

IMPACT OF DIFFERENT FLUORESCENT LIGHT COLOR
TEMPERATURES AND COLOR RENDERING INDICES
ON LIGHTING PREFERENCE, VISUAL COMFORT,
VALUE DISCRIMINATION AND COLOR
DESCRIPTORS FOR ELDERLY
CONSUMERS

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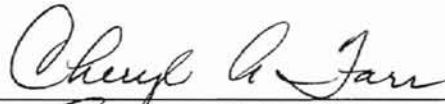
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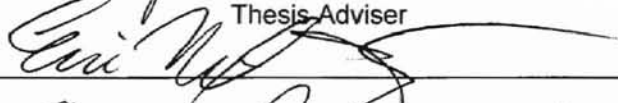
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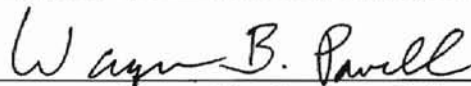
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TABLE OF CONTENTS

Chapter	Page
I. INTRODUCTION	1
Purposes and Objectives	3
Research Hypotheses	3
Definition of Terms	6
II. REVIEW OF LITERATURE	10
Introduction	10
Sight and Vision	11
Light and Color	14
The Aging Eye	16
Illumination for the Aging Eye	18
Store Lighting	19
III. METHODS	24
Introduction	24
Research Design	24
Sample	27
Variables	28
Data Collection	29
Data Analysis	32
IV. FINDINGS AND DISCUSSION	34
Introduction	34
Characteristics of the Sample	34
Tests of Hypotheses and Findings	36
Discussion and Conclusions	78
Implications	82
Recommendations for Future Studies	83
BIBLIOGRAPHY	84
APPENDIXES	88
APPENDIX A -- OKLAHOMA STATE UNIVERSITY INSTITUTIONAL REVIEW BOARD HUMAN SUBJECTS REVIEW	89
APPENDIX B -- INFORMED CONSENT FORM	91
APPENDIX C -- PART I: DEMOGRAPHIC QUESTIONNAIRE	93

Chapter	Page
APPENDIX D -- PART II: STUDY QUESTIONNAIRE	95
APPENDIX E -- MUNSELL COLOR CHART	100

LIST OF TABLES

Page

Table	Page
1. Characteristics of Respondents	35
2. Mean and SD Scores for Subjects' Perception of Visual Appearance of Skin as Being Healthy or Unhealthy.....	38
3. ANOVA of Age, CRI, and K for Subjects' Perception of Visual Appearance of Skin as Being Healthy or Unhealthy.....	39
4. Mean and SD Scores for Subjects' Perception of Lighting Appearance as Being Warm or Cool.....	41
5. ANOVA of Age, CRI, and K for Subjects' Perception of Visual Appearance as Being Warm or Cool.....	42
6. Analysis of Simple Effects (Age x K) in Relation to Subjects' Perceived Warmness of Coolness of Light.....	43
7. Mean and SD Scores for Subjects' Perception of Luminance as Being Too Bright or Too Dim	45
8. ANOVA of Age, CRI, and K for Subjects' Perception of Luminance as Being Too Bright or Too Dim.....	46
9. Mean and SD Scores for Subjects' Perception of Glare	48
10. ANOVA of Age, CRI, and K for Subjects' Perception of Glare.....	49
11. Analysis of Simple Effects (CRI x K) in Relation to Subjects' Perception of Glare or Nonglare of Lights	50
12. Mean and SD Scores for Subjects' Perception of Visual Comfort as Being Comfortable or Uncomfortable.....	52
13. ANOVA of Age, CRI, and K for Subjects' Perception of Visual Comfort as Being Comfortable or Uncomfortable.....	53
14. Mean and SD Scores for Subjects' Preference for Liking or Disliking of Lighting Conditions.....	55
15. ANOVA of Age, CRI, and K for Subjects' Preference for Liking or Disliking of Lighting Conditions.....	56
16. Mean and SD Scores for Responses to Value Discrimination (black letters on Munsell gray scale backgrounds).....	58

Table	Page
17. ANOVA of Age, CRI, and K for Value Discrimination of Black Letters on Munsell Gray Scale Backgrounds	59
18. Chi-square Analysis of Subjects' Preference for the Value Discrimination of Black Letters on Munsell Gray Scale Backgrounds	61
19. Mean and SD Scores for Responses to Value Discrimination (white letters on Munsell gray scale backgrounds).....	62
20. ANOVA of Age, CRI, and K for Value Discrimination of White Letters on Munsell Gray Scale Backgrounds	63
21. Analysis of Simple Effects (CRI x K) of Subjects' Perception in Relation to Ease of Reading White Letters on Munsell 6 Gray Scale Background.....	64
22. Analysis of Simple Effects (CRI x K) of Subjects' Perception in Relation to Ease of Reading White Letters on Munsell 8 Gray Scale Background.....	65
23. Analysis of Simple Effects (Age x K) of Subjects' Perception in Relation to Ease of Reading White Letters on Munsell 6 Gray Scale Background.....	67
24. Analysis of Simple Effects (Age x K) of Subjects' Perception in Relation to Ease of Reading White Letters on Munsell 8 Gray Scale Background.....	68
25. Chi-square Analysis of Subjects' Preference for the Value Discrimination of White Letters on Munsell Gray Scale Backgrounds.....	69
26. Chi-square Analysis of Age, CRI, and K for Color Descriptors to Munsell Red (5R).....	71
27. Chi-square Analysis of Age, CRI, and K for Color Descriptors to Munsell Yellow (5Y)	73
28. Chi-square Analysis of Age, CRI, and K for Color Descriptors to Munsell Green (5G)	74
29. Chi-square Analysis of Age, CRI, and K for Color Descriptors to Munsell Blue (5B)	76
30. Chi-square Analysis of Age, CRI, and K for Color Descriptors to Munsell Purple (5P)	77

LIST OF FIGURES

Figure	Page
1. The Human Eye	12
2. Photo: The Cubicles and the Four Different Lighting Conditions	25
3. Fluorescent Lamp Designation	26
4. Photo: Location of Podium	27
5. Schematic Diagram for Independent Variables	29
6. Photo: Screen	31
7. Photo: Subject	32
8. Interaction (Age x K) Effects in Relation to Subjects' Perceived Warmness or Coolness of Light.....	43
9. Interaction (CRI x K) Effects in Relation to Subjects' Perception of Glare or Nonglare of Lights.....	50
10. Interaction (CRI x K) Effects of Subjects' Perception in Relation to Ease of Reading White Letters on Munsell 6 Gray Scale Backgrounds	64
11. Interaction (CRI x K) Effects of Subjects' Perception in Relation to Ease of Reading White Letters on Munsell 8 Gray Scale Backgrounds	65
12. Interaction (Age x K) Effects of Subjects' Perception in Relation to Ease of Reading White Letters on Munsell 6 Gray Scale Backgrounds	67
13. Interaction (Age x K) Effects of Subjects' Perception in Relation to Ease of Reading White Letters on Munsell 8 Gray Scale Backgrounds	68

CHAPTER I

INTRODUCTION

According to the U.S. Bureau of the Census (1990), the percentage of the U.S. population who are over 65 years of age is increasing. Statistics show that the portion of the population over age 65 is growing twice as fast as the remainder of the population under age 65. For example, in 1870 individuals 65 and older composed 3 percent of the population; by 1988, there were over thirty million (12.3 %) individuals 65 and older. Furthermore, it is projected that by 2010, 13.9 percent of the United States population will be 65 years of age and older. By 2020, it is predicted that, one out of every four Americans will be at least 65 years and older (Weaver, 1994). By the year 2040, the United States could have more people aged 65 years and older than under 20 years of age (Taeuber, 1992).

There are two immutable factors driving this trend; life expectancy/mortality rate and "baby boomers." First, life expectancy at birth has increased dramatically in the past century, and the mortality rate has declined significantly due to the improvements of health and medical technology. For instance, in 1890 a person could expect to live to 43 years of age. However the average life expectancy in 1990 was 76 years (Crandall, 1991; Dychtwald, 1990; Soldo & Agree, 1988). Second, the "baby boomers," those born between 1946 and 1964, are the largest generation in U.S. history. Thus, by the year 2030, the youngest baby boomers will be 66 years old, and one in every five persons in the U.S. will fall into the category of age 65 and older (Baucom, 1996; Dychtwald, 1990; Mergenhagen, 1995).

As a result, Americans aged 65 and older are becoming a fast-growing and formidable market. Growth in the mature market presents a new set of opportunities for businesses. Remarkable changes have occurred in the economic status of the elderly in recent years. In 1959, 35.2 percent of those persons aged 65 and older lived in poverty. In 1987, the mean

income for those over age 65 was \$20,333 and poverty rates for the elderly was 12.2 percent (United States Department of Commerce, 1989). Recent studies indicate that mean income increases with age from young adulthood into mid-life, peaking between ages 45 and 64, and declines after age 65. However, the mean income of persons age 65 and over is the second highest after ages 45-64 (Crystal & Shea, 1990a). The segment of the population that was age 65 and older accounted for over \$60 billion in annual consumer spending in the United States (Lumpkin & Hite, 1988). Hence, the most important transition in attitudes toward the elderly during the 1980s occurred in the area of economic well-being. Baucom (1996) reports that:

Between 1970 and 1986, retail sales in America grew from \$995 billion (in 1986 dollars) to \$1.4 trillion. This money was spent primarily on furniture, clothes, appliances, cars, travel, and other adult symbols of prosperity. Yet, Americans over the age of fifty currently have an aggregate income of \$800 billion and control about 70 percent of the total net worth of all American households. However, the baby boomer generation will soon replace them in this position of monetary power. Thus, as they near the age of 65, the baby boomers will remain an influential force in the marketplace well into the twenty-first century. (p. 23)

It is essential that the needs of an aging population are considered in the marketplace. One crucial point which must be considered is that older consumers' shopping habits differ from those of younger consumers. According to previous studies, several factors affect an older person's decision to buy products in retail stores. For example, directional signs and comfortable store environments are factors which influence decision making (Moschis, 1996). In another study of the marketplace needs of the elderly (Lumpkin, Greenberg, & Goldstucker, 1985) found that mature consumers considered readable labels/tags to be a determinant attribute when choosing a store. Therefore, it can be deduced that aging consumers have need for more visual aids or more consideration of their unique needs than younger consumers do. Readable signs and well-lit, comfortable environments seem to attract the aging eye. Specifically designed lighting could be beneficial to the aging consumer and help to address visual deterioration. Hence, lighting designs must be developed with the understanding that

what is satisfactory for young people may not apply to aging people (Anderson & Noell, 1994; Baucom, 1996).

Purpose and Objectives

The purpose of the study was to understand the impact of different fluorescent light color temperatures and color rendering indices on lighting preference, visual comfort, value discrimination and color descriptors among individuals with different ages. To identify differences that may exist between elderly consumers and younger consumers, the responses of the consumers over sixty-five years of age were compared with the responses of consumers between the twenty and thirty years of age. Results or implications from this study will be applied to store lighting techniques to attract elderly consumers. Specifically, the objectives of the study included:

1. To assess and compare lighting preferences of individuals by age under different color rendering indices (CRI) and color temperatures (K) of fluorescent light.
2. To assess and compare visual comfort according to age difference with regard to color rendering indices (CRI) and color temperatures (K) of fluorescent light.
3. To assess and compare the ability to discriminate value according to age difference with regard to color rendering indices (CRI) and color temperatures (K) of fluorescent light.
4. To assess and compare the ability to designate colors according to age difference with regard to color rendering indices (CRI) and color temperatures (K) of fluorescent light.
5. To develop recommendations for store lighting design specifically for elderly consumers.

Research Hypotheses

To accomplish the objectives of this study, the research was designed to test eight null hypotheses. The hypotheses are:

Hypothesis 1. There is no difference in subjects' perception of visual appearance of skin as being healthy or unhealthy with regard to

- a) age (young and old)
- b) color rendering index of fluorescent light (75 CRI and 85 CRI)
- c) color temperature of fluorescent light (3000 K and 4100 K)
- d) two-way interaction of CRI by K
- e) two-way interaction of age by CRI
- f) two-way interaction of age by K
- g) three-way interaction of age by CRI by K

Hypothesis 2. There is no difference in subjects' perception of appearance as being warm or cool with regard to

- a) age (young and old)
- b) color rendering index of fluorescent light (75 CRI and 85 CRI)
- c) color temperature of fluorescent light (3000 K and 4100 K)
- d) two-way interaction of CRI by K
- e) two-way interaction of age by CRI
- f) two-way interaction of age by K
- g) three-way interaction of age by CRI by K

Hypothesis 3. There is no difference in subjects' perception of luminance as being too bright or too dim with regard to

- a) age (young and old)
- b) color rendering Index of fluorescent light (75 CRI and 85 CRI)
- c) color temperature of fluorescent light (3000 K and 4100 K)
- d) two-way interaction of CRI by K
- e) two-way interaction of age by CRI
- f) two-way interaction of age by K
- g) three-way interaction of age by CRI by K

Hypothesis 4. There is no difference in subjects' perception of glare or non-

glare of lights with regard to

- a) age (young and old)
- b) color rendering Index of fluorescent light (75 CRI and 85 CRI)
- c) color temperature of fluorescent light (3000 K and 4100 K)
- d) two-way interaction of CRI by K
- e) two-way interaction of age by CRI
- f) two-way interaction of age by K
- g) three-way interaction of age by CRI by K

Hypothesis 5. There is no difference in visual comfort with regard to

- a) age (young and old)
- b) color rendering Index of fluorescent light (75 CRI and 85 CRI)
- c) color temperature of fluorescent light (3000 K and 4100 K)
- d) two-way interaction of CRI by K
- e) two-way interaction of age by CRI
- f) two-way interaction of age by K
- g) three-way interaction of age by CRI by K

Hypothesis 6. There is no difference in lighting preference with regard to

- a) age (young and old)
- b) color rendering index of fluorescent light (75 CRI and 85 CRI)
- c) color temperature of fluorescent light (3000 K and 4100 K)
- d) two-way interaction of CRI by K
- e) two-way interaction of age by CRI
- f) two-way interaction of age by K
- g) three-way interaction of age by CRI by K

Hypothesis 7. There is no difference in the ability to discriminate value with regard to

- a) age (young and old)
- b) color rendering index of fluorescent light (75 CRI and 85 CRI)
- c) color temperature of fluorescent light (3000 K and 4100 K)

- d) two-way interaction of CRI by K
- e) two-way interaction of age by CRI
- f) two-way interaction of age by K
- g) three-way interaction of age by CRI by K

Hypothesis 8. There is no difference in the ability to designate colors with regard to

- a) age (young and old)
- b) color rendering index of fluorescent light (75 CRI and 85 CRI)
- c) color temperature of fluorescent light (3000 K and 4100 K)
- d) two-way interaction of CRI by K
- e) two-way interaction of age by CRI
- f) two-way interaction of age by K
- g) three-way interaction of age by CRI by K

Definition of Terms

The following terms are used in this study and are defined as follows:

Accent lighting - Directional lighting to emphasize a particular object or to draw attention to a part of the field of view (Rea, 1993).

Accommodation - The process by which the eye changes focus from one distance to another (Rea, 1993).

Adaptation - The process by which the retina becomes accustomed to more or less light than it was exposed to during an immediately preceding period (Rea, 1993).

Ambient lighting - Lighting throughout an area that produces general illumination (Rea, 1993).

Architectural lighting - Lighting techniques used to provide light for buildings and/or their contents (Angevine, 1997).

Brightness - The intensity of the sensation which results from viewing a surface or space that directs light into the eyes (Chain Store Age Executive, 1991).

Candela (cd) - The international basic physical quantity in all measurements of light (North American Philips Lighting Corporation, 1984).

Color rendering - A general expression for the effect of a light source on the color appearance of objects in conscious or subconscious comparison with their color appearance under a reference light source (Rea, 1993).

Color rendering index (CRI) - A measure of the degree of color shift objects undergo when illuminated by the light source as compared with those same objects when illuminated by a reference source of comparable color temperature (Rea, 1993).

Color temperature (K) of a light source - The absolute temperature of a blackbody radiator having a chromaticity equal to that of the light source (Rea, 1993).

Correlated color temperature (of a light source) - The absolute temperature of a blackbody whose chromaticity most nearly resembles that of the light source (Rea, 1993).

Elderly - Any individual age 65 or older (Crandall, 1991).

Fluorescent lamp - A low-pressure mercury electric-discharge lamp in which a fluorescing coating (phosphor) transforms some of the UV energy generated by the discharge into light (Rea, 1993).

Footcandle (fc) - The illumination at a point on a surface which is one foot from and perpendicular to a uniform point source of one candela (North American Philips Lighting Corporation, 1984).

General lighting - Lighting designed to provide a substantially uniform level of illumination throughout an area, exclusive of any provision for special local requirements (Rea, 1993).

Glare - The sensation produced by luminance within the visual field that is sufficiently greater than the luminance to which the eyes are adapted to cause annoyance, discomfort or loss in visual performance and visibility (Rea, 1993).

Illuminance - The areal density of the luminous flux incident at a point on a surface (Rea, 1993).

Illumination - Quantity of light per unit of surface area; the intensity or density of light falling on a surface (English unit: footcandle) (Lam, 1977).

Interior lighting - Light used within buildings (Angevine, 1997).

Lamp - A generic term for an artificial source of light (Rea, 1993).

Light - Radiant energy that is capable of exciting the retina and producing visual sensation. The visible portion of the electromagnetic spectrum extends from about 380 to 770 nm (Rea, 1993).

Lumen - The light flux falling on a surface one square foot in area, every part of which is one foot from a point source having a luminous intensity of one candela in all directions (North American Philips Lighting Corporation, 1984).

Luminance - The physical measure of brightness; luminous intensity per unit projected area of any surface, as measured from a specific direction (Lam, 1977).

Luminance ratio - The ratio between the luminances of any two areas in the visual field (Rea, 1993).

Luminaire (light fixture) - A complete lighting unit consisting of a lamp or lamps and ballasting (when applicable) together with the parts designed to distribute the light, to position and protect the lamps and to connect the lamps to the power supply (Rea, 1993).

Luminous flux - Time rate of flow of radiant energy measured in lumens (North American Philips Lighting Corporation, 1984).

