Mid-range age group (M = 51.08)
    - Oldest age group (M = 84.47)
- 3500K NVT number matching task time (F = 47.659, *df* = 2 and 97, *p* = .000) where on average the youngest age group performed the number matching task faster by 36.99 seconds, and the mid-range age group by 30.88 seconds faster than oldest age group.
    - Youngest age group (M = 45.73)
    - Mid-range age group (M = 51.84)
    - Oldest age group (M = 82.72)
- 4100K NVT number matching task time (F = 42.836, *df* = 2 and 97, *p* = .000) where on average the youngest age group performed the number matching task faster by 33.51 seconds, and the mid-range age group faster by 27.89 than the oldest age group.

    - Youngest age group (M = 40.97)
    - Mid-range age group (M = 46.59)
    - Oldest age group (M = 74.48)
  - 5000K NVT number matching task time (F = 48.499, *df* = 2 and 97, *p* = .000) where on average the youngest age group performed the number matching task faster by 34.48 seconds, and the mid-range age group by 30.29 seconds faster than the oldest age group.
    - Youngest age group (M = 41.66)
    - Mid-range age group (M = 45.85)
    - Oldest age group (M = 76.14)

7. There will be significant mean differences in performance scores (time and errors) based on the visual acuity test. A One-Way ANOVA and Post HocTukey multiple comparison indicated a significant mean difference in performance scores by visual acuity for the MNReading tasks for the following correlated color temperatures:
   - 2700K MMReading task time (F = 7.002, *df* = 2 and 97, *p* = .001), where test subjects with a visual acuity score of 20/20 on average read faster by 9.12 seconds, and the 20/40 read 5.42 seconds faster than the 20/50 test subjects.

    - 20/20 (M = 19.60)
    - 20/40 (M = 23.30)
    - 20/50 and up (M = 28.72)
- 3500K MNReading task time (F = 9.123, *df* = 2 and 97, *p* = .000), where test subjects with a visual acuity score of 20/20 on average read faster by 9.46 seconds, and the 20/40 read 5.83 seconds faster than the 20/50 test subjects.
    - 20/20 (M = 18.68)
    - 20/40 (M = 22.31)
    - 20/50 and up (M = 28.14)
- 4100K MNReading task time (F = 7.879, *df* = 2 and 97, *p* = .001), where test subjects with a visual acuity score of 20/20 on average read faster by 8.33 seconds, and the 20/40 test subjects read 5.00 seconds faster than 20/50 test subjects.
    - 20/20 (M = 18.79)
    - 20/40 (M = 22.12)
    - 20/50 (M = 27.12)
- 5000K MNReading task time (F = 7.975, *df* = 2 and 97, *p* = .001) where test subjects with a visual acuity score of 20/20 on average read faster by 11.07 seconds, and the 20/40 test subjects read 6.86 seconds faster than the 20/50 test subjects.

    - 20/20 (M = 19.43)
    - 20/40 (M = 23.64)
    - 20/50 (M = 30.50)

A One-Way ANOVA indicated a significant mean difference in performance scores by visual acuity for the NVT number matching tasks for the following correlated color temperatures:

- 2700K NVT number matching task time (F = 25.373, *df* = 2 and 97, *p* = .000), where test subjects with a visual acuity score of 20/20 completed the number matching task on average faster by 49.44 seconds, and the 20/40 test subjects by 31.84 seconds faster than the 20/50 test subjects.
    - 20/20 (M = 48.89)
    - 20/40 (M = 66.49)
    - 20/50 (M = 98.33)
- 3500K NVT number matching task errors (F = 6.225, *df* = 2 and 97, *p* = .003), where test subjects with a visual acuity score of 20/20 made on average fewer errors in the number matching task by 1.60, and the 20/40 subjects made 1.33 less than the 20/50.
    - 20/20 (M = .84)
    - 20/40 (M = 1.33)
    - 20/50 (M = 2.44)

- 3500K NVT number matching task time (F = 24.071, *df* = 2 and 97, *p* = .000), where test subjects with a visual acuity score of 20/20 completed the number matching task on average faster by 43.55 seconds, and the 20/40 test subjects by 25.30 seconds faster than the 20/50 test subjects.
  - 20/20 (M = 49.04)
  - 20/40 (M = 67.29)
  - 20/50 (M = 92.59)
- 4100K NVT number matching task time (F = 20.264, *df* = 2 and 97, *p* = .000), where test subjects with a visual acuity score of 20/20 completed the number matching task on average faster by 37.22 seconds, and the 20/40 test subjects by 20.31 seconds faster than the 20/50 test subjects.
  - 20/20 (M = 44.05)
  - 20/40 (M = 60.96)
  - 20/50 (M = 81.27)
- 5000K NVT number matching task time (F = 25.786, *df* = 2 and 97, *p* = .000), where test subjects with a visual acuity score of 20/20 completed the number matching task on average faster by 42.47 seconds, and the 20/40 test subjects by 25.26 seconds faster than the 20/50 test subjects.

- 20/20 (M = 44.02)
- 20/40 (M = 61.23)
- 20/50 (M = 86.49)

8. There will be significant mean differences in participants correlated color temperature participant preference based on their visual acuity. A One-Way ANOVA did not indicate a significant mean difference between participant preference of correlated color temperature in relation to participant's visual acuity (F = 2.177, *df* = 4 and 95, *p* = .077).
9. There will be significant mean differences in performance scores based on additional eye medical conditions versus not having visual medical conditions other than wearing glasses or contacts. A One-Way ANOVA indicated there was a significant mean difference for the following tasks:
   - 2700K MNReading task time where test subjects having no additional medical eye conditions other than wearing reading glasses or contacts on average took less time to complete the reading task than those with additional visual medical conditions by 3.84 seconds (F = 5.259, *df* = 1 and 98, *p* = .024).
     - No additional medical eye conditions (M = 20.75)
     - Additional medical eye conditions (M = 24.59)

- 3500K MNReading task time where test subjects having no additional medical eye conditions other than wearing reading glasses or contacts on average took less time to complete the reading task than those with additional visual medical conditions by 4.12 seconds (F = 7.449, *df* = 1 and 98, *p* = .008).
    - No additional medical eye conditions (M = 19.75)
    - Additional medical eye conditions (M = 23.87)
- 4100K MNReading task time where test subjects having no additional medical eye conditions other than wearing reading glasses or contacts on average took less time to complete the reading task than those with additional visual medical conditions by 4.81 seconds (F = 11.728, *df* = 1 and 98, *p* = .001).
    - No additional medical eye conditions (M = 19.43)
    - Additional medical eye conditions (M = 24.24)
- 5000K MNReading task errors where test subjects having no additional medical eye conditions other than wearing reading glasses or contacts made on average fewer errors than those with additional visual medical conditions by .86 errors (F = 15.151, *df* = 1 and 98, *p* = .000).
    - No additional medical eye conditions (M = .67)
    - Additional medical eye conditions (M = 1.53)

- 5000K MNReading task time where test subjects having no additional medical eye conditions other than wearing reading glasses or contacts on average took less time to complete the reading task than those with additional visual medical conditions by 5.43 seconds (F = 8.520, *df* = 1 and 98, *p* = .004).
  - No additional medical eye conditions (M = 20.48)
  - Additional medical eye conditions (M = 25.91)
- 2700K NVT number matching task errors where test subjects having no additional medical eye conditions other than wearing reading glasses or contacts made on average fewer errors than those with additional visual medical conditions by .59 errors (F = 6.977, *df* = 1 and 98, *p* = .010).
  - No additional medical eye conditions (M = .54)
  - Additional medical eye conditions (M = 1.13)
- 2700K NVT number matching task time where test subjects having no additional medical eye conditions other than wearing reading glasses or contacts on average took less time to complete the reading task than those with additional visual medical conditions by 26.65 seconds (F = 31.234, *df* = 1 and 98, *p* = .000).
  - No additional medical eye conditions (M = 52.38)
  - Additional medical eye conditions (M = 79.03)

- 3500K NVT number matching task errors where test subjects having no additional medical eye conditions other than wearing reading glasses or contacts on average made fewer errors than those with additional visual medical conditions ($F = 10.769$, *df* = 1 and 98, $p = .001$).
    - No additional medical eye conditions (M = .90)
    - Additional medical eye conditions (M = 1.83)
- 3500K NVT number matching task time where test subjects having no additional medical eye conditions other than wearing reading glasses or contacts on average took less time to complete the reading task than those with additional visual medical conditions by 24.57 seconds ($F = 30.280$, *df* = 11 and 98, $p = .000$).
    - No additional medical eye conditions (M = 52.89)
    - Additional medical eye conditions (M = 77.46)
- 4100K NVT number matching task time where test subjects having no additional medical eye conditions other than wearing reading glasses or contacts on average took less time to complete the reading task than those with additional visual medical conditions by 22.52 seconds ($F = 29.107$, *df* = 1 and 98, $p = .000$).
    - No additional medical eye conditions (M = 47.41)
    - Additional medical eye conditions (M= 69.93)

- 5000K NVT number matching task time where test subjects having no additional medical eye conditions other than wearing reading glasses or contacts on average took less time to complete the reading task than those with additional visual medical conditions by 21.44 seconds (F = 24.762, *df* = 1 and 98, *p* = .000).
  - No additional medical eye conditions (M = 48.29)
  - Additional medical eye conditions (M= 69.73)

10. There will be significant mean differences in correlated color temperature participant preference based on additional eye medical conditions. A One-way ANOVA indicated an insignificant mean difference for participant preference of correlated color temperature related to test subject having additional visual medical conditions versus not having visual medical conditions other than wearing glasses or contacts (F = .018, *df* = 1 and 98, *p* = .893).

Additional Analysis

Analyzing time of day compared to performance using a One-way ANOVA and a Post HocTukey multiple comparison indicated a significant mean difference on average for the following two correlated color temperatures: Table 10 displays time of day count percentages.

Table 10

Time of Day of Tests

Time of Day	Count	Percent	Cumulative Percent
Time of day			
Morning 7 am to 12 noon	32	32	32.0
Afternoon 12 noon to 5 pm	52	52	84.0
Evening 5 pm to 9 pm	16	16	100.0

1. 4100K MNReading task errors (F = 4.852, *df* = 2 and 97, *p* = .010) where the fewest errors were made in the morning and the most were made in the afternoon.
   - Morning test time (M = .34)
   - Evening test time (M = .38)
   - Afternoon test time (M = .90)
2. 3500K NVT number matching task time (F 2.446, *df* = 2 and 97, p = .092) where test subjects on average performed fastest in the evening, performed second fastest in the afternoon, and performed longest in the morning time slot.
   - Evening test time (M = 49.33)
   - Afternoon test time (M = 60.87)
   - Morning test time (M = 64.75).

3. The remaining tests did not indicate a significant mean difference on average for errors or time:
   - 2700K MNReading task errors
     - Afternoon test time (M = .58)
     - Morning test time (M = .78)
     - Evening test time (M = .81)
   - 2700K MNReading task time
     - Evening test time (M = 19.62)
     - Afternoon test time (M = 21.25)
     - Morning test time (M = 24.10)
   - 3500K MNReading task errors
     - Morning test time (M = .59)
     - Afternoon test time (M = .60)
     - Evening test time (M = .94)
   - 3500K MNReading task time
     - Evening test time (M = 19.35)
     - Afternoon test time (M = 20.33)
     - Morning test time (M = 22.87)

- 4100K MNReading task time
    - Evening test time (M = 18.27)
    - Afternoon test time (M = 20.81)
    - Morning test time (M = 22.28)
- 5000K MNReading task errors
    - Evening test time (M = .81)
    - Morning test time (M = .83)
    - Afternoon test time (M = 1.16)
- 5000K MNReading task time
    - Evening test time (M = 19.36)
    - Afternoon test time (M = 21.61)
    - Morning test time (M = 24.29)
- 2700K NVT number matching task errors
    - Afternoon test time (M = .65)
    - Evening test time (M = .69)
    - Morning test time (M = .84)
- 2700K NVT number matching task time
    - Evening test time (M = 51.05)
    - Afternoon test time (M = 59.49)
    - Morning test time (M = 66.48)

- 3500K NVT number matching task errors
  - Evening test time (M = .75)
  - Afternoon test time (M = 1.21)
  - Morning test time (M = 1.34)
- 4100K NVT number matching task errors
  - Evening test time (M = .25)
  - Afternoon test time (M = .27)
  - Morning test time (M = .41)
- 4100K NVT number matching task time
  - Evening test time (M = 45.67)
  - Afternoon test time (M = 54.85)
  - Morning test time (M = 57.29)
- 5000K NVT number matching task errors
  - Evening test time (M = .25)
  - Morning test time (M = .47)
  - Afternoon test time (M = .62)
- 5000K NVT number matching task time
  - Evening test time (M = 46.22)
  - Afternoon test time (M = 55.45)
  - Morning test time (M = 57.80)

Statistical data indicated that the bluer 4100K correlated color temperature did improve task scores in both reading and errors. The data also indicated that participants choose 4100K as their preferred correlated color temperature. Gender and age group categories did not significantly affect participant correlated color temperature preference. Gender did not significantly affect performance error scores but it did significantly affect performance time scores where males took longer to perform tasks, on average than females.