Luminous intensity - The luminous flux per unit solid angle in a given direction, measured in candelas (North American Philips Lighting Corporation, 1984).

Lux - The International System unit of illumination. One lux = .0929 footcandle (North American Philips Lighting Corporation, 1984).

Nanometer (nm) - A unit of wavelength equal to 10^{-9} meter (Rea, 1993).

Perception - A meaningful impression obtained through the senses and interpreted in the mind (Lam, 1977).

Quality of lighting - Favorable distribution of luminance in a visual environment, with regard to visual performance, visual comfort, ease of seeing, safety and esthetics or the specific visual tasks involved (Rea, 1993).

Quantity of light (luminous energy) - The product of the luminous flux by the time it is maintained. It is the time integral of luminous flux (Rea, 1993).

Task lighting - Lighting directed to a specific surface or area that provides illumination for visual tasks (Rea, 1993).

CHAPTER II

REVIEW OF LITERATURE

Introduction

Interior design promotes and sustains quality of life through creating environments that support users' physiological, psychological, and cultural needs. One aspect of interior design which assists in creating such an environment is light. Researchers and designers believe that light is vital to human health, sense of well being, and emotional responses to the environment (Bonnie, 1993; Swain, 1995). Therefore, since lighting is an important element of interior design, it is essential that individuals dealing with shaping interior environments be aware of its potential.

The elderly are especially affected by lighting conditions due to problems of the aging eye (Anderson & Noell, 1994; Miller, 1992; Nuckolls, 1983; Smith & Bartolone, 1986). However, research in architectural lighting has traditionally been focused on observing persons between 20 and 30 years of age who are characterized as young (Boray, Gifford, and Rosenblood, 1989; Veitch, Hine, & Gifford, 1993). A review of lighting literature revealed little research in the area of retail buyers' decision-making criteria with regard to store light and the elderly consumer. Hence, due to the limited research and the lack of theories or conceptual framework, theoretical development of store lighting for the elderly has been slow in its evolution. Furthermore, no study focusing specifically on retail store lighting for elderly consumers has been found. A plethora of information regarding lighting design is available; however, research concerning lighting design for the elderly is not abundant. For this reason, the focus of this study fully concentrated on lighting design for elderly consumers.

The literature related to this study is organized into the following sections: sight and vision (which include the structure and function of the eye), light and color, the aging eye, illumination for the aging eye, and store lighting design.

Sight and Vision

In Architectural Lighting for Commercial Interiors, Sorcar states that "light and vision are interdependent" (Sorcar, 1987, p.7). The author also adds that "we see with our eyes, but even a perfect pair is useless when there is no light" (Sorcar, 1987, p.7). Without light and the use of the human eye, there is neither visual architecture nor interior design (Steffy, 1990). To design lighting for optimal performance, comfort, and utility, the basic interactions between light and vision are studied to provide some fundamental data to designers.

The eye serves as the initial step in the vision and perception process. "The eye is a complex sensory organ which maintains the spatial and temporal relationships of objects in visual space and converts the light energy it receives into electrical signals for processing by the brain" (Rea, 1993, p.69). Consideration of the eye can be divided into two components: first, optical components including the cornea, crystalline lens, pupil and intraocular humors, and second, neurological components such as the retina and optic nerve (Rea, 1993).

The vision process begins when light is reflected from an object. The reflected light from the object enters through the cornea, a transparent portion of the outer membrane surrounding one-fifth of the eyeball. The cornea serves the primary refractive component of the eye since its refractive index is substantially greater than that of air (Boynton, 1979). To better illustrate this eye function, Figure 1 shows the human eye.

The light then enters the body of the eye through the pupil an opening which is controlled by muscles in the iris. The iris, the colored portion of the eye, contracts or expands to control the amount of light passing through the pupil and entering the eye (Baucom, 1996). When the amount of light is excessive, the muscles in the iris make the pupil smaller, and vice versa; this change is called adaptation. The effect of the eye from light to dark is known as dark adaptation. Conversely, light adaptation is the process of the eye to adapt from dark to light

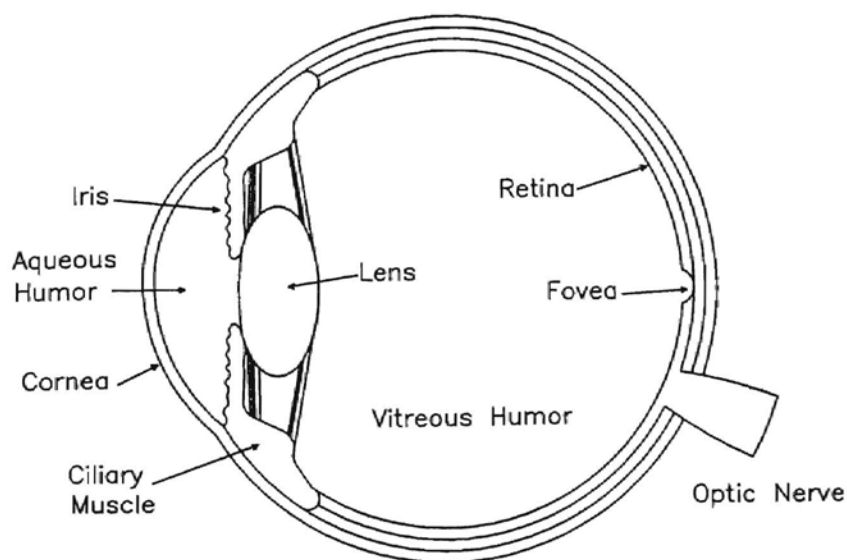


Figure 1. The Human Eye (Adapted from Rea, 1993, p. 70)

conditions. Dark adaptation from light to dark takes longer than light adaptation. Complete dark adaptation can take half an hour or more (Steffy, 1990).

The lens then focuses the incoming visual images from whatever distance received, through the gelatinous vitreous humor onto the retina at the back of the eye. The crystalline lens gives the eye most of the remaining refractive power of the eye. The ciliary muscles on either side of the lens have the ability to control the curvature of the lens by adjusting tension on it, in response to changing object distances. This change is referred to as accommodation (Nuckolls, 1983). To view objects farther removed it becomes flatter in a longer focal length. Closer viewing requires transformation to a more globular form.

The aqueous humor, behind the cornea and vitreous humor in the middle of the eye, are the clear, jelly-like substances that help maintain the shape of the eye and provide nutrients to the nonvascular structures within the eye (Padgham & Saunders, 1975).

As the neurological component, the retina is the nerve layer that lines the back of the eye. It contains the primary neural units of the human visual system consisting of two main classes of light-sensitive receptors which are the rods and cones. The rods and cones convert light

energy into electrical impulses that are sent through the optic nerve to the brain (Boynton, 1979). The dispersion of the rods and cones through the retina varies both in their position and density from one area to another. Cones are highly concentrated in the central part of the retina referred to as the fovea. Rods on the other hand, are found only outside the foveal region, increasing in number with distance from the fovea (Boynton, 1979; Padgham & Saunders, 1975).

The cones and the rods differ in their abilities to interpret radiant energy into images. The divergence of their functions is due to a photopigment known as rhodopsin, a purple liquid, located in the rods. It is sensitive to light and bleaches rapidly when exposed to light. The rods, which are absent in the fovea, are extremely sensitive to light because of the combination of large amounts of rhodopsin and relatively low spontaneous neural activity (noise) levels. The rods are highly sensitive to any movement and flicker and since, compared to cones, they are more highly concentrated nearer the retinal edge their sensitivity and concentration account for what is referred to as peripheral vision. Because rods do not provide distinct, detailed vision and color stimulus to the brain, peripheral vision responds mainly to low light situations. Rhodopsin has a specific spectral sensitivity at about 507 nanometers (Rea, 1993). Rod vision at these low light levels is referred to as night cone vision (scotopic).

The cones on the other hand provide the abilities to discriminate fine detail and to perceive color. They are insensitive at low levels of illumination. The cones are found principally in the central portion of the retina, with the greatest concentration at the fovea, an area about 0.3 mm in diameter. Cones are divided into three types of receptors including erythrolabe, chlorolabe, or cyanolabe each characterized by a photopigment (Rea, 1993). The different photopigments in the cones create multiple variations of color responses. Color discrimination, generally, is high in the fovea and reduces toward the periphery which is mainly rod vision. Color vision in the cones of the retina is called photopic (Evans, 1974).

The eye is able to function over a tremendously wide range of illumination levels by means of adaptation. Adaptation involves a change in the size of the pupil opening, along with photochemical changes in the retina. Photochemical adaptation is affected by the brightness in

the visual field. During constantly brightened conditions, the concentration of photopigment is in equilibrium. When the brightness is changed, the photopigment changes. In the dark, the pigment is regenerated to receive light, while the photopigment is bleached to reestablish equilibrium in the high brightness.

Light and Color

The human eye responds to the electromagnetic energy, from very short cosmic rays to very long rays of electric power, within the limits of the visible spectrum, an exceedingly small portion of the electromagnetic spectrum between the ultraviolet and infrared. These wavelengths are called visible energy or light, even though the human eye cannot see the energy itself. The visible wavelengths extend from approximately 380 nanometers (nm) to 780 nm on the electromagnetic spectrum (Egan, 1983). Each visible spectrum varies in length, and the different wavelengths comprising the light spectrum determine a color. All colors depend on light. "Color is the presence or absence of light as it is reflected or not reflected from a surface" Mills, Paul, and Moormann (1995, p.76). Within the light spectrum, there are all the colors of the rainbow. Light energy at the shortest visible wavelength, from approximately 380 to 450 nm, produces the sensation of violet; the longest wavelengths, between about 630 and 780 nm, appear as red. All other colors (indigo, blue, green, yellow, and orange) are of intermediate wavelengths (Egan, 1983).

Light that contains balanced radiant energy of all visible wavelengths appears as white to the eye. White light is invisible to the eye until it strikes an object. When light waves fall on an object and are reflected, the image is focused onto the retina, absorbed by photoreceptors in the cones and converted into neural signals to the brain as the perceived color of the object (Baucom, 1996).

White light, which is formed of the balanced radiant energy of all visible wavelengths, produces the true color of an object, as opposed to a light that has unbalanced chromaticity. The different wavelengths within a given light source can vary greatly. The most common variations are described as warm or cool. Most fluorescent light is said to be a cool white

source due to its being dominated by the short end of the spectrum, with "cool" color tones of green through blue. In contrast, incandescent lights said to be warm white light because it emphasizes the long end of the spectrum, with "warm" color tones orange through red (Gordon & Nuckolls, 1995). Differences in the color of a light source can have a pronounced effect on the color appearance of objects and surfaces. "No matter how good the finish of an object may be, its true color will never be visible if the light source does not contain a matching wavelength" (Sorcar 1987,p.7).

According to the Lighting Handbook (Rea,1993), the color characteristics of light sources can be described by two standard measurements: color temperature and color rendering index. Color temperature describes the color appearance of a light source. The color temperature of the light source is the specific temperature, measured in degrees Kelvin (K), at which the color of a blackbody exactly matches the color of the incandescent light source. However, the color appearance of discharge lamps such as fluorescent and HID lamps, is specified by the correlated color temperature (CCT). The CCT is the temperature in Kelvin of blackbody radiation that appears closest to the color appearance of light from the lamp. When a blackbody is heated, with increased temperature, the color of its glow changes in a predictable manner from red at a temperature of 800 K, to yellow-white at 2,800 K, to white at about 5,000 K, to bluish white at 8,000 K, and to a brilliant blue at 60,000 K. Incandescent sources have color temperatures between 2,600 K and 3,100 K, whereas selected fluorescent lamps are available with correlated color temperatures from 2,700 K to 7,500 K (North American Philips Lighting Corporation, 1984).

The other color characteristic of light sources is a rating system called the Color Rendering Index (CRI). This method provides to measure and specify the ability of light sources to render colors (Rea, 1993; Nuckolls, 1983). Incandescent lamp is used as a reference on a scale of 100 due to its continuous spectrum distribution (Tregenza & Loe, 1998). The CRI compares the color rendition of a given light source with a reference light source allowing easy consideration of the perceived color of objects and surfaces. Tregenza and Loe (1998) state that lamps with a CRI rating of 80 or above are considered to be high and indicates

that the source has good color properties. They are appropriate to use where accurate color judgement is required. Gordon & Nuckolls (1995) indicate that comparisons are valid only within the similar color temperature of two light sources.

The Aging Eye

Like the rest of the human body, the eye degenerates with age for everyone. After the age of sixty-five; however, there are additional and more dramatic visual challenges. These problems of aging eyesight include increasing sensitivity to glare, decreasing ability to focus on nearby objects, increasing adaptation time, decreasing color sensitivity, a decrease in the amount of light reaching the retina, and decreasing visual acuity (Davidsen, 1991; Hughes & Neer, 1981; Miller, 1992; Nuckolls, 1983; Smith & Bertolone, 1986).

The deterioration of the ability to see begins shortly after birth. Most optometrists consider the age of forty to be the point between young and old eyes. By age twelve, approximately 20 percent of the American population acquires the need for vision correction. Somewhere between mid-twenties and mid sixties, this number increases to sixty percent. After sixty-five years of age, nearly 100 percent of the people require some sort of visual aid (Baucom, 1996).

As a person ages, several normal changes occur in the visual system. First, the lens yellows as a very pale-yellow, thin tissue grows thicker. This additional lens thickness reduces the amount of absorbed light entering the eye, and the remainder is absorbed in the lens. By age 60, the lens passes about one-third of the light as it did at twenty years old (Davidsen, 1991). The thickening of the lens not only reduces the transmission of all wavelengths of light, but it also diffuses the light passing through the lens. Reduced light transmission with the yellowing of the lens affects color perception. Elderly people are less accurate in discriminating finite hue differences at the blue end of the spectrum (blues, greens, and purples), and experience a general loss in all parts of the spectrum (Nuckolls, 1983). The lens develops cataracts by loss of transparency and yellowing of the lens material. Throughout its life, the

lens is exposed to ionizing radiation and ultraviolet light that could cause cataracts (Miller, 1992). The thickening of the lens also adversely affects perceived brightness or color intensity.

Fluorogens, small masses that fluoresce in the lens when stimulated by certain wavelengths of light, can reduce light transmission, cloud the visual image, and scatter light to the wrong receptors in the retina (Nuckolls, 1983). With age, the fluid interior of the eye becomes cloudy. The eyeball shrinks and the cloudiness scatters the light that passes through the lens, thereby reducing transmission. Another effect of aging on the eye is yellowing and clouding of the vitreous humor. When these phenomena occur discrimination of hues becomes less accurate, and sensitivity to perceived contrast declines because light scatters before it arrives on the retina (Smith & Bertolone, 1986).

There are additional physiological changes in the aging eye. Elderly people tend to have a reduced pupil size, and iris openings become smaller and rather rigid. The small pupil size does not readily adapt from one level of brightness another. This causes a lot of trouble when a person moves between bright and dark environments. The small pupil size also reduces the amount of light reaching the retina. The result is that elderly people dark adapt more slowly and have difficulty functioning in low-light spaces.

The crystalline lens is responsible for adjusting the focus from a distant point to a near point. The tiny ciliary muscles pull and push on the lens shaping it appropriately to yield a proper focus. With age, the lens becomes less flexible and more rigid, thereby losing its elasticity. In addition, ciliary muscles become less powerful. Therefore, the lens can no longer be changed to focus on nearby objects. This problem is called presbyopia and greatly affects the accommodation process of the elderly (Hughes & Neer, 1981; Miller, 1992; Nuckolls, 1983). Accommodation begins to decline at an early age and continues at a regular rate until there is little or no focusing power at approximately age 60. Researchers believe the ciliary muscles begin weakening around age 40 and are heavily burdened by age 60.

The elderly have a reduced ability to discern or tolerate extremes of light intensity. Sensitivity to glare increases, particularly the sensitivity to disability glare, during the aging process. The sensitivity to disability glare of older adults is due to the aging eye that increases

the diffusing of light within the eyeball (Sanders & McCormick, 1993). Baucom (1996) mentions that the thickened lens diffuses the light passing through it. This diffusion increases glare. Miller (1992) stated that vision specialists are not exactly sure what other things affect the glare problem. She added however, that increased glare may be due to limited pupil reaction, the high-mass molecules and the fluorogens.

Illumination for the Aging Eye

To compensate for the loss of visual and physical capabilities of elderly people, there are certain concepts. Baucom (1996) states that for many people with reduced vision abilities, visual acuity can be enhanced by lighting designs that reinforce environmental contrast between objects and surfaces. He states good color rendering light also can help one to see more clearly.

Researchers generally agree that the illumination level needs to be increased as overall sensitivity declines and pupil size diminishes, especially for detailed visual tasks, such as reading or sewing (Baucom, 1996; Nuckolls, 1983). However, too bright an environment can cause a serious glare problem for the elderly. To avoid excessive illumination in interior spaces, secondary light sources such as table lamps or accent lights are necessary. Changes in illumination level, however, should be gradual because of the problems of limited adaptation (Nuckolls, 1983).

Since elderly people have a reduced ability to discern or tolerance of extremes in light intensity and are sensitive to glare, direct glare should be minimized through use of well-shielded luminaries. Indirect glare is of particular concern for the elderly in interior lighting. To avoid this problem, surface finishes should be matte. The lighting should be balanced to keep luminance ratios from being too high. A comfortable range of luminance, avoiding extremes in the same space, helps the elderly acclimate to a given space (Nuckolls, 1983; Sanders & McCormick, 1993).

According to Davidsen (1991), shading is especially effective to indicate the existence, height and depth of steps, doorsills, and ramps. She also recommends that high light levels

with good color rendition are necessary to compensate for the yellowing of the lens. All lighting systems should be simple and easy to operate by elderly people. Luminous switches and more than one switch per light are especially helpful. For the table and floor lamps, touch-base lamps are recommended (Nuckolls, 1983).

Store Lighting

Many studies draw attention to the need to gain further understanding of the influence of retail store environments on customer behavior. In previous studies, researchers found that store image attributes including music, color, scent, layout, fixtures, size, shape, and light, are environmental stimuli that interact with consumers' responses in store environments (Baker, Levy & Grewal, 1992; Bellizzi, Crowley & Hasty, 1983; Kotler, 1973-1974; Lindquist, 1974-1975).