Performance scores indicated the older age group took longer and had more errors than any other age group category. Participants with additional visual medical conditions did not significantly affect participant correlated color temperature preference but did significantly affect performance where those with more medical eye conditions did perform more slowly and made more errors. Notable was the fact that some of the older adults who scored as partially color blind on the color-blind test had difficulty choosing a correlated color temperature preference and could not discern between warmer or more yellow/red light versus the cooler/bluer light.

CHAPTER 5

Conclusion

This study explored which correlated color temperature (CCT/K) of artificial light assisted adult individuals to see better in an achromatic task light setting and which of four correlated color temperatures they preferred utilizing a tunable LED lamp. Past research could not account for the increase or decrease in illuminance as correlated color temperatures differed which could affect test subject responses (O'Conner & Davis, 2005; Esperjesi, Fernandez & Barlett, 2007). Only recent advancement in customizable control options allowed the researcher to control illuminance as the correlated color temperature is "tuned" keeping brightness even so tests results would not be biased (Willmorth, 2016).

Performance and Correlated Color Temperature

Test subjects performed best in the 4100K correlated color temperature in all four achromatic tests making the fewest errors and reading the fastest. This finding reinforces research by Figueiro and others regarding the benefits of a shorter wave length light (Figueiro & Rea, 2010). The 4100K was a bluer/white light but not the bluest/white of the four selections. The 3500K scored second and third; the 5000K scored second and fourth; and the 2700K scored third and fourth. Table 9 displays the test performance of the participants by correlated color temperature. Both correlated color temperature extremes 2700K and 5000K scored the poorest.

Table 9

Achromatic Test Performance

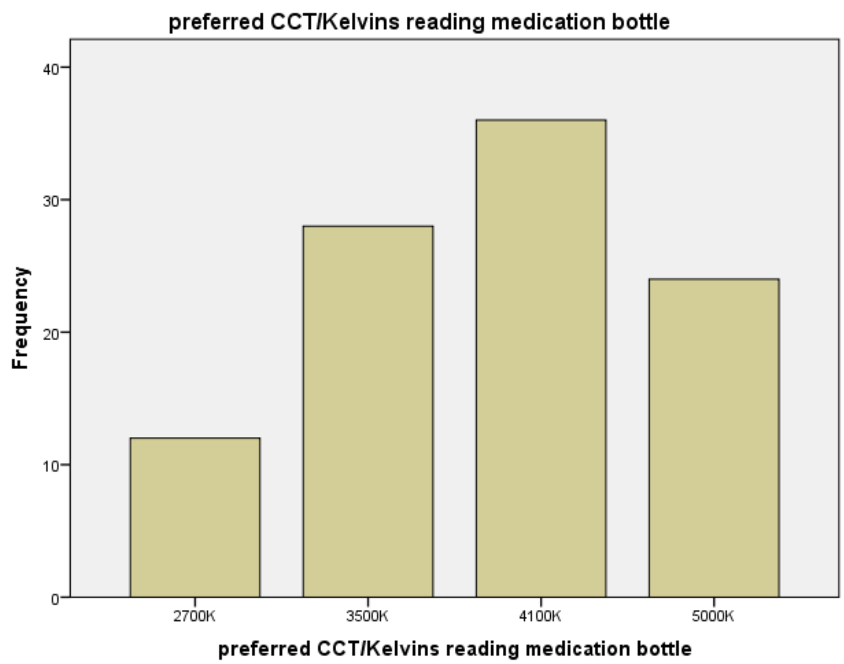
Performance	MNRead Time	MNRead Errors	NVT Number Time	NVT Number Errors
1st	4100K	4100K	4100K	4100K
2nd	3500K	3500K	5000K	5000K
3rd	2700K	2700K	3500K	2700K
4th	5000K	5000K	2700K	3500K

Correlated Color Temperature Preference

Test subject's correlated color temperature personal preferences did not indicate a significant mean relationship to performance, but percentages did show a matching correlation. Test subjects preferred, by percentage, the bluer/white 4100K light first, the slightly warmer/yellow 3500K light second, the bluest/coolest 5000K light third, and the warmest/yellowest 2700K light least. The bar chart in Figure 4 displays test subject's correlated color temperature preference.

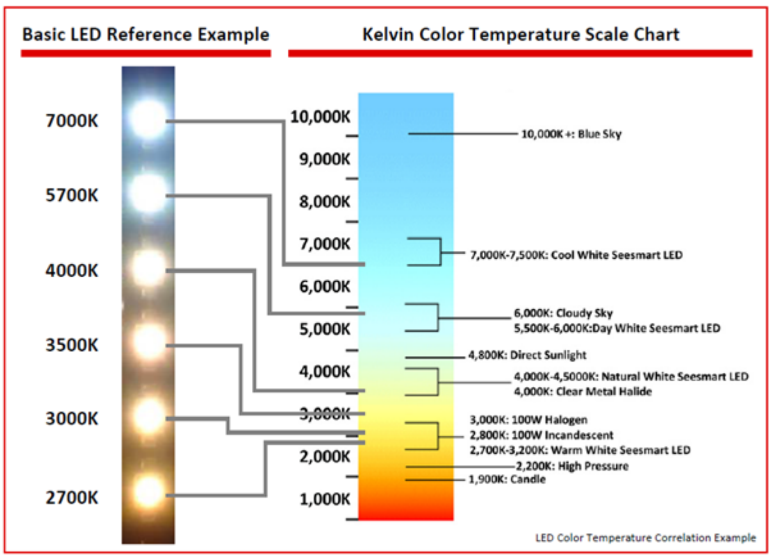
The researcher has observed a greater selection of additional correlated color temperature lamps available to the lay person in home improvement stores in the form of tube fluorescents and LEDs, indicating that as research has progressed, so has the availability. As commercial and residential buyers become educated to the benefits of more specific lamp characteristics, demand increases. Consequently, with more demand, the purchase cost decreases providing more individuals the opportunity to purchase appropriate lamps.

Figure 4. Test subject preferred correlated color temperature



All three age groups were very interested in the dynamics of the testing and the specifics of the lamp characteristics as indicated by their questions after they completed the tasks. Particularly, the older adults inquired which lamps they should purchase to help them see better because of inefficient lighting in their residences and loss of adequate vision. The researcher spent several minutes explaining how to read and understand specifications on lamp packaging. The researcher noticed that lamp manufacturers are placing specifications that have been available only to the professional on lamp packaging supplied to everyday home improvement stores. Thus, educating consumers becomes paramount. Figure 5 displays a correlated color temperature scale providing the reader an idea of the correlated color temperature light the test subjects experienced.

Figure 5. Kelvin Correlated Color Temperature Scale Chart



Retrieved from Retrieved from http://studylib.net/doc/8926648/choosing-the-right-color-temperature

Gender Differences

Males compared to females did not indicate a preferred correlated color temperature. One reading task time, the 3500K MNReading task, indicted males read more slowly than the women by 3.32 seconds. The NVT number matching tasks indicated males took an average of 20.5 seconds longer to perform the number matching test for all four correlated color temperatures. Interestingly, this did not affect task errors between the genders where no significant mean difference indicated whether males or females had on average fewer errors compared to each other. Although men taking longer to perform the tasks is not a significant result to this study, it may have implications to other social science research.

Visual Acuity

Visual acuity of test subjects did not affect correlated color temperature preference of participants. The participant's visual acuity test did affect test performance with 20/20 vision performing best in errors and time in 15 out of 16 of the achromatic reading tasks. For the 2700K MNReading test time, the participants with 20/50 visual acuity performed on average .08 seconds better than the 20/20 visual acuity participants. The researcher cannot explain the exception. All other tasks whether time or error indicated that the poorer the visual acuity the worse the performance on the tasks. Cross sectional findings focused on age differences, not age changes. This finding indicates the paramount importance of regular vision eye care for older adults as age-related visual acuity decreases (Shikder, Mourshed & Price, 2012; Figueiro, 2001).

Color Blindness

Most (95%) of the test subjects (see Table 3) indicated they were not colorblind nor had they been diagnosed as color blind, but 26% of test subjects (see Table 4) had difficulty passing the colorblind test and were surprised by their poor performance. This finding may indicate the yellowing of the aging eye lens may occur without the individual being aware they are losing color discrimination. Interestingly, 34.6% of that 26% chose the 5000K bluest/white light as their preferred correlated color temperature (see Table12). Also, 30% of participants (see Table11) indicated they had cataract surgery or had the beginnings of

Table 11

Cataracts Removed or Developing

Participants had one or both cataracts removed or developing cataracts.				
	Frequency	Percent	Valid Percent	Cumulative Percent
No, did not have cataracts removed	70	70.0	70.0	70.0
Yes, had cataracts removed or developing cataracts	30	30.0	30.0	100.0
Total	100	100.0	100.0	

cataract development. Although 11% of the 30% preferred the 5000K—over 1/3rd (see Table 12), the value of Somers' *d* measure of association is .044 indicating a weak relationship between the variables preferred correlated color temperature and cataracts removed or beginning to develop. Are the partially color blind participants naturally compensating for the yellower lens choosing the bluer/white light? Or did the color of the participant's cataract replacement lens affect their choice? Research indicates that two main types of intraocular lens—a

Table 12

Cataracts Compared to Preferred Correlated Color Temperature

Had one or both cataracts removed * Preferred CCT/Kelvins reading medication bottle

			Preferred CCT/Kelvins reading medication bottle				
			2700K	3500K	4100K	5000K	Total
Had one or both cataracts removed	No did not have cataracts removed	Count	5	23	29	13	70
		% within had one or both cataracts removed	7.1%	32.9%	41.4%	18.6%	100.0%
		% within preferred CCT/Kelvins reading medication bottle	41.7%	82.1%	80.6%	54.2%	70.0%
		% of Total	5.0%	23.0%	29.0%	13.0%	70.0%
	Yes had cataracts removed	Count	7	5	7	11	30
		% within had one or both cataracts removed	23.3%	16.7%	23.3%	36.7%	100.0%
		% within preferred CCT/Kelvins reading medication bottle	58.3%	17.9%	19.4%	45.8%	30.0%
		% of Total	7.0%	5.0%	7.0%	11.0%	30.0%
Total		Count	12	28	36	24	100
		% within had one or both cataracts removed	12.0%	28.0%	36.0%	24.0%	100.0%
		% within preferred CCT/Kelvins reading medication bottle	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	12.0%	28.0%	36.0%	24.0%	100.0%

blue-light filtering intraocular lens implant (purpose of retinal protection) and an ultraviolet blocking intraocular lens implant (clear lens) are used for replacement lens. The researcher did not report on participant cataract surgery lens color and the participants may not know which lens their ophthalmologist chose. The preference for the higher blue correlated color temperature seems to indicate a possible effect from cataract lens replacement (Wei et al., 2013; Xue et al., 2016).

Time of Day

An analysis of 14 performance and preference tests indicated that time of day did not have a significant means difference. Only two of the performance tests had a significant means difference producing contradictory results. The 4100K MN Reading error task had fewest errors in the morning time and the 3500K NVT number matching time was best in the evening.

Limitations of the Study

The researcher recognizes the weaknesses that possibly impacted the study. Perhaps an assembly of sentences for some of the MNReading pages were easier to read than others, or some number-matching sequence pages were easier to match than others. There also could be a learning curve with the first test of the reading and the first test of the number-matching tasks so subsequent tasks seemed easier to the respondent.