According to Kotler (1973-1974), the atmosphere of the store is one of the most influential factors in the purchasing decision. He suggests that atmosphere as a marketing tool can be produced by manipulating the visual, aural, olfactory, and tactile dimensions of the surrounding space. He specifies that the main visual dimensions of an atmosphere-- color, brightness, size, shapes-- can help draw attention, convey messages, and create feelings that may increase purchase probability. Donovan and Rossiter (1982) state that the emotional states of pleasure and arousal created by store atmosphere can affect shopping behaviors within the store environment. Furthermore, Markin, Lillis, and Narayana (1976) report that store image, manipulated by lighting and noise levels influences consumer's behavior.

In short, Grant (1991) defines that "the goal of the store lighting.... to create enough light to sell goods and stimulate interest while still keeping electric bill within reason" (p. 52). He adds that the key to controlling consumer behavior of store lighting is the effective use of the correct lamps by providing correct combination of primary (general) and secondary (accent) lighting. For a general retail lighting, fluorescent lighting systems are the most popular because of cost of energy and length of lamp life (Ward, 1991).

Birren (1988) observes that the eye always concentrates on brightness rather than dimness. Even though the general illumination provides brightness, spot or flood lights are necessary to be able to see clearly and to provide character, depth, plasticity, and texture within a store.

In general researchers conclude good store lighting design requires well-combined quantity and quality of lighting to provide visual focus, safety and security; to attract customers' attention; to direct customer traffic in a specific pattern; to create a mood; and to leave a lasting impression (Roush, 1994; Sorcar, 1987).

The IES Lighting Handbook (Rea, 1993) recommends that the quantity of light in a store be divided into three basic areas. The circulation area should have an illuminance of 10 to 30 footcandles. The merchandise area needs an illuminance of 30 to 100 footcandles. And for the feature display, illumination needs to be 150 to 500 footcandles. However, Smith (1988) suggests that different kinds of stores require different lighting levels. For example, clothing stores need soft general lighting, while food and drug stores need bright general light.

Milliman (1986) reports that consumers stayed longer in a store with soft lighting and additional time provided an opportunity to buy more. Meer (1985) reports that soft lighting tends to create a more relaxing, comfortable atmosphere than bright light. Gorn (1982) state that soft lighting in a store may indicate a high quality of merchandise. Therefore, soft lighting tends to affect an increase willingness to buy by relaxing and slowing consumers' shopping movement.

Butler and Biner (1987) state that individual' preference for lighting levels differs for various behaviors and settings. Biner, Bulter, Fischer, and Westergren (1989) fine preferred lighting levels vary with visual activities, and non-visual activities and the social situation.

As lighting technology improved and lighting users experienced headaches, eye-strain and stress, lighting designers and lighting manufacturers shifted in the beginning to concern with lighting quality in the physical work environment. Recent research focus has shifted from the quantity of light towards the quality of light (Boray et al., 1989). Steffy (1990) states that lighting is more than just foot-candles. Lighting should not and cannot be simply an application of engineering principles. Lighting is both a physiological and a psychological inducer.

McGuinness, Stein, and Reynolds (1980) define lighting quality to include all factors in a lighting installation not directly concerned with quantity. Specific items referred to are: luminance ratios, diffusion, uniformity, chromaticity, uncomfortable brightness ratios where background luminance exceeds object luminance (glare), and the general notion of visual discomfort. Brandston & Cuttle (1994) suggest that good (high quality) lighting is realized when the mood created is consistent with the function of each space, when the lighting provides spatial clarity, and when it promotes productivity. Lighting quality has been described as a multidimensional concept which has biological, psychological, and aesthetic needs in contrast to quantity. Researchers agree that different light patterns and colors help to elicit various feelings or subjective responses, and appear to influence task performance, human comfort, and one's sense of well being (Benya, 1995; Flynn & Spencer, 1977; Heerwagen & Heerwagen, 1986; Steffy, 1990).

Flynn and Spencer (1977) identify several subjective impressions that are influenced by luminance patterns: visual clarity, spaciousness, relaxation, privacy and pleasantness. An impression of visual clarity is achieved with a high level of uniform luminance and higher luminance in the central part of the room. Large, visible area sources with white color rendition and bright surroundings also enhance the visual clarity.

An impression of spaciousness can be elicited when vertical surfaces (walls) and/or ceiling surfaces are comparatively brighter than the lower horizontal surfaces (e.g., work surface and/or floor). Spaciousness can be created with general ambient lighting and a greater amount of perimeter (wall) lighting. Warm colors appear to advance, while cool colors recede, characteristics that can be adopted to open up space (Sorcar, 1987; Meer, 1985).

Relaxation implies making the tired body comfortable. Low levels of ambient light, subdued color, and wall-wash light in a nonuniform pattern provides relaxed and restful atmosphere. Impression of privacy is particularly important in the more intimate casual spaces. A nonuniform lighting pattern, with low luminance in the zone of the user, but higher luminance in zones surrounding the user, yields an impression of privacy (Steffy, 1993).

Few empirical studies of store lighting exist. Many researchers studied the relationship between lighting and general human behavior, and preferred using a lighting laboratory without

the real feeling of a specific environment to obtain responses towards different illuminances (Biner et al., 1989; Butler & Biner, 1987; Forester & Eastlick, 1992). Some studies mentioned lighting as a part of store image attribute without experimental examination (Bellizzi et al., 1983; Kotler, 1973-1974; O'Neill & Jasper, 1992; Zimmer & Golden, 1988).

Baker, Levy and Grewal (1992) study an experimental approach to making retail store environmental decisions using two factors: (1) ambient cues (lighting and music), and (2) social cues (number/friendliness of employees). They considered the effects of these factors on respondents' pleasure, arousal, and willingness to buy in retail card and gift stores. They found arousal and pleasure to have a positive relationship with respondents' willingness to buy.

Areni and Kim (1994) examine the effect of lighting on consumer behavior in a wine store. The results indicate that the consumer prefers testing wine in a bright environment rather than in a softly lit environment. They also find that experienced consumers preferred a well illuminated cellar that enhanced visual acuity and facilitated the examination of merchandise. In contrast, non-experienced consumers preferred softer illumination to enhance their shopping experience. Their findings disagree regarding Markin, Lillis, and Narayan (1976) results in which soft store lighting did not have a significant relationship with the amount of time spent in a store.

Cuttle and Brandston (1995) experiment to compare the new lighting with the lighting that it replaced at two galleries. Measurements were made relating to six aspects of lighting performance: illumination, power density, lighting costs, sales, customer attitudes, and sales staff attitudes. The old lighting provided low illuminances with low efficiency in both galleries. The new lighting increased system efficacy by more than 200 percent, but power densities were affected only slightly. Both customers and sales staff responded positively to the new lighting in both galleries compared to the old lighting. The sales staff believed that the new lighting helped them to do their jobs better.

Even though there is no empirical research about store lighting for elderly consumers, many researchers believe that lighting also needs to be taken into consideration for elderly

users. Blackwell and Blackwell (1971) report visual performance largely differs both among individual observers of the same age and between the averages of different age groups.

Hughes and Neer (1981) indicate that special attention needs to be given to lighting applications for the elderly including such issues as excessive brightness, illuminating differences, discomfort glare, veiling reflections, and the importance of color and the spectral power distribution of the light source. Their finding also indicates that a full spectrum fluorescent light source is recommended rather than the cool white fluorescent lamp because it simulates natural sunlight for indoor illumination.

Davidson (1991) points out that the elderly need high light levels with good color rendition to compensate for the yellowing of the lens. Miller (1992) indicates that store lighting needs to be highly visible for the elderly. However, displays with a lot of bright light and shadow make it hard for an elderly person to discern individual items. A display with high, even light levels are more effective. In circulation areas, light levels need to be generally uniform, whereas merchandise lighting should be free of glare. Miller concluded a mixture of techniques such as low-brightness ambient lighting, a little bit of uplighting to wash out the shadows, and a lot of nonglare concentrated task lighting make an elderly person most comfortable.

CHAPTER III

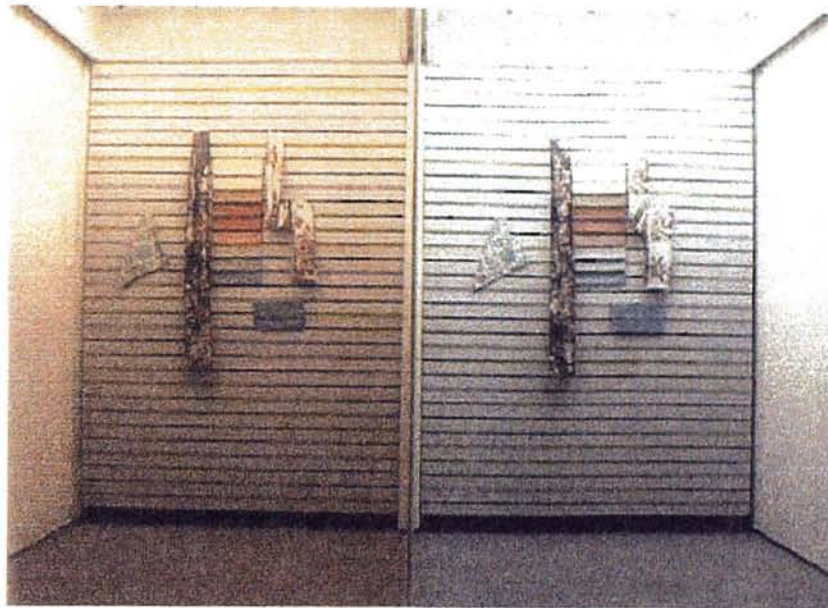
METHODS

Introduction

The question of elderly consumers' special needs of lighting in retail stores has not been fully explored in previous research studies. Therefore, the research design for this study examined the differences in lighting preference, visual comfort, value discrimination and color descriptors among individuals with different ages. These variables were gauged under different color temperatures and with the utilization of different color rendering indices of fluorescent light. This chapter explains and describes the criteria used in this study, specifically addressing the research design, the selection of the sample, the variables involved, method of data collection, and data analysis.

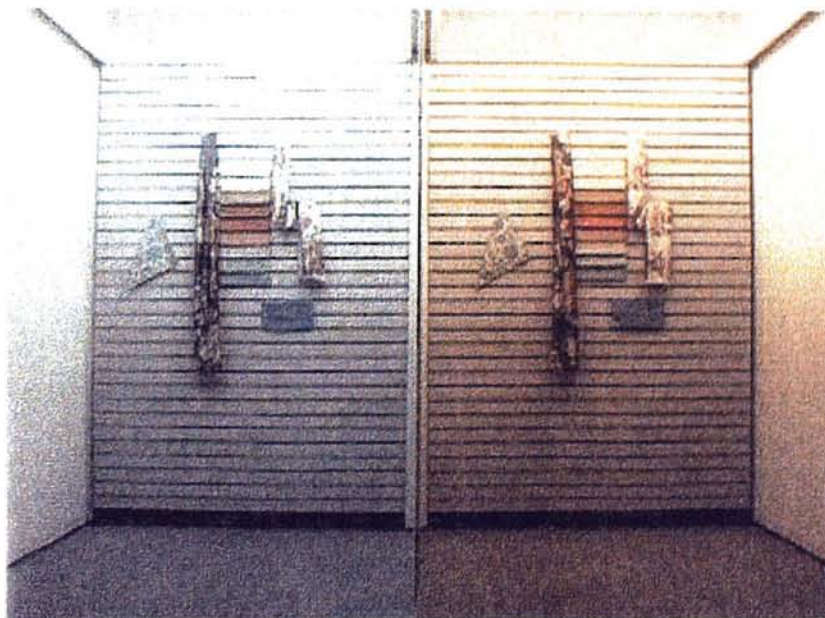
Research Design

The experiment was conducted within the Lighting and Technology Laboratory in the College of Human Environmental Sciences at Oklahoma State University. The laboratory is 21 feet by 45 feet, with a height of nine feet. The front of the room contains four cubicles measuring 5' 0" by 4' 9" (cubicles number 2 and 3 from north side), 4' 9" by 4' 9" (cubicle number 1), and 3' 0" by 4' 9" (cubicle number 4). The two center cubicles were used for this study because they are same size and have same number of lamps. Each cubicle holds 2 circuits of four unshielded 4-foot fluorescent lamps. The cubicles are divided by vertical blinds with matte finish in Pantone Color Cool Gray 1. On the front wall of each cubicle several pieces of patterned fabrics are displayed. The display in each cubicle is identical including type, color, texture and print of each fabric and each display location (see Figure 2 on page 25).



Lighting 730

Lighting 741



Lighting 841

Lighting 830

Figure 2. Photo: The Cubicles and the Four Different Lighting Conditions

Ward (1991) indicates that three basic lamp families are used in retail lighting; fluorescent, incandescent and high intensity discharge (HID). Among them, fluorescent lamps are the most popular for general retail lighting establishments. Ward (1991) also states that color rendering, cost, and lamp life are important factors when selecting a store lighting system. Grant (1991) reports that "fluorescent lamps are still best for general lighting in most stores. Unfortunately, the color rendition of standard fluorescent lamps is pretty dismal" (p. 52). However, modern technology allows fluorescent lamps to render colors with exceptional quality and to provide high efficiency. T8 fluorescent lamps exhibit the combination of excellent energy efficiency and good color rendering. However, the colors depicted in Figure 2 may vary from actual conditions due to the reproduction process. A typical T8 fluorescent lamp designation is outlined in Figure 3. In this study, four groups of T8 fluorescent lamps were used for testing. The four different T8 fluorescent lamps used in this study were including 730, 830, 741, and 841. Figure 2 on page 25 shows the cubicles and the four lighting conditions used for the experiment.

The four fluorescent lamps used are nearly equal in lumen output. The specific illuminance was identified and recorded as 50 footcandles on the surface of the podium (see Figure 4 on page 27). The illumination level utilized is based on the recommendation of the

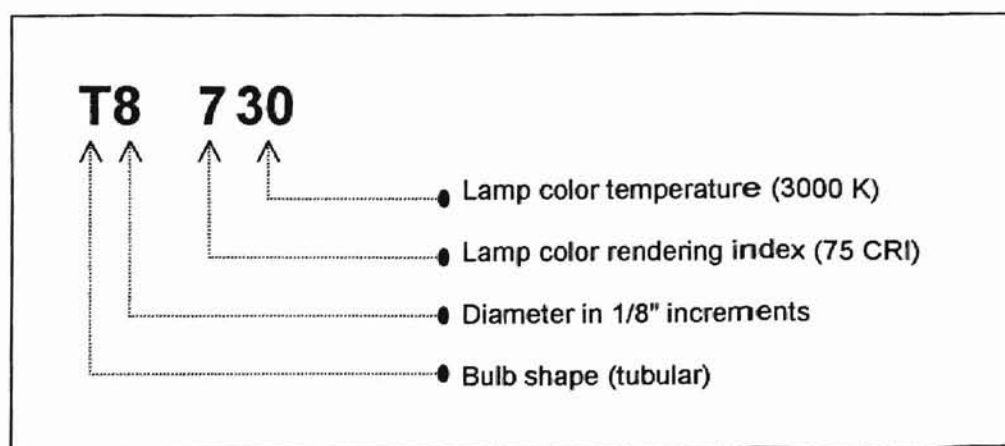


Figure 3. Fluorescent Lamp Designation

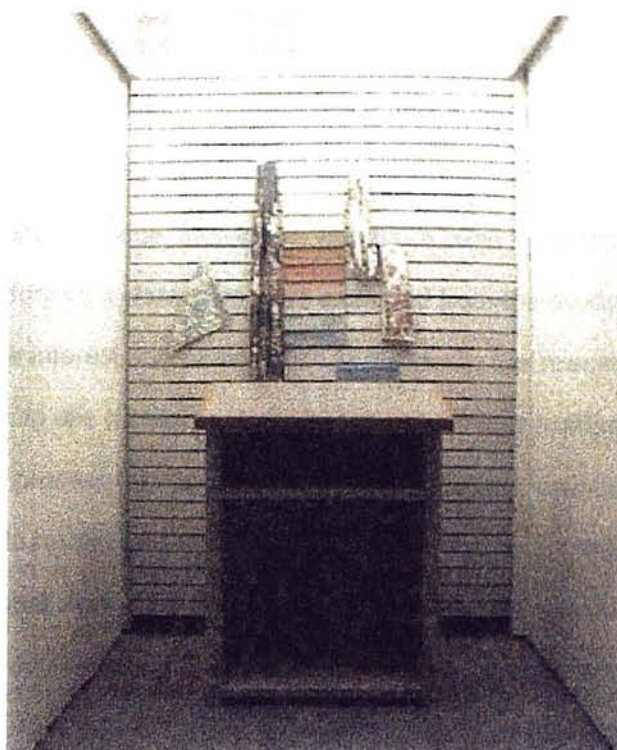


Figure 4. Photo: Location of Podium

Illumination Engineering Society's Lighting Handbook. The recommended illuminance of 30-100 footcandles is appropriate for merchandise areas (Rea, 1993). General illuminance in the room was 15 footcandles.

Sample

Two types of sampling procedures were used subjects. The first was purposive sampling, the selection of subjects to meet specific criteria (Touliatos & Compton, 1992). In this study the criteria for the selection of the subjects were age, visual acuity and absences of color blindness. Subjects were from the local community and solicited via local advertisements, flyers, and personal contact. The subjects were divided into two subgroups to meet the age criteria: 1) over 65 years of age, and 2) between the ages of twenty and thirty. Subjects were screened before the experiment regarding visual acuity and color blindness. Using the process called snowball sampling, participating subjects were asked to identify prospective subjects by

supplying name and phone numbers. The snowball sampling method was especially helpful for identifying older subjects. All snowball sample participants met the same criteria as the purposive sample.

To control for prior knowledge, individuals who have been involved in lighting courses or used the lighting laboratory as a classroom were excluded from the study. Prior to contacting the subjects to gain their interest and participation in the study, the researcher applied for and was granted permission to use human subjects by the University's Institutional Review Board (see Appendix A). The process for the experiment was explained, and the Informed Consent Form was signed prior to testing (see Appendix B). To control the potential influence of visual impairment, the researcher evaluated all subjects. The researcher conducting the visual evaluations was not an ophthalmologist but received training for consistency in administering the eye examinations. The purpose for the eye examinations was to eliminate individuals with visual impairment that would influence on the subjects respond. The tests used were the Ishihara Color Vision test and the Snellen Visual Acuity test. The Snellen Visual Acuity test was used to determine visual distance acuity. The Ishihara Color Vision test was used to determine color vision acuity. No color blindness was required for participation to study visual discrimination and color descriptors. No subjects were color blind. All 80 subjects met the visual acuity requirements and participated in the study.

Variables

The research design of this study was a $2 \times 2 \times 2$ mixed design with one between subject factor and two within subject factors (Keppel, 1991). Independent variables for this investigation were the color temperature and color rendering index of the T8 fluorescent lamps and the age of the subject. The variable color temperature was compared at two levels, 3000 K and 4100 K. The variable the color rendering index was compared at two levels, 75 CRI and 85 CRI. The age groups were compared at two levels, the young and old participants. Figure 5 on page 29 illustrates schematic diagram for the independent variables.

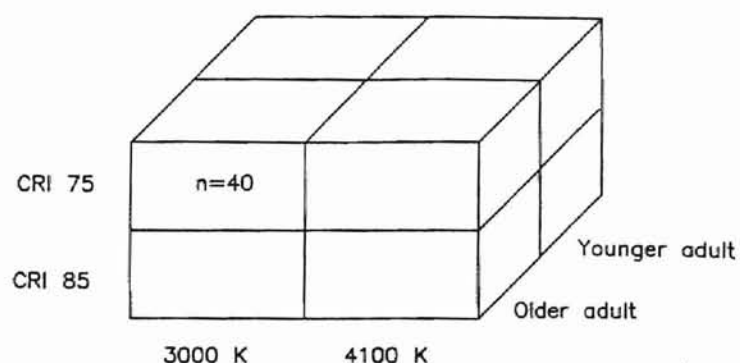


Figure 5. Schematic Diagram for Independent Variables

Dependent variables for this study were perceived visual comfort, lighting preference, value discrimination and color descriptors under different color temperatures and color rendering indices of the fluorescent lamps by the two age groups.

Data Collection

The data-collecting instrument for the purpose of this study was a self-administered questionnaire, presented in two parts. Part one is designed to obtain demographic (e.g., age, sex, educational status) and background information on each subject (e.g., wearing glasses or contacts) (see Appendix C). The second part entailed a series of questions developed by the researcher to assess lighting preference, visual comfort, value discrimination and color descriptors under different color rendering indices and color temperatures of the T8 fluorescent lamps (see Appendix D).

The questions involve six bipolar adjective pairs to describe lighting preference and visual comfort. Selection of the six adjective pairs was based on a list developed by Kasmar (1970) as descriptors to measure environmental settings. Eight-point Likert-type scales were used to differentiate between the bipolar adjective that include "healthy-unhealthy", "warm-cool", "too bright-too dim", "glaring-not glaring", "comfortable-uncomfortable", and "like-dislike".

Questions 2, 3 and 4 in part two were designed to determine the dependent variables of value discrimination and color descriptors under the specified lighting conditions. These questions relate to objective three. Questions 2 and 3 were developed by the researcher to evaluate value discrimination under the experimental lighting conditions. The value discrimination question was developed to identify the difficulty or ease of reading signs using an eight-point Likert-type scale.

Question 2 contained five "sale" signs written in black print on five different Munsell gray scale backgrounds ranging from white to dark gray (Munsell gray 9, 8, 6, 4, and 3) as illustrated in appendixes. Question 3 used same five signs written in white print upon a varied gray background from dark to white (Munsell gray 2, 3, 4, 6, and 8). To avoid the subjects repetition of sign text, a varied sale name and different number of percentage were used. The text sizes and font style for each sign were 8, 10 and 14 sizes with lower and upper case of Arial.

Question 4 in the questionnaire asked for color descriptors under the specified lighting conditions. The colors chosen were the five principal hues of Munsell's Chroma Chart: red (5R), yellow (5Y), green (5G), blue (5B), and purple (5P). Four terms are available for describing each hue, for example: red, yellowish-red, bluish-red, and other (specify). The order of choices moves in accord with Munsell's clockwise progression of colors. Both part one and part two of the questionnaire were pre-tested and adjustments were made before being administered to the research subjects.

In order to collect data, all subjects were scheduled by appointment. Seating thirty feet distant from the data collection cubicle was provided for subjects who arrived early and needed to wait. General illuminance of this area was 15 footcandles. The procedure of the experiment was explained and subjects were given the opportunity to ask questions. Signing of the Informed Consent was requested prior to testing along with answers to demographic questions. Then, all subjects were given the Ishihara Color Vision test and the Snellen Visual Acuity test in the Lighting Technology Laboratory of the opposite end of the room from the experimental lighting cubicles. A screen was placed between the subjects and the cubicles (See Figure 6).

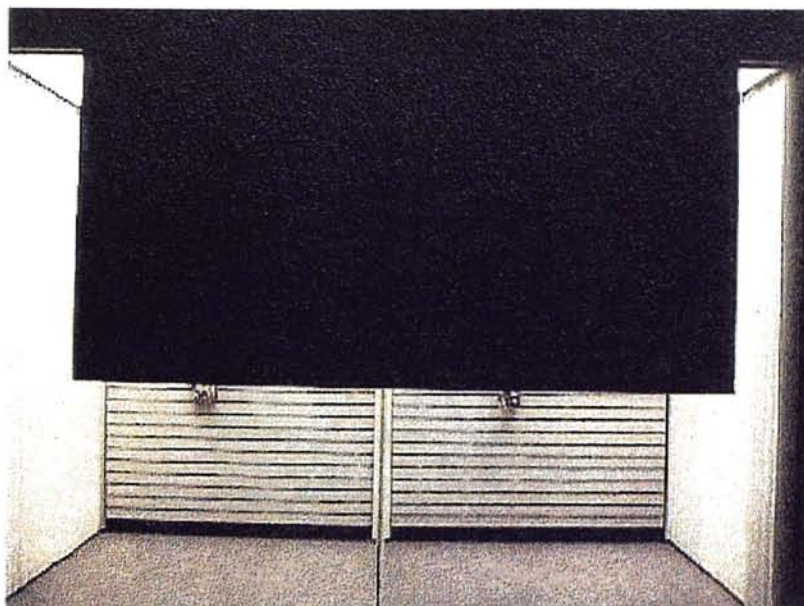


Figure 6. Photo: Screen

After the eye test, each subject received the four pages of questions to be answered during the test. Verbal guidance accompanied the written instructions printed on each page.

All subjects received the same test instrument, however, the sequence for administering each of the lighting conditions was randomized. Administration of the test was repeated in the same manner for each subject. Each subject experienced all four different lighting conditions (730, 741, 830, and 841). There was only one subject completing the questionnaire in the cubicle at a time (see Figure 7, page 32). Lights were turned on after the subject entered the cubicle. The average length of time approximated for each subject to complete the four pages was ten minutes in each lighting condition. Each subject was seated in the waiting area of the Lighting Laboratory and given at least 2 minutes to rest their eyes before viewing the next lighting condition. To control for the influence of daylight, data were collected between 5:00 p.m. and 8:00 p.m. from March 6 through April 4, 1998. When cloudy conditions provided limited daylight, the data collection times were expanded.

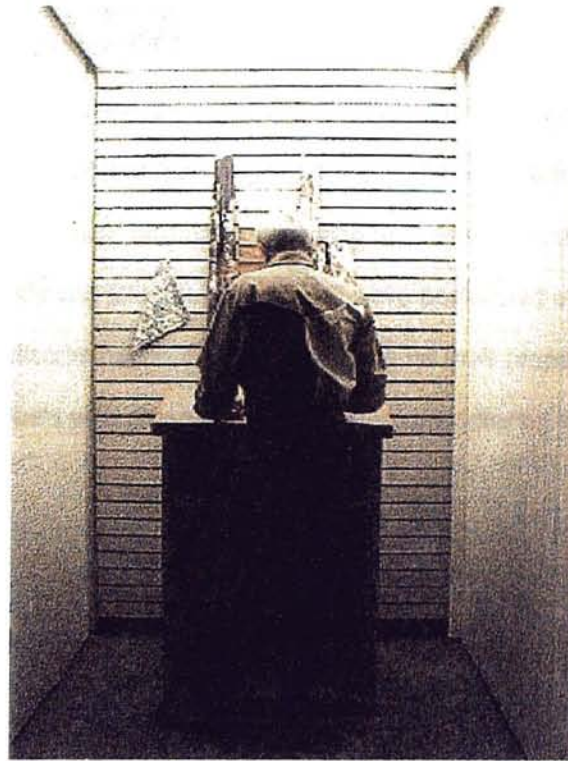


Figure 7. Photo: Subject

Data Analysis

All data collected from the questionnaire were tabulated, coded, and statistically analyzed a manner designed to identify a list of evaluative criteria. Frequencies and percentages were calculated for the respondents and provided criteria factor rankings, demographic data of the respondents, and related issues. This information enabled the researcher to make general observations concerning the sample experimented.

Descriptive statistics such as frequency, percents and measures of central tendency were reported. The data were analyzed using a $2 \times 2 \times 2$ mixed Analysis of variance (ANOVA) with one between subject factor and two within subject factors (Keppel, 1991). Factor A consists of two different groups of age: younger adults (between 20 and 30 years old) and older adults (over 65 years old). Factor B consists of two levels of color temperature, one is lower color temperature (3000 K) and the other is higher color temperature (4100 K). Factor C consists of

two levels of color rendering index (CRI), one is lower color rendering index (75 CRI) and the other is higher color rendering index (85 CRI). Factor A with each participant in each of the age groups was used as between subject factor and factor B and C with four evaluations for the combinations of color temperatures and color rendering indices were used as within subject factors. Categorical analysis and Chi-square analysis were performed on the subjects' preferences for the value discrimination of printed phrases on their respective backgrounds and color descriptors of individuals with different age groups under different lighting conditions.

CHAPTER IV

FINDINGS AND DISCUSSION

Introduction

The findings, discussion and conclusions, implications and recommendations for future studies from the study are presented in this chapter. The research data are organized into two sections. The first section describes the characteristics of the respondents. Background information from on the subjects is reported first under the heading characteristics of the sample. Background information includes subject's age, sex, educational level, and use of glasses or contacts. The second section presents the findings from the testing of the eight hypotheses and their respective subsections. Findings from study hypotheses are reported under the heading called "Tests of Hypotheses and Findings".

Characteristics of the Sample

The sample consisted of eighty volunteers; 40 subjects in the younger adult group (between 20 and 30 years old) and 40 subjects in the older adult group (over 65 years old). The forty subjects in the younger adult group included 22 males (27.5% of the total 80 subjects) and 18 females (22.5% of the total 80 subjects). The forty subjects in the older adult group included 10 males (12.5% of the total 80 subjects) and 30 females (37.5% of the total 80 subjects). To establish a minimum basic education level, all subjects had at least completed high school. The frequency distribution table shows the general characteristics of the respondents in each of the groups tested (see Table 1, page 35).

Thirty of the younger adults (37.5% of the total 80 subjects) and 39 of the older adults (48.75% of the total 80 subjects) usually wear glasses or contacts for visual correction. Ten of the younger adults (12.5% of the total 80 subjects) and one of the older adults (1.25% of the

Table 1

Characteristics of Respondents

Characteristics	Younger Adults		Older Adults	
	Frequency	Percent(%)	Frequency	Percent(%)
Age				
20-30 years	40	100		
65 and older			40	100
Total	40	100	40	100
Gender				
Male:	22	27.5	10	12.5
Female:	18	22.5	30	37.5
Total	40	100	40	100
Educational level				
Not completed high school	0	0	0	0
Completed high school	40	100	40	100
Total	40	100	40	100
Use glasses or contacts¹				
Needed:	30	37.5	39	48.75
Not needed:	10	12.5	1	1.25
Total	40	100	40	100

¹ All older subjects who needed glasses or contacts were wearing them at the time of the study. Two young subjects who needed glasses or contacts were not wearing them at the time they were subjects.

total 80 subjects) did not require glasses or contacts for visual correction. To control the potential influence of visual impairment, all subjects were evaluated by the researchers using the Ishihara Color Vision test and the Snellen Visual Acuity test. One man from the older adult group was identified as being partially color blind and was removed from the study sample. One additional subject was selected to replace the partially color blind subject. Thus, all 80 subjects met the visual acuity requirements for participation in the study.

Tests of Hypotheses and Findings

The remainder of this chapter discusses tests of hypotheses and findings based on the research hypotheses outlined in Chapter One. The data were analyzed using a $2 \times 2 \times 2$ mixed Analysis of variance (ANOVA) with one between subject factor (age group) and two within subject factors (color rendering index and color temperature). To evaluate the relationships that exist in subjects' perceptions of visual appearance of skin as healthy or unhealthy (Hypothesis 1), subjects' perceptions of appearance as being warm or cool (Hypothesis 2), subjects' perceptions of luminance as being too bright or too dim (Hypothesis 3), subjects' perceptions of glare or non-glare of light (Hypothesis 4), visual comfort (Hypothesis 5), and lighting preferences (Hypothesis 6) of individuals by age under different lighting conditions, an Analysis of Variance was utilized for data analysis of the study variables. The ease of reading each of the five value contrast phrases (Hypothesis 7) under different lighting conditions was analyzed using ANOVA. Each participant in each of the age groups was asked to give four evaluations for the combinations of color temperatures and color rendering indices. The analysis was performed as a repeated measure design with participants in the main unit and their evaluations of the four combinations analyzed as a split unit. Because no significant three-way (Age by K by CRI) interaction was obtained among eight hypotheses, decisions to reject or not reject each hypothesis were made on the basis of main effects and two-way interactions.

Categorical analysis was performed on the subjects' preferences for the value discrimination of printed phrases on their respective backgrounds and color descriptors of individuals with different age groups under different lighting conditions. However, there were no significant three-way (age by K by CRI) or two-way (age by K, age by CRI, and CRI by K) interactions. Therefore Chi-square analysis was performed based on main effects (age, K and CRI). An alpha level of .05 was used to determine statistical significance. The selection of an alpha level of .05 is appropriate because this value indicates .95 (95%) of the variation is explained by the variables tested and only .05 (5%) of the variation in individuals responses is not explained by the manipulation of the variables tested.

Hypothesis 1

For the purpose of statistical testing, the first hypothesis for this study is stated in the null form:

Hypothesis 1. There is no difference in subjects' perception of visual appearance of skin as being healthy or unhealthy with regard to

- a) age (young and old)
- b) color rendering index of fluorescent light (75 CRI and 85 CRI)
- c) color temperatures of fluorescent light (3000 K and 4100 K)
- d) two-way interaction of CRI by K
- e) two-way interaction of age by CRI
- f) two-way interaction of age by K
- g) three-way interaction of age by CRI by K

Responses using bipolar adjectives, "healthy or unhealthy," and the eight-point Likert-type scale were used to assess the subjects' perceptions of visual appearance of skin as being healthy or unhealthy. Table 2 on page 38 illustrates the mean and standard deviation scores of individuals by age under different lighting conditions (730, 741, 830, and 841).

Analysis of variance was applied to the bipolar adjective pair of healthy/unhealthy to determine if the subjects' feelings of preference differed for the four lighting conditions. Table 3 on page 39 illustrates the results of the analysis. A significant main effect for color temperatures (K) was found, $F(1,234) = 6.56$, $p = .011$. The results of the subjects' responses to the perceived appearance of their skin show that the two color temperatures are significantly different between 3000 K and 4100 K regardless of the age groups. All participants perceived that their skin looked healthier under the higher (4100 K) than under the lower (3000 K) color temperature of light. Therefore, the Hypothesis 1c was rejected.

There was no significant difference regarding to the main effects of age groups (young and old) and color rendering indices of fluorescent light (75 CRI and 85 CRI). Therefore, the Hypotheses 1a and 1b were not rejected. No significant difference resulted on two-way and

Table 2

Mean and SD Scores for Subjects' Perception of Visual Appearance of Skin as Being Healthy or Unhealthy¹

Source	n	Mean	SD
Age group			
Younger (20-30)	160	3.12	1.80
Older (65 and Older)	160	2.74	1.84
Color Rendering Index			
75 CRI	160	2.94	1.86
85 CRI	160	2.91	1.79
Color Temperatures (K)			
3000 K	160	3.16	1.97
4100 K	160	2.69	1.64
Age by CRI			
Younger x 75 CRI	80	2.98	1.80
Younger x 85 CRI	80	3.26	1.80
Older x 75 CRI	80	2.91	1.94
Older x 85CRI	80	2.56	1.73
Age by K			
Younger x 3000 K	80	3.25	1.89
Younger x 4100 K	80	2.99	1.70
Older x 3000 K	80	3.08	2.05
Older x 4100 K	80	2.40	1.53
CRI by K			
75 CRI x 3000 K	80	3.19	2.02
75 CRI x 4100 K	80	2.70	1.68
85 CRI x 3000 K	80	3.14	1.94
85 CRI x 4100 K	80	2.69	1.61
Age by CRI x K			
Younger x 75 CRI x 3000 K	40	3.25	1.97
Younger x 75 CRI x 4100 K	40	2.70	1.59
Younger x 85 CRI x 3000 K	40	3.25	1.84
Younger x 85 CRI x 4100 K	40	3.28	1.77
Older x 75 CRI x 3000 K	40	3.13	2.09
Older x 75 CRI x 4100 K	40	2.70	2.77
Older x 85 CRI x 3000 K	40	3.03	2.04
Older x 85 CRI x 4100 K	40	2.10	1.19

1. 8 point Likert-type scale with 1 being healthy in appearance and 8 being unhealthy in appearance

Table 3

ANOVA of Age, CRI, and K for Subjects' Perception of Visual Appearance of Skin as Being Healthy or Unhealthy

Source	df	SS	MS	F	p
Age	1	11.63	11.63	2.34	0.1303
Between Error	78	387.97	4.97		
CRI	1	0.08	0.08	0.03	0.8645
K	1	17.58	17.58	6.56	0.0110 *
CRI by K	1	0.03	0.03	0.01	0.9185
Age by CRI	1	8.13	8.13	3.03	0.0828
Age by K	1	3.40	3.40	1.27	0.2608
Age by CRI by K	1	5.78	5.79	2.16	0.1432
Within Error	234	626.76	2.68		

* Indicates significance at $p < .05$

three-way interactions of age groups, color rendering indices, and color temperatures. Thus, the Hypotheses 1d, 1e, 1f, and 1g were not rejected.