The researcher found it difficult to know exactly when to start the stop watch and tried several methods in the pilot study such as “begin after I say start”, or starting the stop watch when the test subject began reading the first word, or putting the pencil to the paper for the number-matching task. Neither method worked perfectly. Each method could cause a discrepancy in 1/100 of a second.

The researcher employed a medicine bottle with a white label on a bright orange background to choose correlated color temperature preference. Could the orange have influenced the preference choice toward the bluer/white light since blue and orange are complementary on a color wheel and enhance each other’s intensity (red, yellow, blue color model) (Tofle et al., 2004) misleading the participant. Color of materials did not affect the achromatic (without color) performance tests.

Not knowing what color of intraocular lens participant’s ophthalmologist utilized to replace cataract lens could also have an influence of participant correlated color temperature preference. A blue-light blocking (yellow) intraocular lens could influence the participant to compensate toward the stronger blue/white light (5000K).

The researcher contacted in person 15 senior housing sites. These locations included community senior centers, libraries with senior groups, independent living facilities, and senior living apartments. Directors at four sites agreed to participate. The remaining directors stated their populations were not appropriate for the study, the study was considered soliciting, or the timing of the study was inconvenient. As a result, only three sites participated. A larger sample size would provide a greater confidence level for the results.

Controlling room luminance at test sites proved to be difficult. The university setting provided windowless rooms for testing and attained a low .1 lumen ambience light level, but the independent living facility could not provide windowless rooms. Every attempt was made to cover windows as much as possible to prevent ambient light from affecting results but a range of .1 to 8.1 lux was obtained. A SPSS analysis would not be useful since the youngest age group from the university site dominated the number of subjects at the .1 testing site which would bias results.

The pilot study indicated test subjects required 20 minutes per test. The independent living facility test sites required 30 minutes between tests requiring an immediate adjustment for scheduling test times.

Further Research

Understanding lamp characteristics and specifications is complicated for the lay population. Understanding how to “tune” lamps is worth pursuing since lighting is an aesthetic and health benefit to residential and commercial environments (Figueiro et al., 2016). A preferred correlated color temperature can be the individual’s choice because one size does not fit all. Do the individual physiological or psychological needs affect the preferred choice? Additional research is needed to ascertain these answers.

Although manufacturers are adding more lamp specifications to packaging understanding lamp characteristics is difficult for the lay person. Developing a simplified universal coding system for lamp packaging or simplify information on how to tune lamps for the best aesthetic or health benefit is another area of research.

With the advancement of lighting controls additional lamp specifics can be researched. For example, using the new system of TM-30-15 measurements and graphics, which can be used to evaluate and communicate a light source's color rendering properties to research CRI preference (U.S. Dept. of Energy, 2015).

Controlling for time of day to administer tests could uncover different preference and performance scores leading to conclusions related to the issues of alertness referencing cortisol, alpha amylase, and melatonin suppression or stimulation when exposed to significant intensities of blue and red light at different times of the day (Figueiro & Rea, 2010).

The researchers sample size of 100 is adequate for a pilot study but a larger sample size would give greater confidence with the results. Researchers could pursue a greater number of case samples to see if results hold true or differ.

The cross-sectional findings of this study focused on the identification of potential age differences in vision not age changes in vision. Further research could involve longitudinal study designs to identify age changes in vision and their effect on performance and preference scores (Verbrugge et al., 1996).

Design Implications

Some test subjects (36%) indicated a personal preference toward the blue/white 4100K correlated color temperature, a small group (24%) preferred the bluer/whiter 5000K. The 3500K correlated color temperature, 28% of respondents, was preferred second, which is bluer than the warm yellow/gold of the 2700K but still considered on the warm side. Only 12% of test subjects preferred the 2700K which is the warmest correlated color temperature. Ironically, most homeowners use 2700K lamps, and most commercial settings use 3500K fluorescents although this trend is changing; LEDs are gaining popularity in the marketplace, and builders, architects, and designers are becoming more knowledgeable of lighting specifications enabling them to select more appropriate lighting (Eaton Cooper Lighting Business, 2015).

Home modification. Test subjects on average performed best in the 4100K correlated color temperature (see Figure 6). Consequently, designers can feel comfortable specifying a day-type white lighting correlated color temperature

Figure 6. Correlated Color Temperature Differences Effect on an Object

Note: Warm white and cool white differences shown on the same object. Red buttons stand out more in the warm white and blue buttons appear more vibrant in the cool white. Retrieved from http://studylib.net/doc/8926648/choosing-the-right-color-temperature

in the 4000K range for typical home modification alterations if there are no other design implications to consider (Seesmart, 2010). If preferred correlated color temperature is determined by personal choice, designers could consider providing clients that choice.

Conclusion

Lighting is a part of everyday life. Turning on a light is an individual's first activity in the morning when waking, and turning it off is the last action an individual performs at night before sleep. No one reflects on the quality of the light; people just need to function. Today, people can do more than just function in their residential or commercial interiors. They can choose lighting which helps them to see more efficiently, to benefit from daylight harvesting settings, to regulate their circadian rhythm, or to enhance the finishes in their personal or commercial environments. They need to be educated regarding availability and cost. The informed designer can provide this education as one contribution to home modification.

The advantages of LED tuning can favorably impact interiors. Their capabilities include warm dimming, color matching, scene/space color tuning, and human-centric correlated color temperature delivery to support photobiologic and visual performance effects (Willmorth, 2016; Figueiro et al., 2016).

The findings of this study may well benefit the home modification market and the designers, builders, and manufacturers who serve it. Study results indicate that on average, the 4100K is the preferred LED correlated color temperature for reading and numerical tasks performed by both males and females at all ages of adult hood. The efficient LED light source not only saves energy but provides correlated color temperature that is both acceptable and supportive for visual task performance.

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APPENDICES

APPENDIX A

Definition of Terms

AARP. American Association of Retired Persons is a nonprofit, nonpartisan organization, with a membership of more than 37 million, that helps people 50+ have independence, choice and control in ways that are beneficial to them and society as a whole (AARP Livable Communities, 2014).

Accent Lighting. Light fixtures which allow light to focus on art, signage, and other interior surfaces and features (Karlen et al., 2012). Also, called focal lighting (Winchip, 2011).

Accessibility. Improving accessibility means making doorways wider, clearing spaces to make sure a wheelchair can pass through, lowering countertop heights for sinks and kitchen cabinets, installing grab bars, and placing light switches and electrical outlets at the heights that can be reached easily. These must comply with the Fair Housing Amendments Act of 1988, the Americans with Disabilities Act accessibility guidelines, and American National Standards Institute regulations for accessibility (US Department of Health and Human Services, 2003).

Accommodation. The process by which the eye changes focus from one-distance to another (Illuminating Engineering Society of North America, 2006)

Activities of Daily Living (ADLs). ADLs are the fundamental activities an individual requires, such as communicating, eating, drinking, dressing, personal cleansing, and grooming, bowel, and bladder management, and sleeping (Lawlor & Thomas, 2008).

Achromatic. Free from color (O'Conner & Davis, 2005).

Adaptability. Adaptability features are changes that can be made quickly to accommodate the needs of seniors or disabled individuals without having to completely redesign the home or use different materials for essential fixtures. Examples include installing grab bars in bathroom walls and movable cabinets under the sink so that someone in a wheel chair can use the space (US Department of Health and Human Services, 2003).

Adaptation. The process by which all or part of the retina becomes accustomed to more or less light than it was exposed to during an immediately preceding period. It results in a change in the sensitivity to light (Illuminating Engineering Society of North America, 2006).

Age related macular degeneration (AMD). AMD affects the portion of the retina called the macula and is used for sharp vision. The macula includes the fovea that provides acute vision. Macular degeneration can have two causes: either atrophy of neural tissue ("dry" type) or severe hemorrhagic disease ("wet" type). Visual acuity can drop to less than 20/400. The rest of the retina remains largely unaffected, so peripheral vision remains normal (Figueiro, 2001; Illuminating Engineering Society of North America, 2007).

Aging-in-place. The concept of remaining in one's home safely, independently, and comfortably, regardless of age, income, or ability level (AARP Livable Communities, 2014).

Assisted living housing. A specialized care facility intended to provide a range of personal services based on Individual needs. Housing for mentally and physically frail older people in the United States. It includes residents with wide range of capability levels. In most cases, residents have personal care needs but do not require 24-hour medical supervision (Regnier, 2002).

Assistive technology. Any service or tool that helps the elderly or disabled do the activities they have always done but must not do differently. These tools are sometimes called "adaptive devices." The technology may be as simple as a walker to make moving around easier or an amplification device to make sounds easier to hear (for talking on the phone or viewing television). It can include a magnifying glass that helps someone who has poor vision read the newspaper or a small motor scooter that makes it possible to travel over distances that are too far to walk. Anything that helps the elderly continue to participate in daily activities, also called gerontechnology (US Department of Health and Human Services, 2003; Young, 2012).

Baby boomer. The generation born between 1946 and 1964 (National Association of Realtors, Seniors Real Estate Specialist Council, 2014).

Big box stores. A large retail store whose physical layout resembles a large square or box when seen from above. A big-box store is characterized by a large amount of floor space (generally more than 50,000 square feet), a wide array of items available for sale, and its location in suburban areas. Big-box stores often can offer lower prices because they buy products in high volume. Also called supercenter, superstore, megacenter (BusinessDictionary.com, 2017).

Candela (cd). The Systeme International d'Unities (SI) unit of luminous intensity from a source focused in a specific direction on a solid angle called the steradian. One candela is one lumen per steradian (lm/sr). Formerly, candle (National Lighting Product Information Program, 2015; Winchip, 2011).

Cataracts. A condition where the previously clear, colorless crystalline lens becomes colored, dark brown, and cloudy (or opaque) with age. Cataracts reduce retinal illuminance and increase light scattering. Subjects with cataracts complain of poor visual acuity and have difficulty seeing under low light levels. To improve visual acuity, light levels can be increased, but this may also increase glare which can be counterproductive. (Figueiro, 2001; Illuminating Engineering Society of North America, 2007).

Circadian entrainment. Circadian rhythms, which are biological cycles that repeat themselves on a daily basis and are regulated or entrained by environmental signals, the most important one being the natural, 24-hour, light-dark cycle (Figueiro, Gonzales, & Pedler et al., 2016).

Circadian rhythms. A biological function that coordinates sleeping and waking times through hormones and metabolic processes (Winchip, 2011). Any physiological or biological process having approximately a 24-hour cycle (Figueiro, 2008).

Correlated color temperature (CCT). The CCT is a specification of the color appearance of the light emitted by a lamp, relating its color to the color of light from a reference source when heated to a particular temperature, measured in degrees Kelvin (K). The CCT rating for a lamp is a general “warmth” or “coolness” measure of its appearance. However, opposite to the temperature scale, lamps with a CCT rating below 3200K are usually considered “warn” sources, while those with a CCT above 4000K are usually considered “cool” in appearance (National Lighting Product Information Program, 2015). It is also, referred to as chromaticity (Winchip, 2011).

Color rendering index (CRI). Measurement of how good a light source makes objects appear. The index range is from 0 – 100. The higher the CRI number, the better the color-rendering ability of the source (Winchip, 2011). The

CRI describes the ability of the lamp to render objects as they would be seen in outdoor sunlight, which has the CRI of 100 (Malkin, 2014).

Daylight. Desirable natural light in a space (Winchip, 2011).

Daylight Harvesting. Controlling the amount of light needed based on how much natural light is penetrating the space. Automated controls turn off or dim artificial lighting in response to the available daylight in the space. Current term is daylight integration (Leviton, 2007).

Daylighting. Maximizing the benefits of sunlight into interior spaces while controlling for the ill effects of direct sunlight (Winchip, 2011).

Diabetic retinopathy. A progressive deterioration of the retina resulting from diabetes mellitus which is a lack of insulin in the blood. Nutrition to the neural cells is cut off when very small blood vessels burst and stop feeding the retina (called ischemia). The visual field of the affected retinal location is lost. Small blood vessels in the retina begin to leak causing edema, exudates, and eventual visual loss (Figueiro, M.G. 2001; Illuminating Engineering Society of North America, 2007).