Hypothesis 2

Hypothesis 2 was stated in the null form for statistical testing as follows:

Hypothesis 2. There is no difference in subjects' perception of appearance as being warm or cool with regard to

- a) age (young and old)
- b) color rendering index of fluorescent light (75 CRI and 85 CRI)
- c) color temperatures of fluorescent light (3000 K and 4100 K)
- d) two-way interaction of CRI by K
- e) two-way interaction of age by CRI
- f) two-way interaction of age by K
- g) three-way interaction of age by CRI by K

Responses using bipolar adjectives, "warm and cool," and the eight-point Likert-type scale were used to assess the subjects' perceptions of appearance as being warm or cool. Table 4 on page 41 illustrates the mean and standard deviation scores of individuals by age under different lighting conditions (730, 741, 830, and 841).

Results of the analysis of variance (ANOVA) are summarized in Table 5 on page 42. Although two main effects (age groups and K) reached statistical significance, they were of little interest because a significant two-way (age groups x color temperatures) interaction was obtained with a calculated $F(1,234) = 7.71, p = .005$. Therefore, the Hypothesis 2f was rejected. To assess the significance of such a finding, analysis of the simple effects was conducted. The outcomes are presented in Figure 8 and Table 6 on page 43. The younger adults' perception was significantly different from the older adults (4.86 vs. 3.69) for the higher color temperature (4100 K), whereas the younger adults' perception of the lower color temperature (3000 K) was not significantly different (2.84 vs. 2.66) from the older adults. The younger adults perceived the lighted area as being cooler under 4100 K than the older adults.

Table 4

Mean and SD Scores for Subjects' Perception of Lighting Appearance as Being Warm or Cool¹

Source	n	Mean	SD
Age group			
Younger (20-30)	160	3.85	2.05
Older (65 and Older)	160	3.18	1.80
Color Rendering Index			
75 CRI	160	3.49	1.86
85 CRI	160	3.53	2.05
Color Temperatures (K)			
3000 K	160	2.75	1.58
4100 K	160	4.28	2.00
Age by CRI			
Younger x 75 CRI	80	3.68	1.97
Younger x 85 CRI	80	4.03	2.12
Older x 75 CRI	80	3.31	1.74
Older x 85 CRI	80	3.04	1.87
Age by K			
Younger x 3000 K	80	2.84	1.50
Younger x 4100 K	80	4.86	2.03
Older x 3000 K	80	2.66	1.69
Older x 4100 K	80	3.69	1.80
CRI by K			
75 CRI x 3000 K	80	2.90	1.72
75 CRI x 4100 K	80	4.09	1.82
85 CRI x 3000 K	80	2.60	1.43
85 CRI x 4100 K	80	4.47	2.16
Age by CRI x K			
Younger x 75 CRI x 3000 K	40	4.48	1.50
Younger x 75 CRI x 4100 K	40	3.83	1.34
Younger x 85 CRI x 3000 K	40	3.93	1.46
Younger x 85 CRI x 4100 K	40	3.95	1.48
Older x 75 CRI x 3000 K	40	3.78	1.31
Older x 75 CRI x 4100 K	40	3.90	0.90
Older x 85 CRI x 3000 K	40	3.55	1.36
Older x 85 CRI x 4100 K	40	3.73	1.04

1. 8 point Likert-type scale with 1 being warm in lighting appearance and 8 being cool in lighting appearance

Table 5

ANOVA of Age, CRI, and K for Subjects' Perception of Visual Appearance as Being Warm or Cool

Source	df	SS	MS	F	p
Age	1	36.45	36.45	8.19	0.0054 **
Between Error	78	347.00	4.45		
CRI	1	0.11	0.11	0.04	0.8352
K	1	186.05	186.05	71.75	0.0001 ***
CRI by K	1	9.11	9.11	3.51	0.0621
Age by CRI	1	7.81	7.81	3.01	0.0839
Age by K	1	20.00	20.00	7.71	0.0059 **
Age by CRI by K	1	6.61	6.61	2.55	0.1116
Within Error	234	606.80	2.59		

** Indicates significance at $p < .01$ *** Indicates significance at $p < .001$

Figure 8. Interaction (Age x K) Effects in Relation to Subjects' Perceived Warmness or Coolness of Light

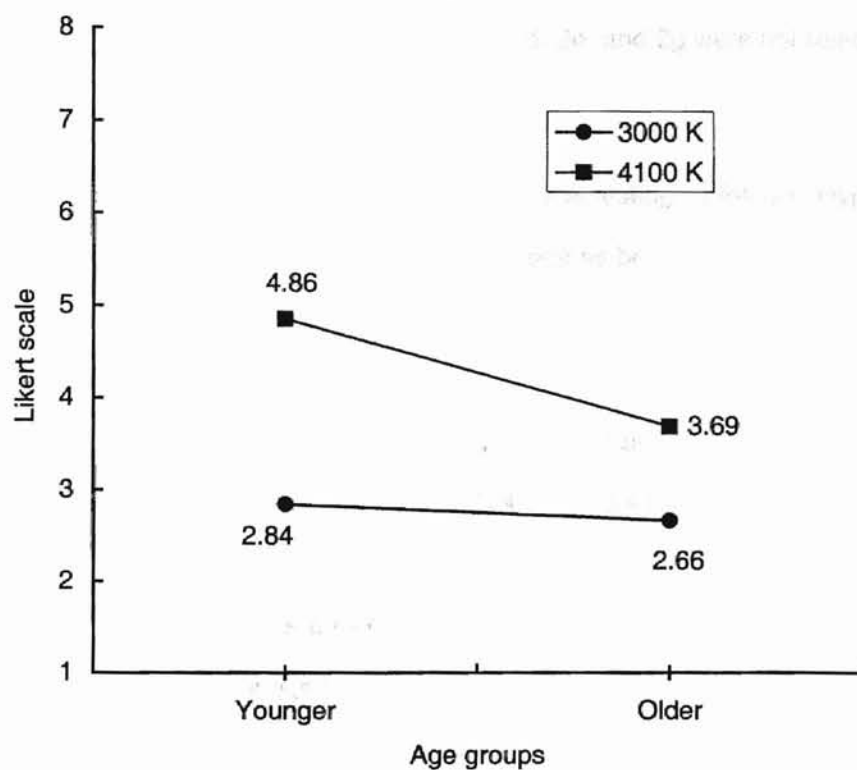


Table 6.

Analysis of Simple Effects (Age x K) in Relation to Subjects' Perceived Warmness or Coolness of Light

Comparison	df	MS	F	p
Line 1 (3000 K)	1	2.450	0.348	0.5627
Line 2 (4100 K)	1	110.450	15.685	0.0002 *

* Indicates significance at $p < .05$

Color rendering indices (CRI) as a main effect was not significant ($p > .05$). Age by CRI and CRI by K as a two-way interaction and age by CRI by K as a three-way interaction were not significant at the $p = .05$. Therefore, Hypotheses 2b, 2d, 2e, and 2g were not rejected.

Hypothesis 3

Hypothesis 3 was stated in the null form for statistical testing as follows: Hypothesis 3. There is no difference in subjects' perception of luminance as being too bright or too dim with regard to

- a) age (young and old)
- b) color rendering Indices of fluorescent light (75 CRI and 85 CRI)
- c) color temperatures of fluorescent light (3000 K and 4100 K)
- d) two-way interaction of CRI by K
- e) two-way interaction of age by CRI
- f) two-way interaction of age by K
- g) three-way interaction of age by CRI by K

Responses using bipolar adjectives, "too bright or too dim," and the eight-point Likert-type scale were used to assess subjects' perception of luminance as being too bright or too dim under four different lighting conditions. The illuminance of each cubicle was recorded as 50 footcandles on the surface of the podium (see Figure 4, page 27). Table 7 on page 45 illustrates the mean and standard deviation scores of individuals by age under different lighting conditions (730, 741, 830, and 841).

Results of the analysis of variance (ANOVA) are summarized in Table 8 on page 46. No interactions were indicated for brightness on CRI by K, age by CRI, age by K, or age by CRI by K. For age, CRI, and K, no main effects were indicated. Therefore, Hypothesis 3 was not rejected. Age groups however, approached significance at $p = .07$ with an F ratio of 3.27.

Table 7

Mean and SD Scores for Subjects' Perception of Luminance as Being Too Bright or Too Dim¹

Source	n	Mean	SD
Age group			
Younger (20-30)	160	4.04	1.46
Older (65 and Older)	160	3.74	1.16
Color Rendering Index			
75 CRI	160	4.00	1.30
85 CRI	160	3.79	1.34
Color Temperatures (K)			
3000 K	160	3.93	1.44
4100 K	160	3.85	1.20
Age by CRI			
Younger x 75 CRI	80	4.15	1.45
Younger x 85 CRI	80	3.94	1.46
Older x 75 CRI	80	3.84	1.19
Older x 85 CRI	80	3.64	1.20
Age by K			
Younger x 3000 K	80	4.20	1.50
Younger x 4100 K	80	3.89	1.41
Older x 3000 K	80	3.66	1.33
Older x 4100 K	80	3.81	0.97
CRI by K			
75 CRI x 3000 K	80	4.13	1.44
75 CRI x 4100 K	80	3.86	1.13
85 CRI x 3000 K	80	3.74	1.41
85 CRI x 4100 K	80	3.84	1.28
Age by CRI x K			
Younger x 75 CRI x 3000 K	40	4.48	1.50
Younger x 75 CRI x 4100 K	40	3.83	1.34
Younger x 85 CRI x 3000 K	40	3.93	1.46
Younger x 85 CRI x 4100 K	40	3.95	1.48
Older x 75 CRI x 3000 K	40	3.78	1.31
Older x 75 CRI x 4100 K	40	3.90	0.90
Older x 85 CRI x 3000 K	40	3.55	1.36
Older x 85 CRI x 4100 K	40	3.73	1.04

1. 8 point Likert-type scale with 1 being too bright in appearance and 8 being too dim in appearance

Table 8

ANOVA of Age, CRI, and K for Subjects' Perception of Luminance as Being Too Bright or Too Dim

Source	df	SS	MS	F	p
Age	1	7.50	7.50	3.27	0.0744
Between Error	78	178.92	2.29		
CRI	1	3.40	3.40	2.21	0.1383
K	1	0.53	0.53	0.34	0.5585
CRI by K	1	2.63	2.63	1.71	0.1925
Age by CRI	1	0.00	0.00	0.00	0.9641
Age by K	1	4.28	4.28	2.78	0.0967
Age by CRI by K	1	1.95	1.95	1.27	0.2610
Within Error	234	359.96	1.54		

* Indicates significance at $p < .05$

Hypothesis 4

Hypothesis 4 was stated in the null form for statistical testing as follows: Hypothesis 4.

There is no difference in subjects' perceptions of glare or non-glare of lights with regard to

- a) age (young and old)
- b) color rendering Indices of fluorescent light (75 CRI and 85 CRI)
- c) color temperatures of fluorescent light (3000 K and 4100 K)
- d) two-way interaction of CRI by K
- e) two-way interaction of age by CRI
- f) two-way interaction of age by K
- g) three-way interaction of age by CRI by K

Responses using bipolar adjectives, "glaring or not glaring," and the eight-point Likert-type scale were used to assess subjects' perceptions of glare or non-glare of lights under four different lighting conditions. Table 9 on page 48 illustrates the mean and standard deviation scores of individuals by age under different lighting conditions (730, 741, 830, and 841).

Results of the analysis of variance (ANOVA) are summarized in Table 10 on page 49. Although the main effect of color rendering indices (CRI) reached statistical significance, it was of little interest because a significant two-way (color rendering indices x color temperatures) interaction was obtained at $p = .02$ with an F ratio of 5.47. Therefore, the Hypothesis 4d was rejected. To assess the significance of such a finding, analysis of the simple effects was conducted. The outcomes are presented in Figure 9 and Table 11 on page 50. There was a significant difference between 75 CRI and 85 CRI with 3000 K (4.91 vs. 4.03) but no difference between 75 CRI and 85 CRI with 4100 K (4.69 vs. 4.73). Both the younger and older adults perceived the lighted area to have less glare under 730 light than 830 light.

Age group and color temperature as a main effect was not significant at the $p = .05$ level. There were no age by CRI and age by K as a two-way interaction and age by CRI by K as a three-way interaction. Therefore, the Hypotheses 4a, 4c, 4d, 4e, 4f, and 4g were not rejected.

Table 9

Mean and SD Scores for Subjects' Perception of Glare¹

Source	n	Mean	SD
Age group			
Younger (20-30)	160	4.46	1.78
Older (65 and Older)	160	4.71	1.97
Color Rendering Index			
75 CRI	160	4.80	1.82
85 CRI	160	4.38	1.92
Color Temperatures (K)			
3000 K	160	4.47	1.92
4100 K	160	4.71	1.84
Age by CRI			
Younger x 75 CRI	80	4.70	1.70
Younger x 85 CRI	80	4.23	1.83
Older x 75 CRI ¹	80	4.90	1.93
Older x 85CRI	80	4.53	2.00
Age by K			
Younger x 3000 K	80	4.46	1.74
Younger x 4100 K	80	4.46	1.83
Older x 3000 K	80	4.47	2.09
Older x 4100 K	80	4.95	1.83
CRI by K			
75 CRI x 3000 K	80	4.91	1.80
75 CRI x 4100 K	80	4.69	1.85
85 CRI x 3000 K	80	4.03	1.94
85 CRI x 4100 K	80	4.73	1.84
Age by CRI x K			
Younger x 75 CRI x 3000 K	40	4.88	1.62
Younger x 75 CRI x 4100 K	40	4.53	1.78
Younger x 85 CRI x 3000 K	40	4.05	1.78
Younger x 85 CRI x 4100 K	40	4.40	1.89
Older x 75 CRI x 3000 K	40	4.95	1.97
Older x 75 CRI x 4100 K	40	4.85	1.92
Older x 85 CRI x 3000 K	40	4.00	2.11
Older x 85 CRI x 4100 K	40	5.05	1.75

1. 8 point Likert-type scale with 1 being glaring in appearance and 8 being not glaring in appearance

Table 10

ANOVA of Age, CRI, and K for Subjects' Perception of Glare

Source	df	SS	MS	F	p
Age	1	5.00	5.00	1.13	0.2917
Between Error	78	346.05	4.44		
CRI	1	14.45	14.45	4.61	0.0327 *
K	1	4.51	4.51	1.44	0.2312
CRI by K	1	17.11	17.11	5.47	0.0202 *
Age by CRI	1	0.20	0.20	0.06	0.8007
Age by K	1	4.51	4.51	1.44	0.2312
Age by CRI by K	1	1.01	1.01	0.32	0.5701
Within Error	234	732.70	3.13		

* Indicates significance at $p < .05$

Figure 9. Interaction (CRI x K) Effects in Relation to Subjects' Perception of Glare or Nonglare of Lights

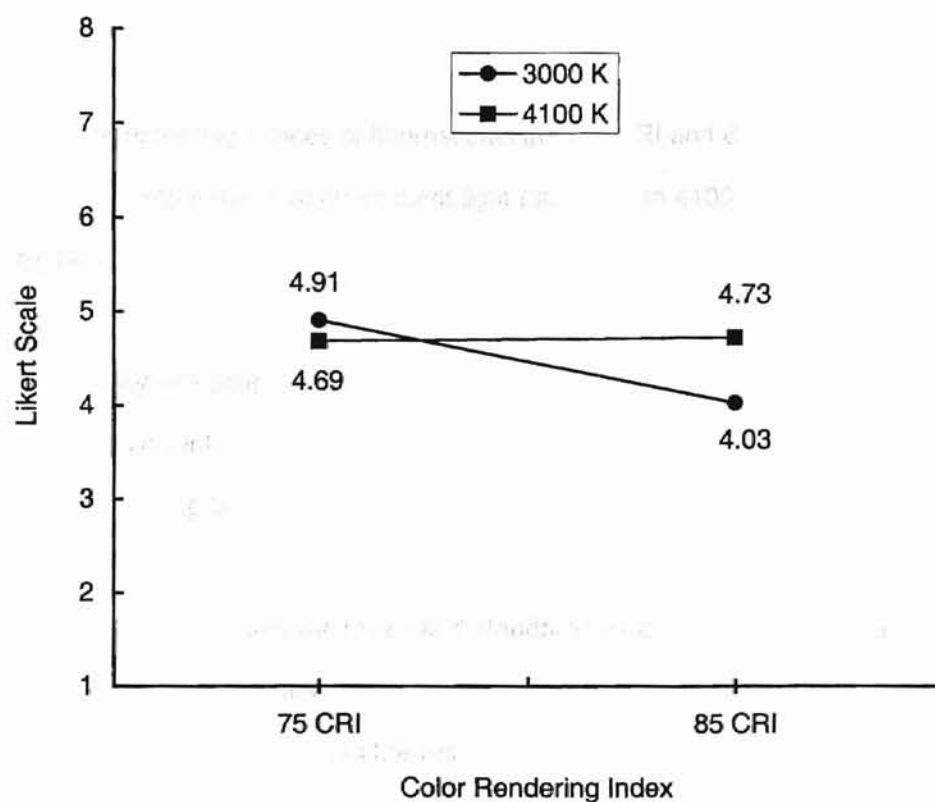


Table 11.

Analysis of Simple Effects (CRI x K) in Relation to Subjects' Perception of Glare or Nonglare of Lights

Comparison	df	MS	F	p
Line 1 (3000 K)	1	13.806	4.409	0.0343 *
Line 2 (4100 K)	1	0.056	0.018	0.8891

* Indicates significance at $p < .05$

Hypothesis 5

Hypothesis 5 was stated in the null form for statistical testing as follows:

Hypothesis 5. There is no difference in visual comfort with regard to

- a) age (young and old)
- b) color rendering Indices of fluorescent light (75 CRI and 85 CRI)
- c) color temperatures of fluorescent light (3000 K and 4100 K)
- d) two-way interaction of CRI by K
- e) two-way interaction of age by CRI
- f) two-way interaction of age by K
- g) three-way interaction of age by CRI by K

Responses using bipolar adjectives, "comfortable or uncomfortable," and the eight-point Likert-type scale were used to assess visual comfort under four different lighting conditions. Table 12 on page 52 illustrates the mean and standard deviation scores of individuals by age under different lighting conditions (730, 741, 830, and 841).

Table 13 on page 53 illustrates the results of analysis of variance (ANOVA) for subjects' visual comfort in different lighting conditions. Age group as a main effect was significant at $p = .047$ with calculated $F(1,78) = 6.17$. The older adults perceived visually less comfort than the younger adults in all lighting conditions. Therefore, Hypothesis 5a was rejected. Regarding color temperatures (K) as a main effect, there was statistical significance at $p = .006$ with an F ratio of 7.51. Both the younger and older adults responded that they are visually more comfortable under 4100 K than under 3000 K. Thus, the Hypothesis 5c was rejected. Color rendering index (CRI) as a main effect was not significant ($p > .3$) for this question. No interactions were indicated for visual comfort on CRI by K, age by CRI, age by K, or age by CRI by K. Therefore, the Hypotheses 5b, 5d, 5e, 5f, and 5g were not rejected.

Table 12

Mean and SD Scores for Subjects' Perception of Visual Comfort as Being Comfortable or Uncomfortable¹

Source	n	Mean	SD
Age group			
Younger (20-30)	160	3.84	1.79
Older (65 and Older)	160	3.35	1.96
Color Rendering Index			
75 CRI	160	3.50	1.86
85 CRI	160	3.70	1.93
Color Temperatures (K)			
3000 K	160	3.86	1.98
4100 K	160	3.33	1.75
Age by CRI			
Younger x 75 CRI	80	3.65	1.72
Younger x 85 CRI	80	4.03	1.84
Older x 75 CRI	80	3.34	1.97
Older x 85 CRI	80	3.36	1.96
Age by K			
Younger x 3000 K	80	4.10	1.78
Younger x 4100 K	80	3.58	1.76
Older x 3000 K	80	3.63	2.15
Older x 4100 K	80	3.08	1.72
CRI by K			
75 CRI x 3000 K	80	3.68	1.93
75 CRI x 4100 K	80	3.31	1.77
85 CRI x 3000 K	80	4.05	2.03
85 CRI x 4100 K	80	3.34	1.75
Age by CRI x K			
Younger x 75 CRI x 3000 K	40	3.88	1.70
Younger x 75 CRI x 4100 K	40	3.43	1.74
Younger x 85 CRI x 3000 K	40	3.33	1.86
Younger x 85 CRI x 4100 K	40	3.73	1.80
Older x 75 CRI x 3000 K	40	3.48	2.14
Older x 75 CRI x 4100 K	40	3.20	1.81
Older x 85 CRI x 3000 K	40	3.76	2.18
Older x 85 CRI x 4100 K	40	2.95	1.63

1. 8 point Likert-type scale with 1 being comfortable in appearance and 8 being uncomfortable in appearance

Table 13

ANOVA of Age, CRI, and K for Subjects' Perception of Visual Comfort as Being Comfortable or Uncomfortable

Source	df	SS	MS	F	p
Age	1	19.01	19.01	4.06	0.0475 *
Between Error	78	365.68	4.69		
CRI	1	3.20	3.20	1.04	0.3090
K	1	23.11	23.11	7.51	0.0066 **
CRI by K	1	2.45	2.45	0.80	0.3733
Age by CRI	1	2.45	2.45	0.80	0.3733
Age by K	1	0.01	0.01	0.00	0.9493
Age by CRI by K	1	0.80	0.80	0.26	0.6107
Within Error	234	720.48	3.08		

* Indicates significance at $p < .05$ ** Indicates significance at $p < .01$

Hypothesis 6

Hypothesis 6 was stated in the null form for statistical testing as follows: Hypothesis 6.

There is no difference in lighting preference with regard to

- a) age (young and old)
- b) color rendering index of fluorescent light (75 CRI and 85 CRI)
- c) color temperatures of fluorescent light (3000 K and 4100 K)
- d) two-way interaction of CRI by K
- e) two-way interaction of age by CRI
- f) two-way interaction of age by K
- g) three-way interaction of age by CRI by K

Responses using bipolar adjectives, "like or dislike," and the eight-point Likert-type scale were used to assess lighting preference. Table 14 on page 55 illustrates the mean and standard deviation scores of individuals by age under different lighting conditions (730, 741, 830, and 841).

Table 15 on page 56 illustrates the results of analysis of variance (ANOVA) for subjects' preferences for like or dislike of lighting conditions. Age groups as a main effect were significant at $F(1,78) = 4.16$, $p = .044$. Generally, the older adults prefer all four lighting conditions more than the younger adults do. Color temperature (K) as a main effect was also significant with an $F(1,234) = 1.39$, $p = .0009$. Both the younger and older adults preferred 4100 K better than 3000 K. Therefore, the Hypotheses 6a and 6c were rejected.

There was no significant difference in lighting preferences with regard to the color rendering index (CRI) of fluorescent light. Thus, the Hypothesis 6b was not rejected. CRI by K, age by CRI, and age by K as a two-way interaction and CRI by K by age as a three-way interaction were not significant for the lighting preference. Therefore, the Hypotheses 6d, 6e, 6f, and 6g were not rejected.

Table 14

Mean and SD Scores for Subjects' Preference for Liking or Disliking of Lighting Conditions¹

Source	n	Mean	SD
Age group			
Younger (20-30)	160	3.61	1.73
Older (65 and Older)	160	3.17	1.86
Color Rendering Index			
75 CRI	160	3.24	1.75
85 CRI	160	3.54	1.85
Color Temperatures (K)			
3000 K	160	3.71	1.86
4100 K	160	3.07	1.70
Age by CRI			
Younger x 75 CRI	80	3.41	1.72
Younger x 85 CRI	80	3.81	1.73
Older x 75 CRI	80	3.06	1.78
Older x 85 CRI	80	3.28	1.94
Age by K			
Younger x 3000 K	80	3.91	1.66
Younger x 4100 K	80	3.31	1.75
Older x 3000 K	80	3.51	2.04
Older x 4100 K	80	2.83	1.61
CRI by K			
75 CRI x 3000 K	80	3.50	1.82
75 CRI x 4100 K	80	2.98	1.65
85 CRI x 3000 K	80	3.93	1.89
85 CRI x 4100 K	80	3.16	1.74
Age by CRI x K			
Younger x 75 CRI x 3000 K	40	3.80	1.65
Younger x 75 CRI x 4100 K	40	3.03	1.72
Younger x 85 CRI x 3000 K	40	4.03	1.69
Younger x 85 CRI x 4100 K	40	3.60	1.77
Older x 75 CRI x 3000 K	40	3.20	1.95
Older x 75 CRI x 4100 K	40	2.93	1.61
Older x 85 CRI x 3000 K	40	3.83	2.10
Older x 85 CRI x 4100 K	40	2.73	1.62

1. 8 point Likert-type scale with 1 being like in appearance and 8 being dislike in appearance

Table 15

ANOVA of Age, CRI, and K of Subjects' Preference for Liking or Disliking of Lighting Conditions

Source	df	SS	MS	F	p
Age	1	15.75	15.75	4.16	0.0449 *
Between Error	78	295.67	3.79		
CRI	1	7.50	7.50	2.58	0.1097
K	1	33.15	33.15	11.39	0.0009 ***
CRI by K	1	1.128	1.13	0.39	0.5342
Age by CRI	1	0.70	0.70	0.24	0.6236
Age by K	1	0.15	0.15	0.05	0.8188
Age by CRI by K	1	6.90	6.90	2.37	0.1249
Within Error	234	681.21	2.91		

* Indicates significance at $p < .05$ *** Indicates significance at $p < .001$

Hypothesis 7

Hypothesis 7 was stated in the null form for statistical testing as follows: Hypothesis 7.

There is no difference in the ability to discriminate value with regard to

- a) age (young and old)
- b) color rendering indices of fluorescent light (75 CRI and 85 CRI)
- c) color temperatures of fluorescent light (3000 K and 4100 K)
- d) two-way interaction of CRI by K
- e) two-way interaction of age by CRI
- f) two-way interaction of age by K
- g) three-way interaction of age by CRI by K

Questions two and three were used to test this hypothesis. To investigate the difference in readability to discriminate value, two sign sets (10 signs) of the Munsell gray scale were used. One sign set included five "sale" signs written in black print on five different Munsell gray scale backgrounds ranging from white to dark gray (Munsell gray scale 9, 8, 6, 4 and 3). The other sign set included the same five "sale" signs written in white print on five different Munsell gray scale backgrounds ranging from dark to white gray (Munsell gray scale 2, 3, 4, 6 and 8).

Table 16 on page 58 illustrates the mean and standard deviation scores of responses to value discrimination for the first set (black letters on five gray scale backgrounds). Analysis of variance was calculated for visual discrimination on the independent variables. Results of the analysis are summarized in Table 17 on page 59.

No interactions were indicated statistical significance for value discrimination of this set on CRI by K, age by CRI, age by K, or age by CRI by K. Therefore, the Hypotheses 7d, 7e, 7f, 7g were not rejected. For age and K, no main effects were indicated significant differences on this set (five signs). Thus, the Hypotheses 7a and 7c were not rejected. However, Munsell 8 approached significance at $p = .07$ for age groups as a main effect and Munsell 4 approached significance at $p = .057$ for color temperatures as a main effect.

Color rendering index as a main effect was significant on Munsell 6, 4 and 3 gray scale backgrounds as indicated in Table 17. Calculated F-values were, Munsell 6; $F(1,234) = 4.04$, p

Table 16

Mean and SD Scores for Responses to Value Discrimination (black letters on Munsell gray scale backgrounds)¹

Condition	Lighting Conditions							
	730		830		741		841	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Munsell 9								
Younger: 20-30	1.73	1.15	1.83	1.45	1.73	1.06	1.63	0.81
Older: 65 and older	1.63	1.23	1.48	0.99	1.50	0.91	1.55	1.06
Munsell 8								
Younger: 20-30	2.23	1.12	2.05	1.06	1.93	1.05	1.96	0.89
Older: 65 and older	1.73	1.06	1.75	1.19	1.70	0.82	1.70	0.85
Munsell 6								
Younger: 20-30	3.15	1.33	3.23	1.42	3.20	1.32	3.05	1.40
Older: 65 and older	3.13	1.65	2.95	1.68	3.03	1.51	2.58	1.41
Munsell 4								
Younger: 20-30	4.63	1.72	4.45	1.88	4.53	1.77	4.23	1.87
Older: 65 and older	4.75	1.86	4.38	1.78	4.55	2.02	4.13	1.95
Munsell 3								
Younger: 20-30	5.88	1.73	5.63	1.84	5.83	1.97	5.50	2.11
Older: 65 and older	6.08	1.65	5.53	2.04	5.88	1.94	5.40	2.25
Most prefer								
Younger: 20-30	1.50	0.78	1.73	0.91	1.58	0.87	1.58	0.68
Older: 65 and older	1.45	0.55	1.75	0.71	1.58	0.68	1.53	0.75

1. 8 point Likert-type scale with 1 being very easy to read and 8 being very difficult to read.

Table 17

ANOVA of Age, CRI and K for Value Discrimination of Black Letters on Munsell Gray Scale Backgrounds

Source	df	Munsell 2		Munsell 3		Munsell 4		Munsell 6		Munsell 8	
		F	p	F	p	F	p	F	p	F	p
Age	1	0.92	0.3417	3.27	0.0744	0.66	0.4191	0.00	0.9868	0.00	0.9746
CRI	1	0.09	0.7701	0.10	0.7545	4.04	0.0455*	9.89	0.0019**	13.07	0.0004***
K	1	0.54	0.4652	1.98	0.1602	2.97	0.0862	3.65	0.0572	1.28	0.2598
CRI x K	1	0.00	1.0000	0.39	0.5318	2.06	0.1524	0.19	0.6664	0.00	1.0000
Age x CRI	1	0.09	0.7701	0.22	0.6391	2.49	0.1156	0.64	0.4236	1.03	0.3104
Age x K	1	0.19	0.6612	0.88	0.3486	0.01	0.9159	0.10	0.7581	0.11	0.7350
Age x CRI x K	1	1.37	0.2431	0.61	0.4346	0.02	0.8859	0.03	0.8534	0.11	0.7350

* Indicates significance at $p < .05$ ** Indicates significance at $p < .01$ *** Indicates significance at $p < .001$

= .045, Munsell 4; $F(1,234) = 9.89$, $p = .001$, Munsell 3; $F(1,234) = 13.07$, $p = .0004$. All respondents read more easily under 85 CRI than 75 CRI with Munsell 6, Munsell 4 and Munsell 3. Since three of five signs were significant, the Hypothesis 7b was rejected.

The preference of the five signs was analyzed by using Chi-square analysis. Table 18 on page 61 shows the results of the analysis. For the main effect of age, CR, and K, over 50% of the subjects preferred the high contrast (black letters on a white background) represented by Munsell 9. Munsell 8, also a high contrast condition, was preferred by many of the subjects. Each of the conditions represented by Munsell 6, 4, and 2 were preferred by declining numbers of subjects as the contrast between letters and background were reduced (see Table 18).

Table 19 on page 62 illustrates the mean and standard deviation scores of responses to value discrimination for the second set (white letters on five gray scale backgrounds). Analysis of variance was applied for visual discrimination on the independent variables. Table 20 on page 63 shows all calculated F values and p-values.

Although two main effects (CRI and K) reached statistical significance, they were of little interest because significant two-way interactions (CRI by K, and age by K) were found. For Munsell 6 and Munsell 8, the two-way interaction between color rendering indices (CRI) and color temperature (K) was statistically significant. The calculated F ratio for Munsell 6 was $F(1,234) = 4.46$, $p = .035$, and for Munsell 8 was $F(1,234) = 13.00$, $p = .0004$. Therefore, the Hypothesis 7d was rejected.

To assess the significance of such findings, analysis of the simple effects was conducted. The outcomes are presented in Figure 10 and Table 21 on page 64 for Munsell 6 and Figure 11 and Table 22 on page 65 for Munsell 8. For the Munsell 6, there was a significant difference between 75 CRI and 85 CRI with 3000 K (4.51 vs. 4.78) and no difference between 75 CRI and 85 CRI with 4100 K (4.75 vs. 4.61). Both the younger and older adults read the sign on the Munsell 6 gray background more easily under 730 than 830 light. For the Munsell 8, there was also a significant difference between 75 CRI and 85 CRI with 3000 K (6.5 vs. 7.08) and no difference between 75 CRI and 85 CRI with 4100 K (7.06 vs. 7.0). All participants read more easily under 730 than 830 light.

Table 18

Chi-Square Analysis of Subjects' Preference for the Value Discrimination of Black Letters on Munsell Gray Scale Backgrounds

Variable	Total subject ^a	Munsell 9		Munsell 8		Munsell 6		Munsell 4		Munsell 2		χ^2	p
		n	(%) ^b	n	(%) ^b	n	(%) ^b	n	(%) ^b	n	(%) ^b		
Age group												4.563	0.335
Younger	160	90	(56.25)	52	(32.50)	12	(7.50)	5	(3.13)	1	(0.63)		
Older	160	82	(51.25)	67	(41.88)	8	(5.00)	3	(1.88)	0	(0.00)		
Color rendering index												4.347	0.361
75 CRI	160	92	(57.5)	57	(35.63)	7	(4.38)	3	(1.88)	1	(0.63)		
85 CRI	160	80	(50.0)	62	(38.75)	13	(8.13)	5	(3.13)	0	(0.00)		
Color temperature												1.801	0.772
3000 K	160	84	(52.5)	60	(37.50)	11	(6.88)	5	(3.13)	0	(0.00)		
4100 K	160	88	(55.0)	59	(36.88)	9	(5.63)	3	(1.88)	1	(0.63)		

^a Total subject: 40 in the younger group (20-30yrs) and 40 in the older group (65yrs and older). Repeated measured design yields 4 observations per person, thus a total of 320 observations.

^b % base on 160 observations for each main effect.

Table 19

Mean and SD Scores for Responses to Value Discrimination (white letters on Munsell gray scale backgrounds)¹

Condition	Lighting Conditions							
	730		830		741		841	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Munsell 2								
Younger: 20-30	1.45	0.81	1.58	1.26	1.58	1.28	1.58	1.26
Older: 65 and older	1.58	0.93	1.63	1.25	1.48	1.06	1.60	1.32
Munsell 3								
Younger: 20-30	2.20	1.07	2.20	1.30	2.00	1.04	1.88	1.02
Older: 65 and older	2.10	1.13	2.03	1.07	1.75	0.87	2.03	1.19
Munsell 4								
Younger: 20-30	3.28	1.45	3.23	1.48	3.15	1.61	3.08	1.40
Older: 65 and older	2.80	1.49	2.65	1.21	2.85	1.51	2.53	1.26
Munsell 6								
Younger: 20-30	4.93	1.72	5.28	1.62	4.90	1.72	4.75	1.63
Older: 65 and older	4.10	1.89	4.28	1.83	4.60	1.77	4.48	1.78
Munsell 8								
Younger: 20-30	6.58	1.72	7.00	1.41	6.85	1.41	6.73	1.57
Older: 65 and older	6.43	1.57	7.15	1.39	7.28	0.91	7.28	0.99
Most prefer								
Younger: 20-30	1.48	0.72	1.50	0.75	1.55	0.71	1.60	0.87
Older: 65 and older	1.60	0.84	1.78	0.77	1.63	0.77	1.53	0.68

1. 8 point Likert-type scale with 1 being very easy to read and 8 being very difficult to read.