Dynamic lighting. Lighting which provides light output parameters varying over time so that this variation can be perceived by people. The varying lighting parameters can be illuminance or spectral characteristics or both. Natural light is almost always dynamic. Just as daylight changes throughout the day dynamic artificial lighting changes automatically throughout the day. A change of correlated color temperature and light intensity can be achieved by mixing the light output of different lamps. For example, one lamp has a correlated color temperature of 2700K (warm white) and the other 6000 K (cool white). Varying the light output of the lamps throughout the day varies the correlated color temperature simulating the effects of natural daylight (Izso et al., 2009).

Efficacy. The ratio of light output (in lumens) to input power (in watts), expressed as lumens per watt (LPW), or the ratio of the light output of a lamp (lumens) to its active power (watts), expressed as lumens per watt (National Lighting Product Information Program, 2015).

Electroluminescence. Electroluminescence (EL) is an optical phenomenon and electrical phenomenon in which a material emits light in response to the passage of an electric current or to a strong electric field. EL lamps or “high field electroluminescent” lamps use electric current directly through a phosphor to make light. Unlike most lamps, they can be shaped to be extremely flat, or in narrow wire-like shapes. Electroluminescence or “EL” is the non-thermal conversion of electrical energy into light energy. This phenomenon is used in EL lamps, LEDs, and OLEDs (Edison Tech Center, 2013).

Estimated useful life. The time a LED light source will last before it reaches 70% of the original light output (Ray-Barreau, 2015).

Floaters. An increase in vitreous clumps which appear as spots in the field of vision, causing light which enters the eye to scatter increasing the need for more light (Illuminating Engineering Society of North America, 2007).

Footcandle (fc). A measure of illuminance in lumens per square foot. One footcandle equals 10.76 lux, although for convenience 10 lux commonly is used as the equivalent. The amount of light that falls on a surface in a 1-foot radius of the source (National Lighting Product Information Program, 2015) (Winchip, 2011).

Full-spectrum color index. A mathematical transformation of full-spectrum index into a zero to 100 scale, where the resulting values are directly comparable to color rendering index. An equal energy spectrum is defined as having an FSCI value of 100, a “standard warm white” fluorescent lamp has an FSCI value of 50, and a monochromatic light source (e.g., low pressure sodium) has an FSCI value of 0 (National Lighting Product Information Program, 2015).

Full-spectrum lamps. Lamps that range from 5,000 to 6,500 Kelvins with a CRI of 90-98. This is a high-quality lamp ideal for color-critical applications. It produces a bright white light that simulates the full color and ultraviolet spectrum of sunlight (Malkin, 2014).

Gerontechnology. Use of technological innovations in products and services that address older peoples’ ambitions and needs based on scientific knowledge about aging processes including cultural and individual differences. Use of technology to serve the aging society (Young, 2012).

Glare. When a light source or bright reflection in the field of view impairs vision, or is uncomfortable. The sensation produced by luminance within the visual field that are sufficiently greater than the luminance to which the eyes are adapted, which causes annoyance, discomfort, or loss in visual performance and visibility. There are two types of glare: disability glare and discomfort glare. Reflected glare from specular surfaces or highly reflective matte surfaces having light-value can be reduced by utilizing indirect lighting spread over a large surface (Figueiro, 2001; Illuminating Engineering Society of North America, 2007).

Glaucoma. Disruption of ocular blood flow can lead to decreased clearance of aqueous fluid from the anterior chamber of the eye and an increase in fluid pressure damaging the optic nerve leading to vision loss or blindness. Often called the “silent thief of sight,” the fluid pressure cuts off nutrition to the retina killing neural cells leading to “tunnel vision” called “dry” type glaucoma; or “wet” type from severe hemorrhagic disease (Figueiro, 2001; Illuminating Engineering Society of North America, 2007).

Heat Generated. Electricity in a light source not converted to visible light is often converted to heat, which must be considered for safety concerns and for additional cooling load needs (Russell, S. 2012).

Heat Sink or Heat Sinking. Adding a material, usually metal, adjacent to an object in to cool it through conduction (Phillips Lighting, 2017).

Home Modifications. The conversion or adaptation of the environment to make performing tasks easier, reduce accidents, and support independent living. Changes made to adapt living spaces to meet the needs of people with physical limitations so that they can continue to live independently and safely. These modifications may include assistive technology or making structural changes to a home. Modifications can range from something as simple as replacing cabinet doorknobs with pull handles to full-scale construction projects that require installing wheelchair ramps and widening doorways (US Department of Health and Human Services, 2003).

Illuminance. The total amount or intensity of light falling on a surface area, (Winchip, 2011). If the area is measured in square feet, the unit of illuminance is footcandles (fc). If measured in meters' square, the unit of illuminance is lux (lx) (Philips Lighting, 2017).

Illumination. The act of illuminating or state of being illuminated (Illuminating Engineering Society of North America, 2006).

Infra-red radiation. Any radiant energy within the wavelength range of 770 to 106 nanometers is considered infrared energy. (1 nanometer = 1 billionth of a meter, or 1 X 10-9 m) (National Lighting Product Information Program, 2015).

Kelvin Color Temperature (K). Color temperature measured in degrees in degrees Kelvin, which indicate hue of a specific type of light source. Higher temperatures indicate whiter, “cooler” colors, while lower temperatures indicate yellower, “warmer” colors (National Lighting Product Information Program, 2015). Kelvin is the absolute color temperature (Konica Minolta, 2007).

Lamp. A radiant light source commonly referred to as a light bulb (Winchip, 2011).

*Lamp Lumen Depreciation (LLD).*The reduction in output over time. The data is normally shown as a graph with the percentage reduction shown against hours. For example, L70 at 50,000 hours, means that the output is 70% of the initial output after 50,000 hours (Philips Lighting, 2017).

Light-Emitting Diode (LED.) A solid-state electronic device formed by a junction of P- and N-type semiconductor material that emits light when electric current passes through it. LED commonly refers to either the semiconductor by itself, i.e. the chip, or the entire lamp package including the chip, electrical leads, optics, and encasement (National Lighting Product Information Program, 2015). A light source technology that relies on electricity passed through a solid state electrical device that emits a single wavelength of radiation (Russell, S. 2012).

Light Loss Factor (LLF). The amount of illuminance lost because of the type of lamp, ambient temperature of the space, time, input voltage, ballast, lamp position, interior conditions, or burnouts. A factor used in calculating illuminance after a given period of time and under given conditions. It takes into account temperature and voltage variations, dirt accumulation on luminaire and room surfaces, lamp depreciation, maintenance procedures, and atmospheric conditions. Formerly called maintenance factor (Illuminating Engineering Society of North America, 2006; Winchip, 2011).

Lumen (lm). 1 lumen equals the quantity of light falling on a 1 square foot area illuminated to 1 footcandle. Lumens are basic data used in several types of calculations and needed when designing the general or ambient lighting for a room. The lumens for lamp types can be found in a manufacturer's lamp catalog (Karlen, 2012). A measure of the total amount of visible light emitted by a source, derived from the SI term luminous flux. It tells you nothing about the color, intensity, or quality of light, only the description of how much light the source emits (Philips Lighting, 2017).

Lumen Depreciation. The decrease in lumen output that occurs as a lamp is operated, until failure, also referred to as lamp lumen depreciation (LLD) (N National Lighting Product Information Program, 2015).

Lumens per Watt. Source efficacy or he performance of the module or LED array (USAI Lighting, 2012).

Luminance. The amount of light reflected off a surface. The unit of measurement is (Cd/m2). An objective measure of the intensity of a surface. It varies with the reflectance, texture, and angle of view (Philips Lighting, 2017).

Luminous Flux. The amount of light coming from a light source is luminous flux (the unit of measurement is lumen lm). The international System (SI) unit of illuminance. It is the illuminations on a surface one square meter in area on which there is a uniformly distributed flux of one lumen, or the illumination produced at a surface of which all points are at a distance of one meter from a uniform point source of one candela (Illuminating Engineering Society of North America, 2006). A source of light radiates energy in the form of electromagnetic waves. Light energy is ‘flux’ and luminous flux is a measure of the flow of light energy emitted by a source, or received by a surface. The quantity is derived from the radiant flux, W (in Watts), by evaluating the radiation in accordance with the relative luminous efficiency of the ‘standard eye’ (Konica Minolta, 2015).

Luminous Intensity. The amount of light that travels in certain directions from the source and is measured in candelas. A candle emits about one candela in all directions (this candle would emit a total of 12.6 lumens) (DiLaura et al., 2011).

Luminaires. Light Fixtures. These fall into six categories: recessed, ceiling-mounted, suspended, architectural, wall-mounted, and plug-in (Figueiro, M.G. 2001).

Lux. The unit of illumination level (the SI term is illuminance). One lux is one lumen per square meter (lm/m^2) (Philips Lighting, 2017).

Mesophic vision. Vision which occurs when the average scene luminance is between approximately 0.005 and 5.0 cd/m2, as both the rods and cones contribute to what we perceive (Fotios, S. & Cheal, C. 2009).

MNREAD Acuity Charts. Charts of continuous-text used for measuring the reading acuity and reading speed of normal and low-vision patients (Rubin, G. S. 2013; Ahn, S. J., Legge, G. E. & Luebker, A. 1995; Legge, G. E., Ross, J. A., Luebker, A. & LaMay, J. M. 1989)

Organic light-emitting diodes (OLEDs). A solid-state technology that is composed of extremely thin sheets of carbon-based compounds that illuminate when their electrodes are stimulated by an electrical charge (Winchip, 2011).

PAR Lamp. Lamp shape that utilizes a parabolic aluminized reflector to deliver controlled directional light. Commonly associated with Halogen and Metal Halide sources (Russell, S. 2012).

Photoentrainment. The entrainment of an organism's circadian rhythm to the pattern of light and dark in its environment. The use of the dawn/dusk light transition as the main time-giver to adjust circadian time to local time, (Foster, Russell, G. 2008).

Photosensory. Relating to the perception of light in animals (Merriam-Webster Dictionary, 2015).

Presbyopia. A decreasing capacity to focus at close range. The primary cause of lost accommodation is hardening of the crystalline lens capsule. By age

45 most people require positive diopter lenses (reading glasses) for close work. By age 65, multi-focal lenses are required (Figueiro, 2006).

Quality of Life. The degree of gratification perceived from one's contextual experience, including composite satisfaction with physical, emotional, social, and spiritual environmental conditions (Taira. E.C. & Carlson, J.C. 1999).

Rated lamp life. A rating indicating the hours a lamp will continue to burn before it totally burns out based on the number of hours at which half of a group of product samples fail. This includes lamp types such as incandescent, halogen, linear fluorescent, compact fluorescent, metal halide, and high pressure sodium (Ray-Barreau, 2015).

Recessed Luminaire. A luminaire that reside primarily in the plenum above the ceiling line of a space (Russell, S. 2012).

Retinal detachment. Progressive deterioration of the retina as it becomes separated from the choroid or the back of the eye. It is usually associated with trauma to the retina or other degenerative problems. It causes changes in floaters and flashes of light. It can be a complication of cataract surgery (Figueiro, 2001; Illuminating Engineering Society of North America, 2007).

Scotopic vision. The vision of the eye in low light levels or conditions (Russell, S. 2012).

Semiconductor. A solid material with a varying ability to conduct electrical current (Ray-Barreau, 2015).

Senile miosis. A reduction in the size of a person's pupil in old age caused by muscle atrophy that control dilation of a pupil. This restricts the amount of light to fall on the retina (Psychology Dictionary, 2012).

Soffit. An architectural feature of geometry added to a space through built-up construction (Russell, S. 2012).

Solid-State Lighting (SSL). A lighting technology that uses semiconductor materials to convert electricity into light. The light sources that use semiconductor light-emitting diodes are light-emitting diodes (LEDs), organic light emitting diodes (OLEDs), and polymer light-emitting diodes (PLEDs) (DiLaura et al., 2011).

Spectral Content. Color content of lighting (O'Conner D.A. and Davis, R.G. 2005).

Spectral Power Distribution (SPD). A representation of the radiant power emitted by a light source as a function of wavelength (National Lighting Product Information Program, 2015). Also, *spectral luminous efficiency function* which is a bell-shaped curve describing the sensitivity of a human eye with normal vision to the spectrum of visible light. Also, known as the eye–sensitivity curve (Phillips Lighting, 2017).