Table 20

ANOVA of Age, CRI and K for Value Discrimination of White Letters on Munsell Gray Scale Backgrounds

Source	df	Munsell 2		Munsell 3		Munsell 4		Munsell 6		Munsell 8	
		F	p	F	p	F	p	F	p	F	p
Age	1	0.01	0.9153	0.20	0.6558	2.94	0.0904	2.90	0.0927	0.80	0.3728
CRI	1	1.36	0.2450	0.07	0.7961	2.62	0.1065	0.44	0.5097	8.40	0.0041**
K	1	0.00	1.0000	9.11	0.0028**	0.89	0.3456	0.16	0.6924	7.60	0.0063**
CRI x K	1	0.04	0.8461	0.60	0.4385	0.29	0.5897	4.46	0.0357*	13.00	0.0004***
Age x CRI	1	0.04	0.8461	1.26	0.2634	0.89	0.3456	0.16	0.6924	1.44	0.2306
Age x K	1	0.94	0.3324	0.36	0.5467	0.29	0.5897	10.90	0.0011**	7.60	0.0063**
Age x CRI x K	1	1.60	0.4379	2.68	0.1027	0.16	0.6858	0.28	0.5979	0.24	0.6211

* Indicates significance at $p < .05$ ** Indicates significance at $p < .01$ *** Indicates significance at $p < .001$

Figure 10. Interaction (CRI x K) Effects of Subjects' Perception in Relation to Ease of Reading White Letters on Munsell 6 Gray Scale Background

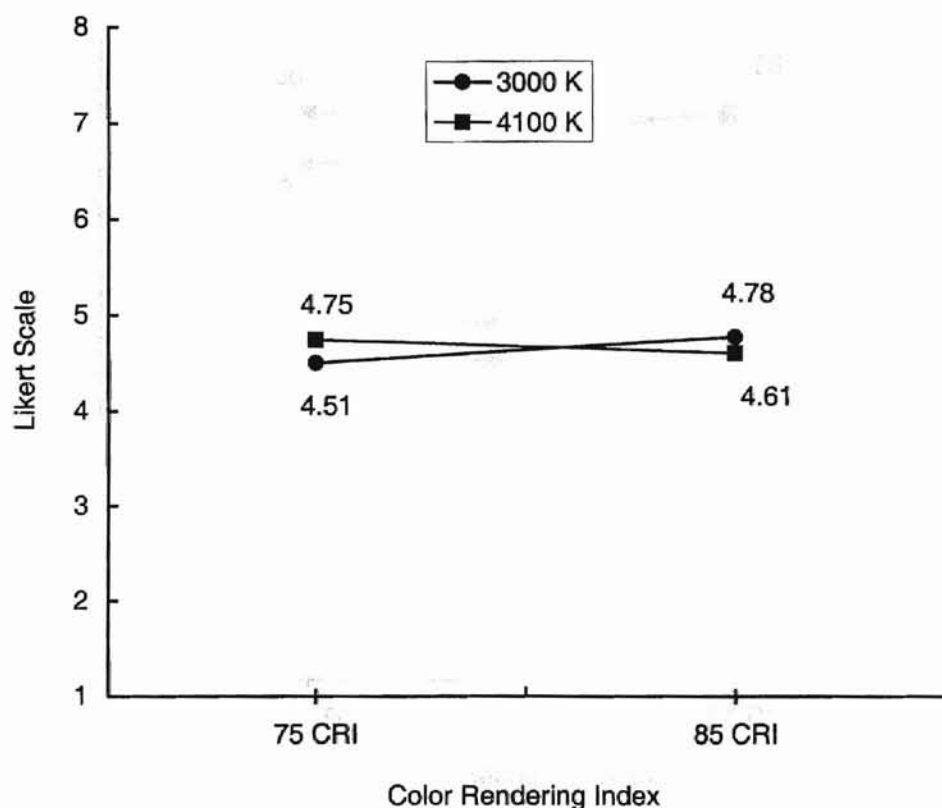


Table 21.

Analysis of Simple Effects (CRI x K) of Subjects' Perception in Relation to Ease of Reading White Letters on Munsell 6 Gray Scale Background

Comparison	df	MS	F	p
Line 1 (3000 K)	1	2.756	3.844	0.0478 *
Line 2 (4100 K)	1	0.0756	1.055	0.3058

* Indicates significance at $p < .05$

Figure 11. Interaction (CRI x K) Effects of Subjects' Perception in Relation to Ease of Reading White Letters on Munsell 8 Gray Scale Background

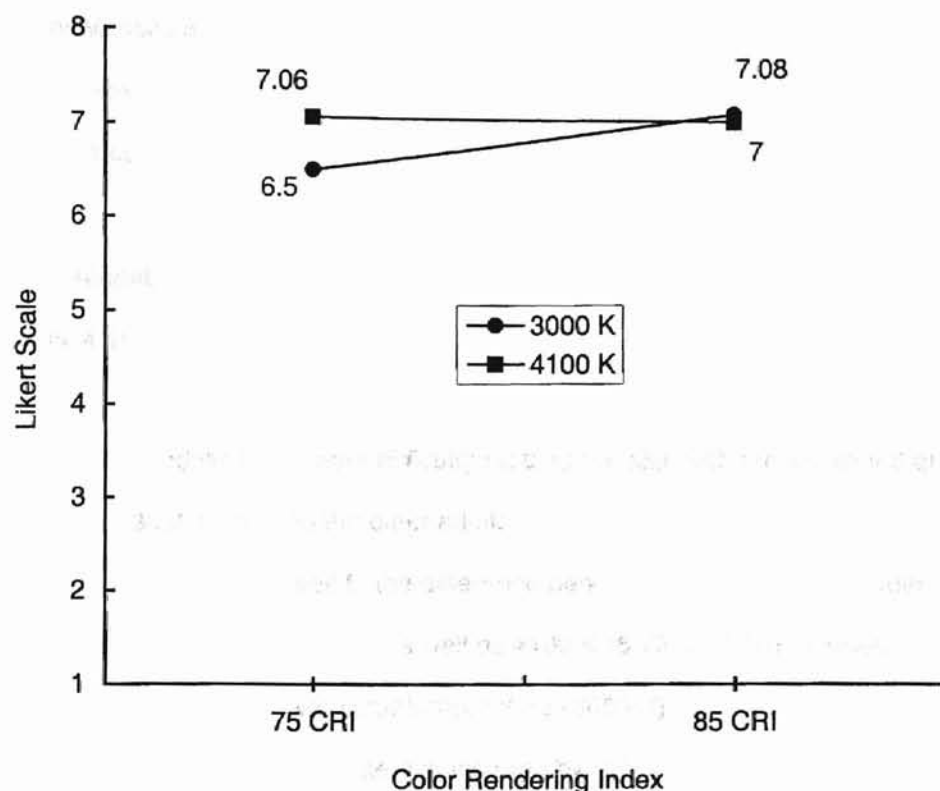


Table 22.

Analysis of Simple Effects (CRI x K) of Subjects' Perception in Relation to Ease of Reading White Letters on Munsell 8 Gray Scale Background

Comparison	df	MS	F	p
Line 1 (3000 K)	1	13.456	21.521	0.0001 *
Line 2 (4100 K)	1	0.231	0.231	0.6368

* Indicates significance at $p < .05$

The two-way interaction between age group and color temperature (K) for Munsell 6 and Munsell 8, was statistically significant. The calculated F ratio for Munsell 6 was $F(1,234) = 10.90$, $p = .0011$, and for Munsell 8 was $F(1,234) = 7.60$, $p = .0063$. Therefore, the Hypothesis 7f was rejected. To assess the significance of such findings, analysis of the simple effects was conducted. The outcomes are presented in Figure 12 and Table 23 on page 67 for Munsell 6 and Figure 13 and Table 24 on page 68 for Munsell 8.

For the readability on Munsell 6, the older adults are significantly different from the younger adults (5.1 vs. 4.19) for the lower color temperature (3000 K), however, the older adults in the higher color temperature (4100 K) are not significantly different (4.83 vs. 4.54) from the younger adults. The younger adults have more difficulty reading the sign with the Munsell 6 gray background under 3000 K than do the older adults.

For the readability on Munsell 8, the difference between the younger and older adults is not significant under 3000 K (6.79 vs. 6.79) as well as 4100 K (6.79 vs. 7.28). However, between the younger and older adults with lower color temperature (3000 K) approached significance at $p = .069$. Neither main effect of age nor interactions (age by CRI and age by CRI by K) were statistically significant for the value discrimination of the second set (white letters on five gray scale backgrounds). Therefore, the Hypothesis 7a, 7e, and 7g were not rejected.

The preference of the five signs written in white lettering was analyzed by using Chi-square analysis. Table 25 on page 69 shows the results of the analysis. For the main effect of age, CRI, and K, over 50% of the subjects preferred the high contrast (White letters on a black background) represented by Munsell 2. Munsell 3, also a high contrast condition, was preferred by many of the subjects (about 30 %). Each of the conditions represented by Munsell 4, 6, and 8 were preferred by declining numbers of subjects as the contrast between letters and background were reduced (see Table 25).

Figure 12. Interaction (Age x K) Effects of Subjects' Perception in Relation to Ease of Reading White Letters on Munsell 6 Gray Scale Background

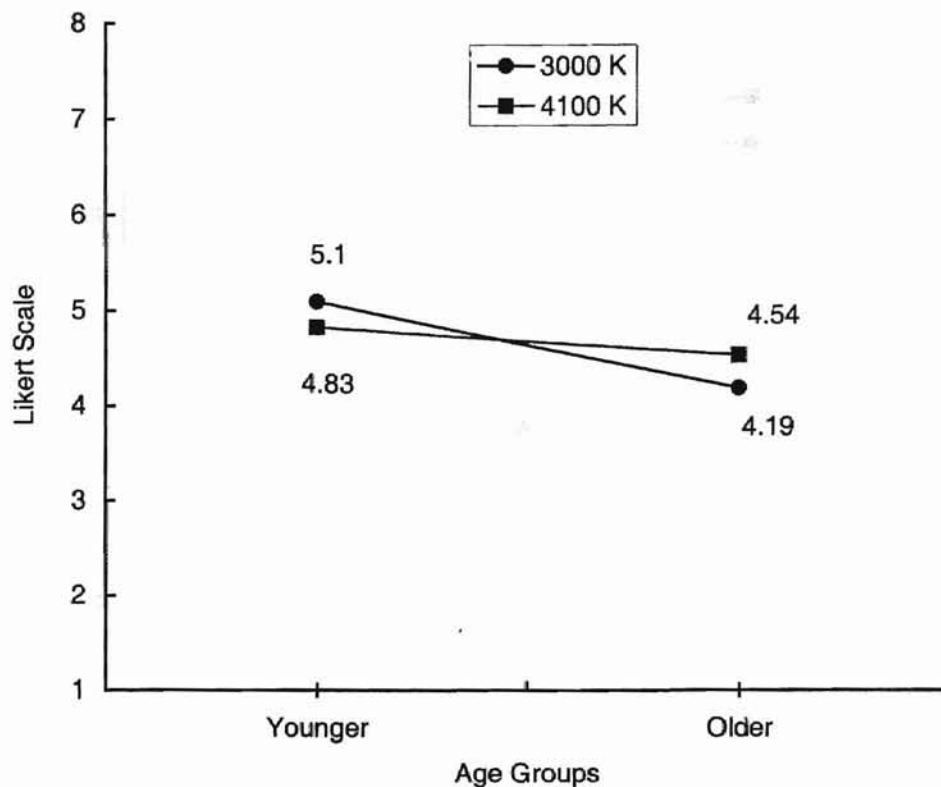


Table 23.

Analysis of Simple Effects (Age x K) of Subjects' Perception in Relation to Ease of Reading White Letters on Munsell 6 Gray Scale Background

Comparison	df	MS	F	p
Line 1 (3000 K)	1	66.612	6.702	0.0096 *
Line 2 (4100 K)	1	6.613	0.665	0.4236

* Indicates significance at $p < .05$

Figure 13. Interaction (Age x K) Effects of Subjects' Perception in Relation to Ease of Reading White Letters on Munsell 8 Gray Scale Background

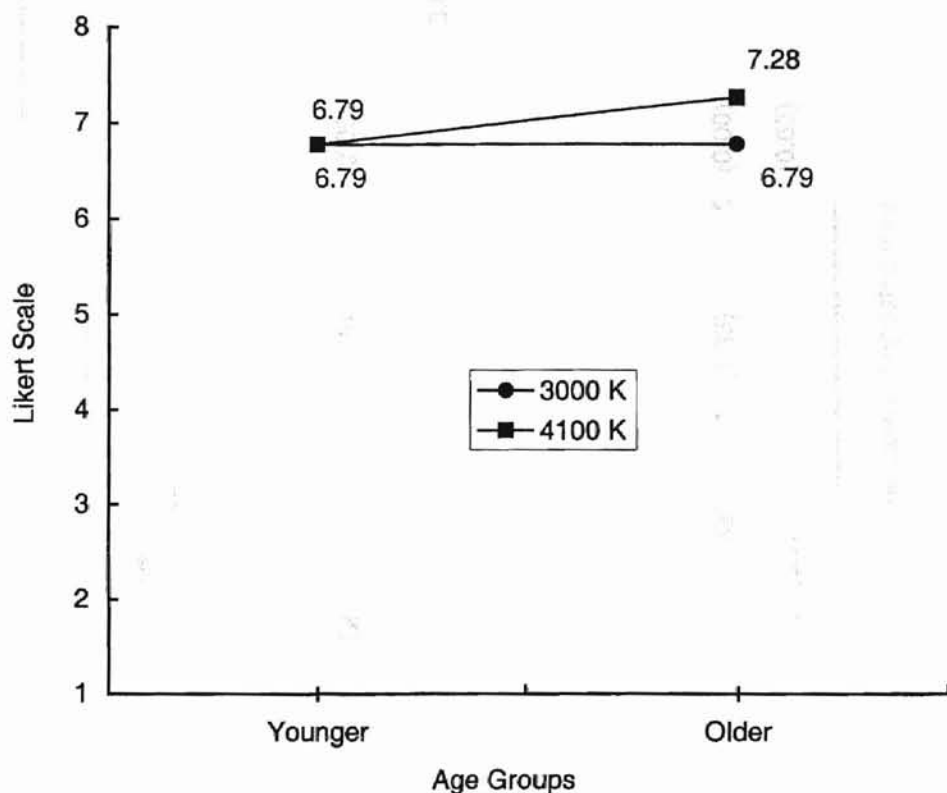


Table 24.

Analysis of Simple Effects (Age x K) of Subjects' Perception in Relation to Ease of Reading White Letters on Munsell 8 Gray Scale Background

Comparison	df	MS	F	p
Line 1 (3000 K)	1	0.000	0.000	0.9898
Line 2 (4100 K)	1	19.012	3.214	0.0698

Table 25

Chi-Square Analysis of Subjects' Preference for the Value Discrimination of White Letters on Munsell Gray Scale Backgrounds

Variable	Total subject ^a	<u>Munsell 2</u>		<u>Munsell 3</u>		<u>Munsell 4</u>		<u>Munsell 6</u>		<u>Munsell 8</u>		χ^2	p
		n	(%) ^b	n	(%) ^b	n	(%) ^b	n	(%) ^b	n	(%) ^b		
Age group												5.432	0.246
Younger	160	95	(59.38)	50	(31.25)	11	(6.88)	3	(1.88)	1	(0.63)		
Older	160	85	(53.13)	51	(31.88)	22	(13.75)	2	(1.25)	0	(0.00)		
Color rendering index												3.656	0.455
75 CRI	160	92	(57.5)	50	(31.25)	14	(8.75)	4	(2.50)	0	(0.00)		
85 CRI	160	88	(55.0)	51	(31.88)	19	(11.88)	1	(0.63)	1	(0.63)		
Color temperature												2.465	0.651
3000 K	160	91	(56.88)	47	(29.38)	19	(11.88)	3	(1.88)	0	(0.00)		
4100 K	160	89	(55.63)	54	(33.75)	14	(8.75)	2	(1.25)	1	(0.63)		

^a Total subject: 40 in the younger group (20-30yrs) and 40 in the older group (65yrs and older). Repeated measured design yields 4 observations per person, thus a total of 320 observations.

^b % base on 160 observations for each main effect.

Hypothesis 8

Hypothesis 8 was stated in the null form for statistical testing as follows: Hypothesis 8.

There is no difference in the ability to designate colors with regard to

- a) age (young and old)
- b) color rendering indices of fluorescent light (75 CRI and 85 CRI)
- c) color temperatures of fluorescent light (3000 K and 4100 K)
- d) two-way interaction of CRI by K
- e) two-way interaction of age by CRI
- f) two-way interaction of age by K
- g) three-way interaction of age by CRI by K

To investigate the difference in the ability to designate color, the five principal hues of Munsell's Chroma Chart were tested. The five principal hues were red, yellow, green, blue, and purple. First, Categorical analysis was performed on this hypothesis. However, there were no significant three-way (age by K by CRI) or two-way (age by K, age by CRI, and CRI by K) interactions. Therefore, Chi-square analysis was conducted to test color designation of individuals with different age groups under different lighting conditions.

The results of the analysis for Munsell red (5R) are shown in Table 26 on page 71. Both the younger and older adults designated Munsell red (5R) as tomato red (orange red) under all lighting conditions with no significant differences. The designation as orange red indicated subjects perceived the color as more orange than the actual true red color of 5R. Although the differences are not significant, more subjects designated Munsell red (5R) as true red under lower color rendering index (75 CRI) than under higher one (85 CRI). Color temperature (3000 K and 4100 K) had a significant impact ($\chi^2 = 10.057$, $p = 0.018$) on the subjects' perception of Munsell red (5R). Therefore, the Hypothesis 8c was rejected. Subjects perceived and designated 5R as tomato red (orange red) when, in fact, the color was true red. Under 3000 K, 95 (59.38 %) of the 160 observers designated tomato red as the best color description for 5R. Under 4100 K, 68 (42.50%) of the 160 observers designated tomato red as the best color description for 5R.