Specular. Description of a material's ability to directly reflect light images. Commonly expressed as "shiny" (Russell, S. 2012).

Task lighting. Lighting which is directed at a specific surface or area providing illumination for specific visual tasks (Illuminating Engineering Society of North America, 2006).

Tunable Lighting. Light source which can adjust CCT, CRI, or intensity using adaptive controls to suit a user's preference to promote well-being, create human centric healing environments, and support the circadian biological systems (Ray-Barreau, J.A. 2015).

Universal design. Features which are usually built into a home when the first blueprints or architectural plans are drawn. These features include appliances, fixtures, and floor plans that are easy for all people to use, flexible enough so that they can be adapted for special needs, sturdy and reliable, and functional with a minimum of effort and understanding of the mechanisms involved (US Department of Health and Human Services, 2003). It includes designing environments and products that are more easily accessed and used by a greater continuum of people without specified adaptations. A key concept of universal design is to provide accessibility without stigmatization by integrating accessibility features that are essentially unnoticed (Carr et al., 2013).

Ultraviolet Radiation. Any radiant energy within the wavelength range 100 to 400 nanometers is considered ultraviolet radiation (1 nanometer = 1 billionth of a meter, or 1 X 10-9 m) (National Lighting Product Information Program, 2015)

Visitability. Features which include home modifications for people who may want to entertain friends and family with physical impairments. Visitability refers to a set of principles in home design to promote basic accessibility and elimination of three fundamental barriers—front steps, narrow hallways and doors, and inaccessible first-floor bathrooms (US Department of Health and Human Services, 2003; Pynoos et al., 2009).

Wall Washer. Any type of asymmetric luminaire that is intended to flatly light the wall from the ceiling down to the floor (Karlan, Benya, and Spanglar, 2012).

White Light. Commonly described by its correlated color temperature. Measuring the hue of “white” light started in the late 1800s when the British physicist William Kelvin heated a block of carbon. The block of carbon changed color as it heated up, going from a dim red, through various shades of yellow, all the way up to a bright bluish white at its highest temperature. The measurement scale for color temperatures, named after Kelvin was based on Centigrade degrees. However, since the Kelvin scale starts at “absolute zero”, which is -273°C, you can get the equivalent Centigrade temperature (compared to the visible colors of a heated black body) by subtracting 273 from the Kelvin color temperature (Seesmart, 2010).

APPENDIX B

Institutional Review Board Approval Letter

Institutional Review Board for the Protection of Human Subjects in Research
P.O. Box 13018, SFA Station • Nacogdoches, Texas 75962-3040
Phone (936) 468-5496 • Fax (936) 468-1573

TO: Dr. Mitzi Perritt & Laura J. Maher
Human Sciences
PO Box 13014
Nacogdoches, TX 75962

RE: Project Title: Aging-In-Place Home Modification: LED Lamp Color Temperature and Luminance Preference Among Older Adults
Case # AY2016-1047

TYPE OF RESEARCH: Project Type: Thesis

FROM: Pauline M. Sampson, Chair, IRB-H Pauline M. Sampson

DATE: October 5, 2015

I would like to thank you for submitting your project entitled "Aging-In-Place Home Modification: LED Lamp Color Temperature and Luminance Preference Among Older Adults" to the IRB for review. It has been reviewed and has been **Approved**, based on the following review criteria:

> CFR §46.101(b)(2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless:(i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.

Your project has approval through **October 5, 2016**, should you need additional time to complete the study you will need to apply for an extension prior to that date. The IRB should be notified of any planned changes in the procedures during the approval period, as additional review will be required by the IRB, prior to implementing any changes, except when changes are necessary to eliminate immediate hazards to the research participants. The researcher is also responsible for promptly notifying the IRB of any unanticipated or adverse events involving risk or harm to participants or others as a result of the research.

All future correspondence regarding this project should include the case number **AY2016-1047.**

From Stephen F. Austin State University, a comprehensive institution dedicated to excellence in teaching, research, scholarship, creative work, and service.

APPENDIX C

Sample Site List

Facility	Yes/no	Facility	Yes/no
Rockynol Retirement Community 1150 W. Market St. Akron, OH 44313 330-867-2150 Kara Hanzie Executive Director	Yes	*Copley Place Independent Living Apartments* 528 Rothrock Road Copley, OH 44321 330-668-9670 Susan Darule Enrichment Coordinator Will use Chapel for set up	Yes
Breckenridge Willoughby, OH 440-942-4342 Kara Hanzie Executive Director	Verbal Yes	*Pearl Crossing* 19205 Pearl Road Strongsville, OH 44136 440-853-4344 Carol Sechkar Enrichment Coordinator	Verbal Yes
Brookdale Montrose 100 Brookmont Road Akron, OH 44333	No Called it soliciting		

APPENDIX D

Letter to Sample Sites

Dear Director,

RE: THESIS RESEARCH

I am a graduate student studying Healthcare Interior Design through Stephen F. Austin State University. Part of my degree requirements are to conduct an original research study and to write a Master's thesis. The topic I am studying is: *Aging-in-place home modification: Led lamp color temperature preference among adults.* I will be testing using a tunable LED lamp set with four different color temperatures. I am looking for volunteers from residents of independent living facilities. It should be an interesting and useful activity for those who volunteer to participate in the research study.

The projected time frame for conducting the experiments would begin during Feb. 2017. My plan for collecting data is to utilize a light box outfitted with a tunable LED lamp. After signing an informed consent form and answering a few personal data questions, the resident would be asked to complete a task such as reading a sentence or label on a bottle of medication, and/or do a simple scored reading task under the different lamp color temperatures. Lastly, the resident would fill out a preference survey indicating which light setting they preferred.

Examples of typical questions would include the following:

- Was there noticeable glare?
- Did the light feel comfortable?

My graduate advisor at SFASU is Dr. Mitzi Perritt. If you have any questions regarding this study, you may contact her at mperritt@sfasu.edu or 936-468-2155. She will be pleased to speak with you or you can contact me at lmaher@uakron.edu or 440-212-1156.

If you agree to allow me to seek volunteers from your facility and allow me to set up the experiment in one of your rooms, I need proof in the form of a simple permission slip signed by you to send to my advisor and my schools Institutional Review Board at SFASU before I can proceed with the study. I will be so delighted to hear from you! Thank you for your time.

APPENDIX E

Permission Slips from Sample Sites

STEPHEN F. AUSTIN STATE UNIVERSITY

School of Human Sciences
P.O. Box 13014, SFA Station • Nacogdoches, Texas 75962-3014
Starr at Raguet • Human Sciences North Building Room 101
Phone (936) 468-4502 • Fax (936) 468-2140

PERMISSION

Laura J. Maher, thesis student, has my permission to request voluntary participants from the following facility for her research study of:

AGING-IN-PLACE HOME MODIFICATION: LED LAMP COLOR TEMPERATURE AND LUMINANCE PREFERENCE AMONG OLDER ADULTS

And to be able to set up the experiment on the premises.

Susan E. Narula of COPLEY PLACE

~~Executive Director~~ Enrichment Coordinator — Facility

Nov. 19, 2015

Date

STEPHEN F. AUSTIN STATE UNIVERSITY

School of Human Sciences
P.O. Box 13014, SFA Station • Nacogdoches, Texas 75962-3014
Starr at Raguet • Human Sciences North Building Room 101
Phone (936) 468-4502 • Fax (936) 468-2140

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AGING-IN-PLACE HOME MODIFICATION: LED LAMP COLOR TEMPERATURE AND LUMINANCE PREFERENCE AMONG OLDER ADULTS

And to be able to set up the experiment on the premises.

Kara B. Manzie of Rockynol Retirement Comm.
Executive Director Facility

11-19-15
Date

STEPHEN F. AUSTIN STATE UNIVERSITY

School of Human Sciences
P.O. Box 13014, SFA Station • Nacogdoches, Texas 75962-3014
Starr at Raguet • Human Sciences North Building Room 101
Phone (936) 468-4502 • Fax (936) 468-2140

PERMISSION

Laura J. Maher has my permission to contact the Ohio chapters of retired teachers for possible voluntary participants for her study of:

AGING-IN-PLACE HOME MODIFICATION: LED LAMP COLOR TEMPERATURE AND LUMINANCE PREFERENCE AMONG OLDER ADULTS

Executive Director

1-5-16

Date

ORTA Ohio Retired Teachers Association

www.orta.org • Facebook Group: Ohio Retired Teachers Association • twitter: @ortastaff

DR. JOHN W. CAVANAUGH, PH.D.
EXECUTIVE DIRECTOR
jcavanaugh@orta.org

8050 N. HIGH STREET, STE. 190 (614) 431-7002
COLUMBUS, OH 43235-6488 FAX (614) 431-7003

Serving Ohio's Retired Teachers Since 1947

APPENDIX F

Presentation Script and Volunteer Sign-up Form

Hello. My name is Laura Maher. I am a graduate student at Stephen F. Austin State University of Texas. For my master's thesis, I am examining LED lighting preferences for older and younger adults. I am requesting volunteers to participate in this experiment.

If you choose to be a volunteer you will be asked to:

1. Sign an informed consent form agreeing to participate.
2. Fill out a personal data form asking your name, age, gender, occupation, and vision status.
3. Complete a simple color blindness test and vision acuity test.
4. Sit in front of a light box, and complete several simple reading and number tasks under four different light settings.
5. Afterward, you will be asked which of four light settings you preferred and then read the label from an empty bottle of medication under your preferred light setting.
6. Then you will be asked to complete a short survey on the comfort level of the light.

This experiment should not take more than 20 minutes to complete. There is no anticipated risk in this experiment and there is no compensation for participating. The results of this study will be shared with the school department, campus community, and possibly published in a journal or presented at a conference. The information obtained will be kept confidential.

VOLUNTEER SIGN-UP FORM EXAMPLE

Facility	Volunteer Name	Contact	Date of Study
Copley Place			
10:00 am			
10:30 am			
11:00 am			
Pearl Crossing			
10:00 am			
10:30 am			
11:00 am			
Rockynol			
10:00 am			
10:30 am			
11:00 am			
Total			

APPENDIX G

Informed Consent Form

I understand:

1. I am being asked to select a comfortable level of light from a pre-selected light source while sitting at a table using a light box while sitting in a desk chair.

2. The testing process will take approximately 15 to 20 minutes.

3. I am being asked to complete a personal data sheet which identifies my age, gender, vision problems and test measurements.

4. I am being asked to complete a simple visual acuity eye test and color blindness test.

5. I am being asked to complete an interview questionnaire on my observations about the light source.

6. I may be photographed upon my approval during the course of the study.

7. My name will not be published in the study results. The identity of research participants will remain anonymous.

8. The testing and data collection procedures of this study will involve no physical discomfort. No potential risks are foreseen for study participants.

9. I may withdraw from participating in the study at any time.

10. I authorize the researcher to have access to my study-related health information. My health information will be used only for the study purpose(s) described in this research consent form. The information from this study may be published in applicable journals or presented at conventions or seminars.

11. Study information and conclusions will be used to benefit the fields of interior design in home modification, healthcare facilities, architecture, universal design applications, and to improve supportive environments for adults with and without disabilities.

12. I will receive a copy of the signed consent form for my records.

13. If you have any questions or concerns about your rights as a research participant you may contact the researcher, Laura J. Maher, School of Human Sciences, Stephen F. Austin State University at (440) 212-1156 or lmaher@uakron.edu, or Dr. Mitzi R. Perritt, Professor/Graduate Coordinator, School of Human Sciences, Stephen F. Austin State University at (936) 468-2155 or mperritt@sfasu.edu

I agree to participate in this study.

______________________________ ______________________________

Participants Signature Date

APPENDIX H

Researcher Testing Instructions

1. The researcher and her research assistant set up the light box in a specified room at a test site. The ambient room lumens/lux was recorded with the spectrophotometer. A quiet room location with the ability to lower the ambient light is recommended for a testing room such as in a chapel or windowless room.
2. Testing was performed in the morning, afternoon, or evening.
3. The researcher introduced herself.
4. The researcher assigned the subject a control number and the participant signed the informed consent form.
5. The researcher explained the reading tasks to the subject.
6. The time taken to explain the tasks and sign the consent form allowed for light adaptation of the subject's eyes to the testing room.
7. The participant was asked to keep their eyes closed before and between testing tasks.
8. The researcher asked the subject to adjust the office chair for comfort if needed.
9. The participant was asked to read sentences selected from the MNReading Test bank of sentences. A different page of reading task sentences was performed under each of the four, correlated color temperature LED lamp

settings. The task was timed for completion and the number of reading errors was recorded.

10. The participant performed a second reading task, the Numerical Verification Test, comparing matching and non-matching numbers in two columns. A different NVT score card was performed under each of the four, correlated color temperature LED lamp settings. The researcher recorded test times and errors.
11. The participant performed a third reading task using an orange medication bottle with a white label. The participant was asked which of the four correlated color temperature settings he/she preferred while examining the writing on the medication bottle label as the researcher cycled through the four correlated color temperatures. After selecting the preferred correlated color temperature setting the participant read the instruction line on the medication bottle. The test was timed and the number of errors recorded.
12. Three reading tests and one preference/comfort survey was conducted. The test time was approximately 20 minutes for each subject.

APPENDIX I

Personal Data Form, Vision Data Form, and Test Results

1. To be filled out by researcher.

FACILITY OR COMMUNITY GROUP		
Control No.	001	
Date		
Time of day	Start Test	End Test
Facility Name		
Address		
Contact		
Tel.		
Public/Private		
Participant Name		
Incentive:	No❑ Yes❑ Other❑	

CHECK appropriate box.

GENDER/AGE	
Male ❑	Female ❑
Age	Age

2. CHECK appropriate box. To be answered by study participant.

MARITAL STATUS			
Married or Living together	Single	Divorced	Widowed
❑	❑	❑	❑

3. CHECK the appropriate box.

OCCUPATION				
Student	Part Time Student	Full Time Employment	Part Time Employment	Retired
❑	❑	❑	❑	❑

4. CHECK the appropriate box.

EDUCATION			
High school or less	More than High School - College	More than Undergraduate or Graduate	Doctorate
❑	❑	❑	❑

5. Do you have any of the following medical vision conditions?

VISUAL MEDICAL CONDITIONS				
Cataracts	Glaucoma	Macular Degeneration	Diabetic Retinopathy	Retinal Detachment
❑ Yes❑ No	❑ Yes❑ No	❑ Yes❑ No	❑ Yes❑ No	❑ Yes❑ No

6. Do you have any other vision problems or have had medical procedures done on your eyes?

❑ Yes❑ No	Explain:

7. Glasses or Contacts: Do you wear glasses or contacts. Should you be wearing glasses or contacts?

GLASSES or CONTACTS				
No	Glasses	Contacts	Should Be	Inconclusive
❑	❑	❑	❑	❑
Notes				

8. Visual Acuity Awareness: Do you know if you are near sighted or far sighted?

VISUAL ACUITY AWARENESS						
Near Sighted	Far Sighted	Bifocal/Trifocal	Astigmatism	Don't Know	Inconclusive	Other
❑	❑	❑		❑	❑	❑

9. Peripheral Vision: Do you know if you have peripheral vision?

PERIPHERAL VISION			
No	Yes	Don't Know	Inconclusive
❑	❑	❑	❑

10. Depth Perception: Do you know if you still have depth perception?

DEPTH PERCEPTION			
No	Yes	Don't Know	Inconclusive

❑	❑	❑	❑

11. Visually Active: Do you consider yourself visually active? Meaning do you perform visual tasks such as sewing, reading, or driving?

VISUALLY ACTIVE			
No	Yes	Don't Know	Inconclusive
❑	❑	❑	❑

12. Color Blind Test: Do you know if you are color blind?

COLOR BLIND AWARENESS				
No	Full Colorblind	Partial Colorblind	Don't Know	Inconclusive
❑	❑	❑	❑	❑

13. Glare Sensitivity Awareness: Does glare bother you?

GLARE SENSITIVITY AWARENESS			
Never	Occasionally	A Lot	All of the Time
❑	❑	❑	❑

14. Night Vision Difficulty: Is it difficult to see at night?

NIGHT VISION DIFFICULTY			
No	Yes	Don't Know	Inconclusive
❑	❑	❑	❑
Notes:			

15. Reading Medication Bottle: Do you read medication bottle labels?

MEDICATION BOTTLE			
No	Yes	Don't Know	Inconclusive
❑	❑	❑	❑

16. Conduct Visual Acuity Exam. **To be filled out by researcher:**
(They can read 20/40. If they can't read 2/40 what could they read?)

VISUAL ACUITY TEST with Glasses				
SCORE	Right Eye		Left Eye	
20/20	20/40	20/50	20/60	20/80 and UP
❑	❑	❑	❑	❑

Notes:

17. Conduct Color Blind Test:

COLOR BLIND TEST				
No	Full Colorblind	Partial Colorblind	Don't Know	Inconclusive
❑	❑	❑	❑	❑

Last test:

18. Light Source Preference Measurements: To be filled out by researcher.

LIGHT SOURCE PREFERENCE MEASUREMENTS					
Light Box	Errors	Time	CCT/Kelvins	CRI	Illuminance FC/Lux
Adjusted LED for reading medication bottle					

End of Test Time________________________________

Room Ambient Lumens check at time of respondent test:	

Room Ambient CRI check at time of respondent test:	

APPENDIX J

Light Source Comfort Preference Survey

1. **To be filled out by study participant.**

LIGHT SOURCE COMFORT PREFERENCE SURVEY-MEDICATION BOTTLE (CCT/K)

To what degree was the light comfortable or uncomfortable to me?

Very Uncomfortable	Slightly Uncomfortable	Comfortable	Very Comfortable
❑	❑	❑	❑

To what degree did I experience glare.

Blinding Glare	More Glare	Slight Glare	No glare at all
❑	❑	❑	❑

Was the light too bright or too dim or just right?

Too bright	Too dim	Just right	No Opinion or don't know
❑	❑	❑	❑

Did the light appear warmer (yellow or red) or cooler (bluer)?

Warmest or most yellow/red	Warm or Yellow/red	Coolest or Bluest	Cool or Blue	No Opinion or Don't know
❑	❑	❑	❑	❑

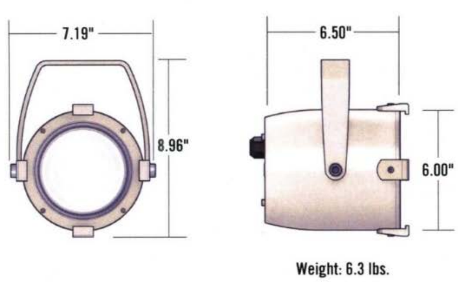
APPENDIX K

AVID LABS KETRA S38 LED Test Lamp Specifications

Figure 7. KETRA S38 tunable LED lamp and fixture

Project:
Type:
Notes:

AVERE™ 6 PAR CAN
with KETRA® S38 Tunable Spectrum LED



Weight: 6.3 lbs.

Ketra S38 Tunable Spectrum LED: 10° Beam

Distance Feet (m)	2 (0.60)	4 (1.21)	6 (1.82)	8 (2.43)	10 (3.04)
Beam Diameter Feet (50% FWHA)	0.40	0.70	1.10	1.40	1.80
Output LUX	2,589	647	288	162	104

All information is based on featured bulb. Bulbs priced separately. Specifications subject to change without notice.

KETRA
AVID LABS PRODUCT DESIGN

AVIDLABS.COM • 260.969.9225 • 4121 FOURIER DRIVE / FORT WAYNE, IN 46818

Ketra’s S38 lamp is an all-encompassing LED solution with the ability to render 90+ CRI white light, saturated colors, and pastels from a fully mixed, single point source. Ketra’s custom driver chip and optics incorporate closed-loop thermal and optical feedback, maintaining a factory-calibrated color point to one MacAdam ellipse over the product’s lifetime. Each lamp is wirelessly controlled and individually addressable through Ketra’s accompanying software. The S38 is also compatible with TRIAC dimmers, thus enabling an infinite range of possible new construction and retrofit applications.

Fully tunable spectrum single point source produces wide range of 90+ CRI white, pastels and saturated colors

Closed-loop color point maintenance to <1 MacAdam ellipse over lifetime and full operating temperature range

Integrated temperature protection maintains product within safe operating conditions

Wireless and TRIAC dimmable to 0.1%

On-board wireless control enables individual addressability and control at a competitive system level price point

Lamps may be ordered pre-programmed from the factory to specific CCTs, x,y chromaticity coordinates, gel, Pantone, and traditional lamp dimming curves

Available Configurations:

Outputs:

900 lumens to 1100 lumens

Beam Angles:

Spot (10º)

Flood (25º)

Wide Flood (40º)

Very Wide Flood (60º)

Housing Colors:

White

Silver

Black

Base Types:

E26 Edison Screw

GU24 Pin

Adapted from http://www.ketra.com/

Figure 8. KETRA S38 Tunable LED Lamp

Avid Labs created the control device so a specific correlated color temperature can be selected and changed while keeping lumens (LUX/FC) the same. Adapted from http://www.ketra.com/

APPENDIX L

KETRA Design Studio Information

Ketra's Design Studio software empowers users to find, configure, and program lamps, luminaires, and controls within the network. Included in your purchase of any Ketra hardware, our software was designed with ease-of-use in mind, and offers a suite of functionality that follows an intuitive workflow. Complementary to Design Studio, the Ketra Tech Tool is a technician oriented programming software tool that enables power-user functions such as updating firmware on lighting and controls products.

- Sets color and intensity information on all products
- Authors preset scenes and shows
- Content management for your customized library of light settings
- Remote backup and multi-user collaboration via Ketra's cloud servers
- Local file storage and archiving for project data
- Configuration of I/O ports in controls automation products

Adapted from http://www.ketra.com/design-studio/

APPENDIX M

Measuring Instrument

Figure 9. The CL-500A Illuminance Spectrophotometer

The CL-500A Illuminance Spectrophotometer by Konica Minolta's is a portable solution for measuring light-source color and illuminance in a compact, lightweight illuminance spectrophotometer. It can be used to evaluate light sources such as light emitting diode (LED) and electroluminescence (EL) illumination lamps. The sensor measures CRI (Color Rendering Index), illuminance, chromaticity, and correlated color temperature (CCT/K) of any light source. The built-in display means that it is suitable for use in the lab or out in the field.

Main applications include:

- Spectral evaluation of light sources including next-generation lamps such as LEDs, OLEDs, and EL illumination.
- Checking the illuminance, chromaticity, dominant wavelength, and correlated color temperature of various kinds of light sources including organic EL lighting (OLED), LEDs, etc.
- LED billboard development, quality control, and maintenance.
- Evaluating the light distribution characteristics of LED illumination modules.
- Evaluating the illuminance distribution of lighting fixtures.
- Building and interior lighting research.
- Spatial lighting production and adjustment.
- Color-viewing cabinet maintenance.
- Projector light source research and color inspection.
- Checking environments for psychological research experiments.

Adapted from http://sensing.konicaminolta.us/products/cl-500-illuminance-

The CL-500A Illuminance Spectrophotometer is a hand-held instrument capable of measuring CRI and illuminance right on the unit. It's completely stand-alone and turn-key. The CL-500A can be used where it's important to measure CRI, correlated color temperature and illuminance all at the same time. It is compact and easy to use and has a built-in lithium battery which can be charged via a USB port. In addition to spectral power distribution, the instrument is capable of measuring illuminance in foot candles or lux and chromaticity, excitation levels, dominant wavelength, correlated color temperature and CRI. The instrument is simple to use. There are only a few controls to deal with – the on / off switch, the measure button, the up / down controls for the screen, the back key, the menu key, and the return key. To take a measurement, point the cosign-corrected receptor head of the device at the light source, hit the measure button, and there will be an instant return of the reading. Another component of this spectrophotometer is its zero-calibration cap that fits over the receptor head. It serves two purposes: one is to protect the receptor head; and two is to provide a means to zero out the unit. Periodically it will ask you to do a zero calibration to ensure the accuracy of the instrument. After performing a measurement, other metrics can be accessed other than the one showing on the screen by going into the menu, scrolling down to Measure Options, hit return, go down again to Color Space, hit the return button again, where all the different combinations of data are displayed on the screen.

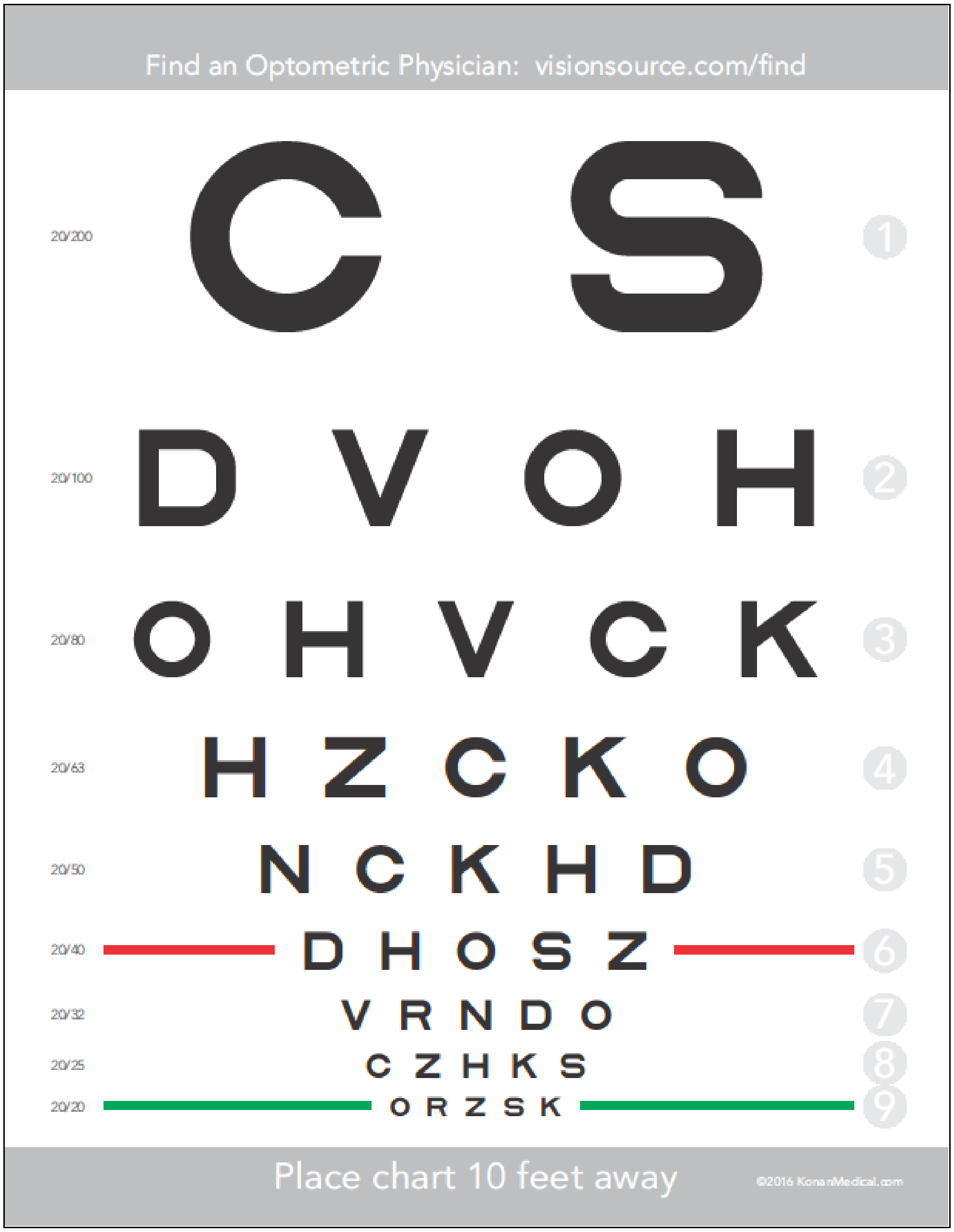
Among the displayable data are:

- Lux or foot candles and x and y
- Lux color temperature for delta UV
- Lux dominant wavelength and excitation
- CRI, which will show individual indices from R1 through R15, including CRI, which is a combination or an average of R1 through R8
- Spectral data
- Customized readings

APPENDIX N

Visual Acuity Test

Figure 10. Eye Acuity Chart and Instructions



How to use the eye chart for eye chart used at 10 feet:

1. Print in color the eye chart on regular 8 1/2 x 11-inch paper
2. Tack or tape the chart to a windowless wall in a well-lit room at eye level
3. Measure ten feet from the wall
4. Cover one eye with the eye occluder keeping glasses on if wearing glasses for distance vision
5. Read the letters aloud while a tester keeps track of which letters are correct
6. Continue to the bottom row or until letters can no longer be read
7. Write down the number of the smallest line with the majority of letters read correctly. (Ex. 5 out of 8 letters on line 8 read correctly would be 20/20.)
8. Cover the other eye with the eye occluder and repeat steps 5-7

What do the results mean?

That depends on the age of the person being tested. A 3 to 4-year-old should be able to read the 20/40 line and a 5-year-old the 20/30 line. Older children and adults should be able to read the majority of letters on the 20/20 line. Free download adapted from http://visionsource.com

APPENDIX O

Eye Occluder

Figure 11. Eye Occluder

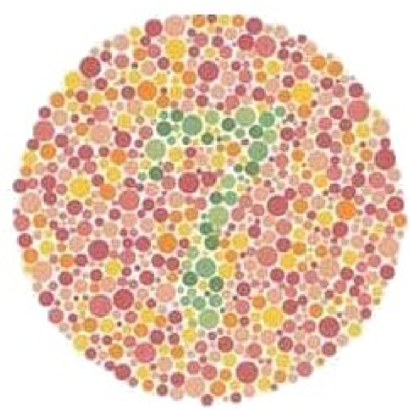
APPENDIX P

Color Blindness Test

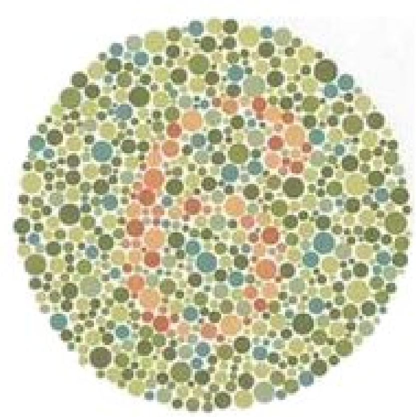
Figure 12. Ishihara Plates Test Example. Adapted from http://visionsource.com/

Look at the pictures below, and report the numbers that you see.

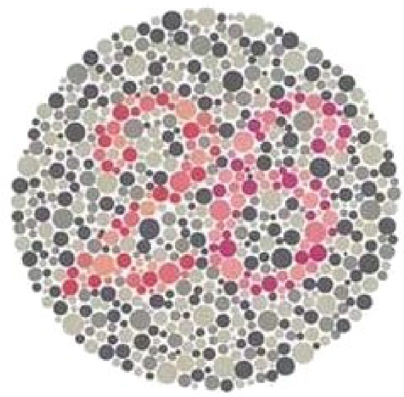
Number: 1



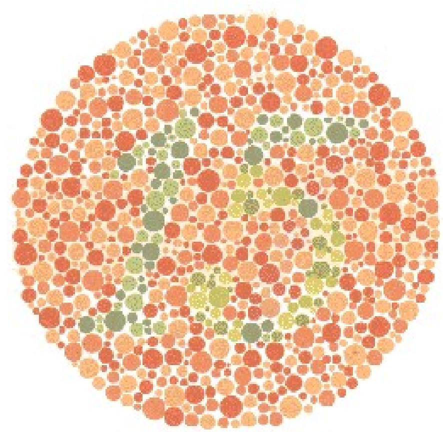
Number: 2



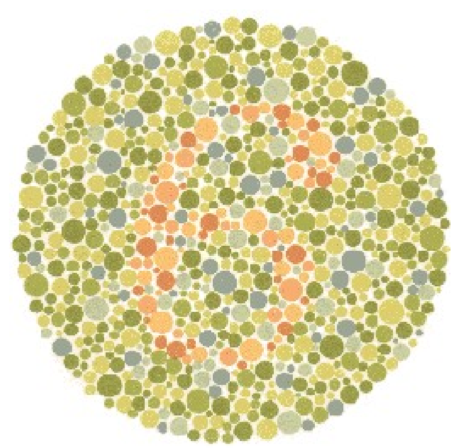
Number: 3



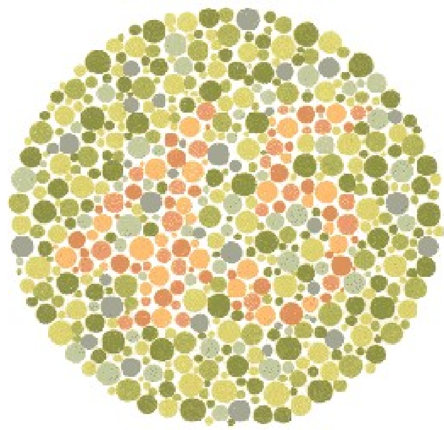
Number: 4



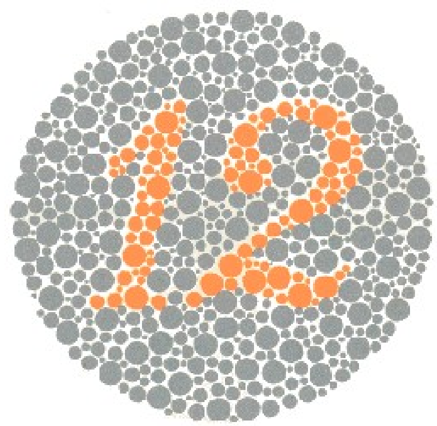
Number: 5



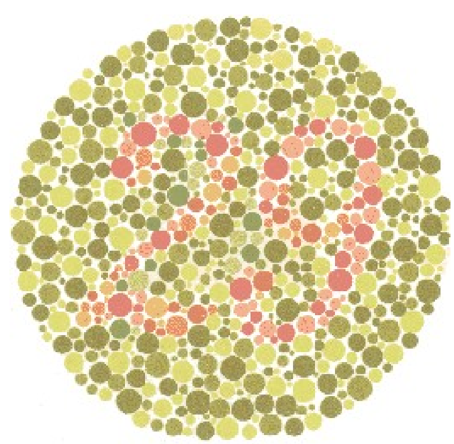
Number: 9



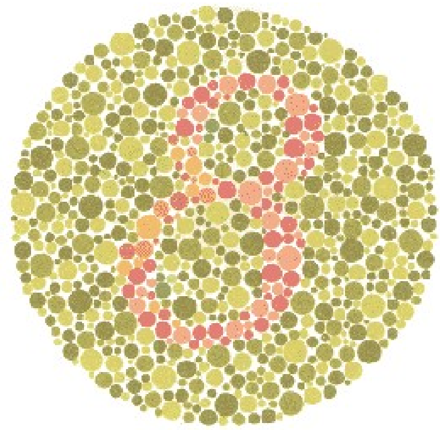
Number: 10



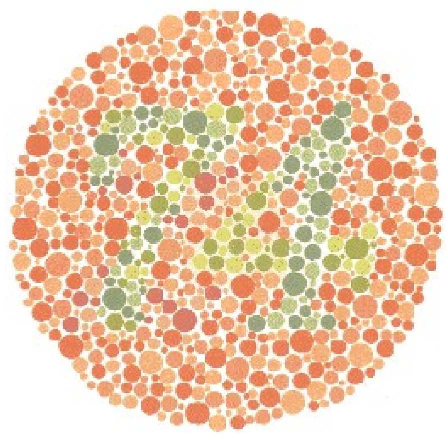
Number: 11



Number: 12



Number: 13



APPENDIX Q

MNRead Acuity Chart Reading Task Bank of Sentences

Figure 13. MNRead Acuity Chart Reading Task List of Sentences

1. MNread: Sentences

You must type precisely one space between all the words	Our tiny bird ate the seeds before flying off its perch	His friend is also involved in the latest charity event	He made plans to go camping and hiking in the mountains
Children find the chocolate factory to be very exciting	An electrical appliance may be useful for certain tasks	Students know class will be held outdoors on sunny days	The secretary who last used the copier is getting paper
She could not listen to the records while studying late	We never open the window in the winter or summer months	The bakery in that town has pastries that are wonderful	The show ends very late but my brother is allowed to go
My sister was going to play the piano but it was broken	The day began with a friend coming to see me and my dog	A young child cried for the bird who fell to the ground	The walls are made of brick and the steps made of stone
The leaves on my maple tree fall off late in the autumn	The night sky sparkled with shining stars until morning	My pants were too short and the neighbors laughed at me	This chair is so large that I feel like I am very small
The telephone rang only one time before I walked inside	My babysitter told me to go to bed before Mom came home	Everyone went outside after I started the painting task	Our old clock chimes hourly if I remember to wind it up
Every Tuesday the jazz band took requests to play songs	The delicious new ice cream is not easily obtained here	Pirates never bury treasure before making a careful map	The sounds of the waves and the gulls are very peaceful

APPENDIX R

MNRead Reading Task Cards 1-4

CARD 1

ID#

Sequence of K (CCT)
2700______
3500______
4100______
5000________

The leaves on my maple tree fall off late in the autumn.

The three elephants in the circus walked around very slowly.

We could not guess what was inside the big box on the table.

The two friends did not know what time the play would start.

The night sky sparkled with shining stars until morning.

CARD 2

ID#

Sequence of K (CCT)
2700_______
3500________[
4100_______
5000_________

Everyone wanted to go outside when the rain finally stopped.

They were not able to finish playing the game before dinner.

Everyone went outside after I started the painting task.

The phone rang six times before we all rushed to pick it up.

The delicious new ice cream is not easily obtained here.

CARD 3

ID#

Sequence of K (CCT)
2700________
3500________
4100________
5000_________

She was waiting for over an hour before the doctor returned.

I did not read all of the book because it was making me sad.

I am making a cake today for my family and friends to enjoy.

My little puppy has a small white patch below her right eye.

The sounds of the waves and the gulls are very peaceful.

ID#

CARD 4

Sequence of K (CCT)
2700________
3500________
4100________
5000_________

Nobody thought we would ever find any treasure in the chest.

The cat climbed up onto the giant chair and had a short nap.

The bakery in that town has pastries that are wonderful.

You must type precisely one space between all the words.

Every Tuesday the jazz band took requests to play songs.

APPENDIX S

Numerical Verification Reading Task (NVT) Example

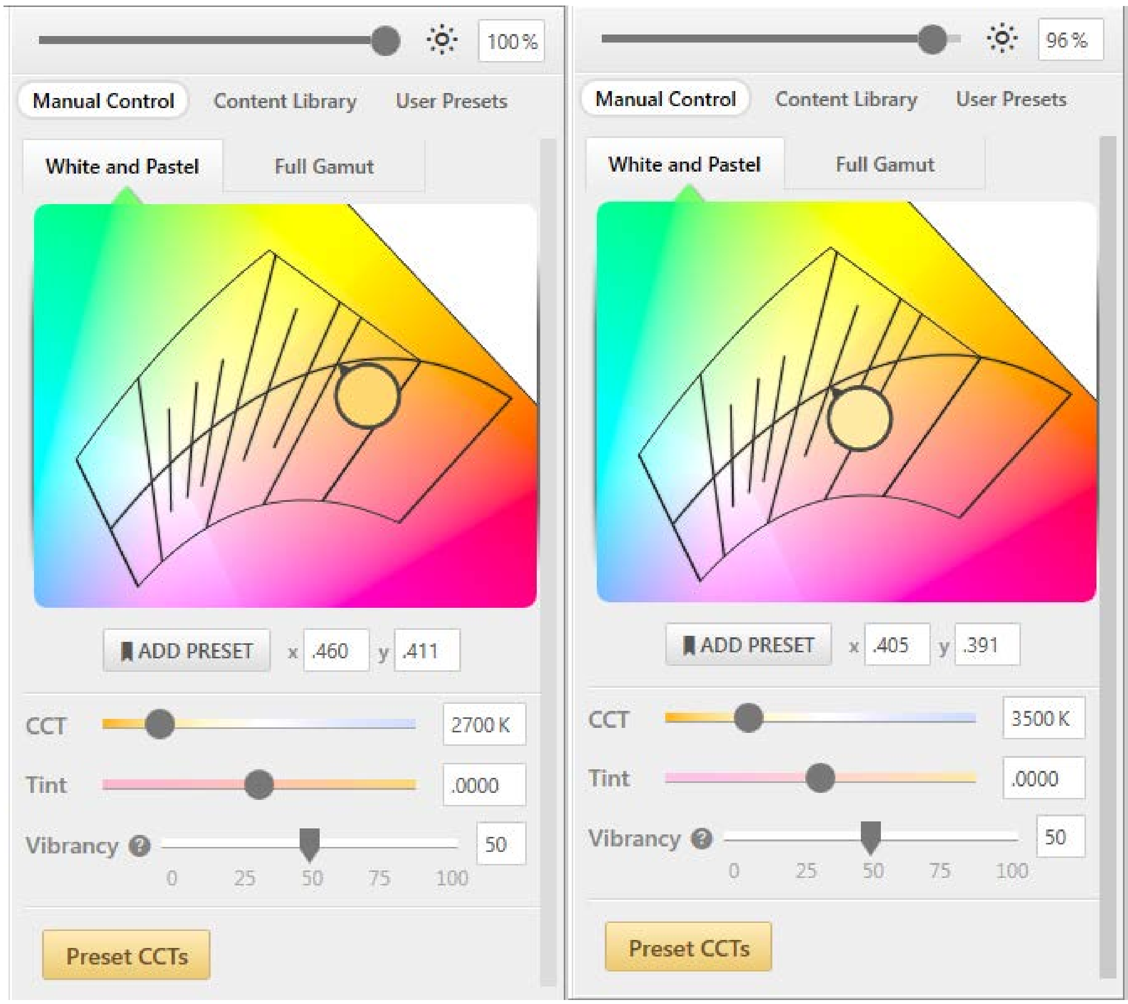
Figure 14. NVT Example

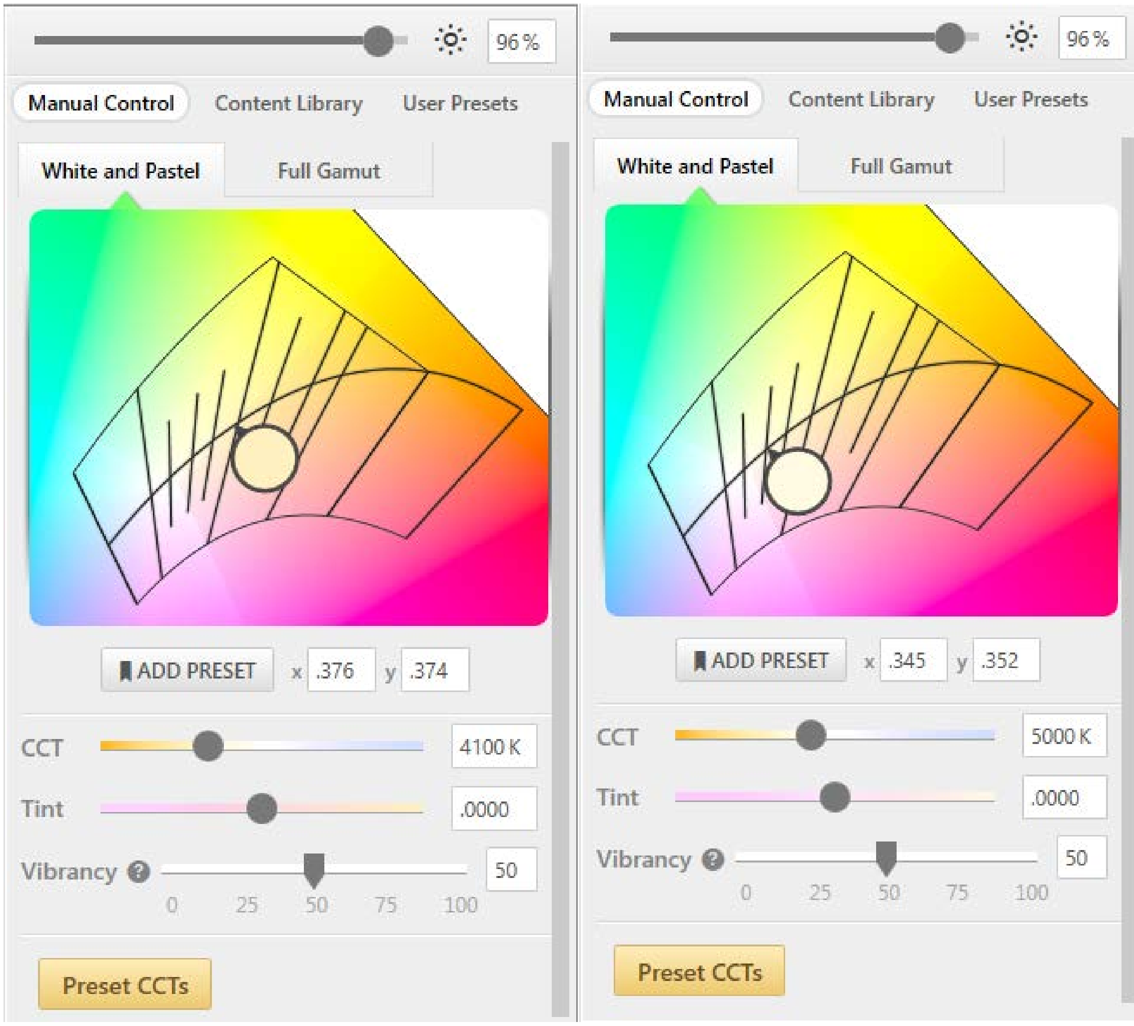
Number	Number	Match	Not match	Correct	Not Correct
83243	83243	X			
76475	76475	X			
05023	05123		X		
89236	89236	X			
17958	17958	X			
77426	77486		X		
00199	00199	X			
28431	28931		X		
41047	41547		X		
41073	41073	X			
97614	97614	X			
95168	95168	X			
72276	72376		X		
49882	49882	X			
14197	14197	X			
08457	08457	X			
06783	06783	X			
45858	45856		X		
94660	92660	X			
85160	85160	X			

APPENDIX T

Ketra Design Studio Control

Figure 15. Ketra Computer Program Control Settings




96 %
Manual Control
Content Library
User Presets
White and Pastel
Full Gamut
ADD PRESET
x .376
y .374
CCT
4100 K
Tint
.0000
Vibrancy
50
0
25
50
75
100
Preset CCTs
96 %
Manual Control
Content Library
User Presets
White and Pastel
Full Gamut
ADD PRESET
x .345
y .352
CCT
5000 K
Tint
.0000
Vibrancy
50
0
25
50
75
100
Preset CCTs

APPENDIX U

Volunteer Flyer

Figure 16. Independent Living Facility Volunteer Flyer

VOLUNTEERS NEEDED

LIGHTING EXPERIMENT

Research Experiment

I am testing which color temperature of an LED light bulb helps us see better when performing tasks such as reading.

More information is placed on lighting packages today which can assist us in choosing better lighting for our place of residence.

This lighting experiment only takes 15 to 20 minutes of your time.

The experiment is fun and informative.

Please help me research this subject.

MONDAY

Learn about tunable lighting.

Learn about color temperature of light bulbs.

Which color temperature helps you see better.

Sign-up sheet at desk.

BY LAURA J. MAHER

Interior Design Teacher
at the University of Akron

Email: lmaher@uakron.edu
440-212-1156

Research is sponsored by Steven F. Austin State University, Texas

APPENDIX V

Stopwatch

Figure 17. Testing Stop Watch

VITA

Laura J. Maher has a multidisciplinary background combining construction, real estate, interiors, and architectural design expertise. Mrs. Maher acquired an Occupational Therapy Allied Healthcare Bachelor of Science degree from Ohio State University, an Interior Design and Business Associate degree from Cuyahoga Community College, and a Master of Science degree in Healthcare Interior Design from Steven F. Austin State University awarded May 2017. Mrs. Maher has owned and operated a general contracting, interior design, and real estate company since 1993.

Utilizing a diverse yet interrelated background, she has taught interior design as an interior design adjunct instructor since 2004 and is presently teaching interior design at the University of Akron. Mrs. Maher has received numerous academic, art, and teaching awards. Her future endeavors include pursuing a doctoral candidacy.

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Style Manual Designation:	*Publication Manual of the American Psychological Association, 6th Edition*

Laura J. Maher typed this thesis.