Table 26

Chi-Square Analysis of Age, CRI, and K for Color Descriptors to Munsell Red (5R)

Variable	Total subject ^a	Munsell Red (5R) Descriptors								χ^2	p
		True Red		Tomato Red (orange red)		Cherry Red (blue red)		Other			
		n	(%) ^b	n	(%) ^b	n	(%) ^b	n	(%) ^b		
Age Group										4.065	0.255
Younger	160	55	(34.38)	80	(50.00)	24	(15.00)	1	(0.63)		
Older	160	50	(31.25)	83	(51.88)	21	(13.13)	6	(3.75)		
Color Rendering index										3.912	0.4271
75 CRI	160	57	(35.64)	83	(51.88)	18	(11.25)	2	(1.25)		
85 CRI	160	48	(30.00)	80	(50.00)	27	(16.88)	5	(3.13)		
Color Temperature										10.057	0.018 *
3000 K	160	44	(27.50)	95	(59.38)	17	(10.63)	4	(2.50)		
4100 K	160	61	(38.13)	68	(42.50)	28	(17.50)	3	(1.88)		

^a Total subject: 40 in the younger group (20-30yrs) and 40 in the older group (65yrs and older). Repeated measured design yields 4 observations per person, thus a total of 320 observations.

^b % base on 160 observations for each main effect.

* Indicates significance at $p < .05$

The results of Chi square analysis for the color designation to the Munsell yellow (5Y) are shown in Table 27 on page 73. Age group (younger and older) was statistically significant ($\chi^2 = 11.717$, $p = 0.008$) on subjects color designation to Munsell yellow (5Y). Although most of the subjects described the Munsell yellow as true yellow, a greater proportion of the older adults ($n = 115$, 71.88 %) designated Munsell yellow as a true yellow than younger adults ($n = 100$, 62.50 %). Although the differences are not significant for color temperature, all respondents designated slightly better Munsell yellow as true yellow under higher color temperature (4100 K) than under lower color temperature (3000 K). Color rendering index did not have a significant impact for Munsell yellow. However, more than 66% of the 160 observers designated true yellow as the best color description for 5Y under both color rendering indices.

Chi square analysis for the color descriptor to the Munsell green (5G) is shown in Table 29 on 74. Significant differences ($\chi^2 = 16.844$, $p = 0.001$) in the younger and older adults for color designation to Munsell green was ascertained. Although most of the respondents described the Munsell green as true green, a greater proportion of difference showed between kelly green (blue green) and lime green (yellow green) by both the younger and older adults. A higher proportion of the older adults ($n = 58$, 36.25 %) designated Munsell green as kelly green (blue green) than the younger adults ($n = 39$, 24.38 %). However, a higher proportion of the younger adults ($n = 31$, 19.38 %) designated Munsell green as lime green (yellow green) than the older adults ($n = 9$, 5.63 %).

Color temperature was not significant for Munsell green. Although the differences are not significant, all respondents designated slightly better Munsell green as true green under higher color temperature (4100 K) than under lower color temperature (3000 K). Color rendering index did not have a significant impact for Munsell yellow. However, more than 55 % of the 160 observers designated true yellow as the best color description for 5G under both color rendering indices.

Chi square analysis for the color designation to the Munsell blue (5B) is shown in Table 29 on page 76. Significant differences ($\chi^2 = 14.035$, $p = 0.003$) in the younger and older adults for color designation to Munsell blue was ascertained. Although most of the respondents described

Table 27

Chi-Square Analysis of Age, CRI, and K for Color Descriptors to Munsell Yellow (5Y)

		Munsell Yellow (5Y) Descriptors										
Variable	Total subject ^a	True Yellow		Citrus Yellow (green yellow)		Orange Yellow		Other		χ^2	p	
		n	(%) ^b	n	(%) ^b	n	(%) ^b	n	(%) ^b			
Age group											11.717	0.008 *
Younger	160	100	(62.50)	47	(29.38)	7	(4.38)	6	(3.75)			
Older	160	115	(71.88)	44	(27.50)	0	(0.00)	1	(0.63)			
Color rendering index											0.301	0.960
75 CRI	160	108	(67.50)	45	(28.13)	4	(2.50)	3	(1.88)			
85 CRI	160	107	(66.88)	46	(28.75)	3	(1.88)	4	(2.50)			
Color temperature											3.105	0.376
3000 K	160	101	(63.13)	50	(31.25)	4	(2.50)	5	(3.13)			
4100 K	160	114	(71.25)	41	(25.63)	3	(1.88)	2	(1.25)			

^a Total subject: 40 in the younger group (20-30yrs) and 40 in the older group (65yrs and older). Repeated measured design yields 4 observations per person, thus a total of 320 observations.

^b % base on 160 observations for each main effect.

* Indicates significance at $p < .05$

Table 28

Chi-Square Analysis of Age, CRI, and K for Color Descriptors to Munsell Green (5G)

		Munsell Green (5G) Descriptors									
Variable	Total subject ^a	True Green		Kelly Green (blue green)		Lime Green (yellow green)		Other		χ^2	p
		n	(%) ^b	n	(%) ^b	n	(%) ^b	n	(%) ^b		
Age group										16.844	0.001 *
Younger	160	90	(56.25)	39	(24.38)	31	(19.38)	0	(0.00)		
Older	160	92	(57.50)	58	(36.25)	9	(5.63)	1	(0.63)		
Color rendering index										1.348	0.718
75 CRI	160	89	(55.63)	51	(31.88)	20	(12.50)	0	(0.00)		
85 CRI	160	93	(58.13)	46	(28.75)	20	(12.50)	1	(0.63)		
Color temperature										5.156	0.161
3000 K	160	84	(52.50)	57	(35.63)	19	(11.88)	0	(0.00)		
4100 K	160	98	(61.25)	40	(25.00)	21	(13.13)	1	(0.63)		

^a Total subject: 40 in the younger group (20-30yrs) and 40 in the older group (65yrs and older). Repeated measured design yields 4 observations per person, thus a total of 320 observations.

^b % base on 160 observations for each main effect.

* Indicates significance at $p < .05$

the Munsell blue as true blue, a greater proportion of the older adults ($n = 119$, 74.38 %) designated Munsell blue as a true blue than the younger adults ($n = 95$, 59.38 %). The second high proportion of the color descriptor was purple blue for Munsell blue. Color temperature was not significant for Munsell blue. Although the differences are not significant, all respondents designated slightly better Munsell blue as true blue under higher color temperature (4100 K) than under lower color temperature (3000 K).

Chi square analysis for the color designation to the Munsell purple (5P) is shown in Table 30 on page 77. Significant differences ($\chi^2 = 24.65$, $p = 0.001$) between the younger and older adults for color designation to Munsell purple was ascertained. Although most of the respondents described the Munsell purple as true purple, a greater proportion of difference showed between violet (red purple) and bluish purple by both the younger and older adults. A higher proportion of the older adults ($n = 55$, 34.38 %) designated Munsell purple as violet (red purple) than the younger adults ($n = 30$, 18.75 %). However, a higher proportion of the younger adults ($n = 44$, 27.50 %) designated Munsell purple as bluish purple than the older adults ($n = 15$, 9.38 %).

Color temperature was not significant for Munsell purple. Although the differences are not significant for Munsell purple under the different color rendering indices, all respondents designated slightly better Munsell purple as true purple under lower color rendering index (75 CRI) than under higher color rendering index (85 CRI).

Table 29

Chi-Square Analysis of Age, CRI, and K for Color Descriptors to Munsell Blue (5B)

		Munsell Blue (5B) Descriptors									
Variable	Total subject ^a	<u>True Blue</u>		<u>Green Blue</u>		<u>Purple Blue</u>		<u>Other</u>		χ^2	p
		n	(%) ^b	n	(%) ^b	n	(%) ^b	n	(%) ^b		
Age group										14.035	0.003 *
Younger	160	95	(59.38)	12	(7.50)	48	(30.00)	5	(3.13)		
Older	160	119	(74.38)	1	(0.63)	35	(21.88)	5	(3.13)		
Color rendering index										1.236	0.745
75 CRI	160	110	(68.75)	6	(3.75)	38	(23.75)	6	(3.75)		
85 CRI	160	104	(65.00)	7	(4.38)	45	(28.13)	4	(2.50)		
Color temperature										7.304	0.063
3000 K	160	98	(61.25)	6	(3.75)	52	(32.50)	4	(2.50)		
4100 K	160	116	(72.50)	7	(4.38)	31	(19.38)	6	(3.75)		

^a Total subject: 40 in the younger group (20-30yrs) and 40 in the older group (65yrs and older). Repeated measured design yields 4 observations per person, thus a total of 320 observations.

^b % base on 160 observations for each main effect.

* Indicates significance at $p < .05$

Table 30

Chi-Square Analysis of Age, CRI, and K for Color Descriptors to Munsell Purple (5P)

		Munsell Purple (5P) Descriptors									
Variable	Total subject ^a	True Purple		Violet (red purple)		Bluish Purple		Other		χ^2	p
		n	(%) ^b	n	(%) ^b	n	(%) ^b	n	(%) ^b		
Age group										24.650	0.001 *
Younger	160	81	(50.63)	30	(18.75)	44	(27.50)	5	(3.13)		
Older	160	89	(55.63)	55	(34.38)	15	(9.38)	1	(0.63)		
Color rendering index										3.310	0.346
75 CRI	160	92	(57.50)	41	(25.63)	24	(15.00)	3	(1.88)		
85 CRI	160	78	(48.75)	44	(27.50)	35	(21.88)	3	(1.88)		
Color temperature										3.105	0.376
3000 K	160	81	(50.63)	47	(29.38)	30	(18.75)	2	(1.25)		
4100 K	160	89	(55.63)	38	(23.75)	29	(18.13)	4	(2.50)		

^a Total subject: 40 in the younger group (20-30yrs) and 40 in the older group (65yrs and older). Repeated measured design yields 4 observations per person, thus a total of 320 observations.

^b % base on 160 observations for each main effect.

* Indicates significance at $p < .05$

Discussion and Conclusions

The purpose of the study was to understand the impact of different fluorescent color temperatures and color rendering indices on lighting preference, visual comfort, value discrimination and color descriptors for elderly consumers. Specifically, the objectives of the study included: (1) to assess and compare lighting preferences of individuals by age under different color rendering indices (CRI) and color temperatures (K) of fluorescent light, (2) to assess and compare visual comfort according to age difference with regard to color rendering indices (CRI) and color temperatures (K) of fluorescent light, (3) to assess and compare the ability to discriminate value according to age difference with regard to color rendering indices (CRI) and color temperatures (K) of fluorescent light, (4) to assess and compare the ability to designate colors according to age difference with regard to color rendering indices (CRI) and color temperatures (K) of fluorescent light, (5) to develop recommendations for store lighting design specifically for elderly consumers.

Findings are discussed in relation to previous research findings and to aging eye theory. The results of this study indicate that color temperature is an important factor that influences the lighting preferences for individuals based on age. All participants perceived their skin to be healthier under the higher color temperature (4100 K) than under the lower color temperature condition (3000 K). However, this finding does not support Steffy's (1990) statement that skin tones look better under lower color temperature of same color rendering index. Perhaps, the difference between the findings in this study and Steffy's statement can be explain by differences in approaches. There is no evidence of a controlled experimental design being used to support the information presented by Steffy. The statements may be grounded in empirical research, but this is not evident in the literature. If Steffy's information is based on empirical research, perhaps the differences could be attributed to the specific levels of CRI and K conditions used in this study.

Results of this study indicate that both the younger and older adults perceived the light as being cooler under 4100 K than under 3000 K. This finding supports the theory of color temperature reported by North American Philips Lighting Corporation (1984). This theory states

that 3000 K fluorescent lamps are perceived as warm white and 4500 K fluorescent lamps are perceived as cool white. Results of this study also indicate the younger adults perceived the lighted area as being cooler under 4100 K than the older adults. These findings support the part of aging eye theory that elderly people are less accurate in discriminating finite hue differences at the blue end of the spectrum (Nuckolls, 1983).

Under all lighting conditions, the older adults perceived the level of illuminance, set at approximately 50 footcandles, as dimmer than the younger adults (see table 1, page 42). Although statistical analysis does not find the differences as being significant level at the $p \leq .05$, the results of $F = 3.27$ with $p = .07$ indicates a need for further study. The lack of significance at the $p \leq .05$ level might be attributed to sample size or other unidentified confounding factors.

Previous research (Miller, 1992; Sanders & McCormick, 1993) suggested that the level glare perceived by the subjects is greater for older persons, due to reduced tolerance to extremes in light intensity and sensitive to glare. In this study, there was no significant difference between the younger and older adults. However, the findings of the subject perception of glare indicate that the color rendering index (CRI) and color temperature (K) impact on visual comfort. Both the younger and older adults perceived less glare under 730 light than 830 light. This indicates that a lower CRI with lower color temperature provides less glare problem than a higher CRI. Davidsen (1991) recommends that high light levels with good color rendition are necessary to compensate for the yellowing of the lens. A recommendation for a lower color rendering index and color temperature conflicts with Davidsen's (1991) recommendation. Previous recommendations related lighting conditions for the elderly have been based on increasing illuminance levels due to reduced light entering the eye due to yellowing lens, reducing pupil size, and clouding vitreous humor. Although increasing illuminance addresses one situation, it conflicts with the eye's inability to adjust to changes in lighting intensity.

The findings related to visual comfort indicate significant differences in color temperatures and age groups. The participants in both age groups indicated a greater difference in visual comfort between 3000 K and 4100 K as identified in Table 13 on page 50. All subjects indicated that they experienced better visual comfort under higher color temperature (4100 K) than under

lower color temperature (3000 K). In all lighting conditions, the older adults perceived less visual comfort than the younger adults.

Generally, the older adults had a more positive response to all four lighting conditions than the younger adults as indicated by question 6 responses. The mean scores for all lighting conditions were higher for older adults than for the younger adults. Regarding the color temperature, however, both the younger and older adults preferred the higher color temperature (4100 K). This finding suggests that the use of the higher color temperature lamps might be a good choice for lighting stores that seek to attract both younger and older adults.

The items related to value discrimination for black letters on different Munsell gray scale backgrounds indicates significant differences in color rendering indices. Significant difference was found for the lower value contrast including the Munsell 6 gray scale, the Munsell 4 gray scale, and the Munsell 3 gray scale in the color rendering indices. The participants in both age groups indicated that they could read these items more easily under 85 rather than 75 CRI. This finding indicates that a higher CRI provides better readability in the low value contrast items (black letters on Munsell gray 6, 4, and 3 scales).

The findings of value discrimination for white letters on different Munsell gray scale backgrounds indicate significant differences in color temperatures, and interactions of CRI by K and age by K. With the Munsell 3 gray scale background, all participants in both groups read more easily under the higher color temperature (4100 K) than under the lower one. Except this finding, there was no significant difference among high value contrast items (white letters on Munsell 2, and 6 gray scales). It can be concluded that the signage with high value contrast provides better readability under higher color temperature lighting for the older adults as well as the younger adults.

With low value contrast items (white letters on Munsell 6 gray scale and 8 gray scale), there were significant differences regarding the two-way interactions of CRI by K and age by K. All participants in both age groups read both Munsell 6 and 8 gray scale items more easily under 730 than 830 light. However, the older adults read the Munsell 6 gray scale item more easily than the younger adults under 3000 K. The younger adults read the Munsell 8 gray scale item

more easily than the older adults under 4100 K. This finding indicates that older adults have more difficulty reading lower value contrast items than younger adults.

The findings of the color designation for the five principal hues (red, yellow, green, blue, and purple) of Munsell's Chroma Chart indicate significant differences in color temperature and age group. With Munsell red (5R), color temperature had a significant impact on the subjects' perception. Ninety-five (59.38 %) of the 160 subjects from both age groups perceived and designated 5R under 3000 K as tomato red (orange red) when, in fact, the color was true red. However, under 4100 K, 68 (42.50%) of the 160 observers designated tomato red as the best color description for 5R.

Perception of Munsell yellow (5Y) and Munsell blue (5B) was significantly different between younger and older adults. That is a greater proportion of the older adults designated Munsell yellow as a true yellow than the younger adults, and a greater proportion of the older adults designated Munsell blue as a true blue than the younger adults.

With Munsell green (5G), there was a significant difference between the younger and older adults. A higher proportion of the older adults designated Munsell green as kelly green (blue green) than the younger adults, while a higher proportion of the younger adults designated Munsell green as lime green (yellow green) than older adults. Significant difference was found between the younger and older adults for Munsell purple (5P). A higher proportion of the older adults designated Munsell purple as violet (red purple) than the younger adults, while a greater proportion of the younger adults designated Munsell purple as bluish purple than the older adults.

In summary, the following conclusions were made.

1. Research indicates that all participants perceived their skin to be healthier under the higher color temperature (4100 K) than under the lower color temperature (3000 K).
2. Research indicates that both the younger and older adults perceived the light as being cooler under 4100 K than under 3000 K, and the younger adults perceived the lighted area as being cooler under 4100 K than the older adults.
3. Research indicates that both the younger and older adults perceived less glare under 730 than 830 light.

4. Research indicates that both the younger and older adults perceived more visual comfort under higher (4100 K) than lower (3000 K) color temperature, but the older adults perceived less visual comfort than the younger adults under all lighting conditions (730, 830, 741, and 841).
5. Research indicates that both the younger and older adults preferred higher (4100 K) rather than lower (3000 K) color temperature.
6. Research indicates that both the younger and older adults read black letters on different Munsell gray scale backgrounds more easily under higher color rendering index than lower color rendering index as the contrast between letters and background were reduced.
7. Research indicates that all participants in both age groups read low value contrast items (white letters on Munsell 6 gray scale and 8 gray scale) more easily under 730 than 830 lights
8. Research indicates that the older adults read the Munsell 6 gray scale more easily than the younger adults under 3000 K, while the younger adults read the Munsell 8 gray scale more easily than the older adults under 4100 K.
9. Research indicates that 95 of the 160 subjects perceived and designated Munsell red (5R) under 3000 K as tomato red (orange red), while 68 of the 160 observers designated Munsell red as tomato red under 4100 K.
10. Research indicates that a greater proportion of the older adults designated Munsell yellow and blue as their true color than younger adults.
11. Research indicates that a greater proportion of the older adults designated Munsell green and purple as yellow green and red purple respectively, than younger adults

Implications

The assumption that there are differences in how individuals by age perceive and feel about four different lighting conditions in store environments is supported by this study. Research results provide insight about the specific variables of lighting and how those variables are perceived and liked by different age groups. However, the study of human response to various lighting conditions is very complex and findings should be interpreted with care.

Retailers, merchandisers, lighting designs, interior designers, and graphic designers can benefit from the insights this study provides. Other applications that may benefit from these findings include mall lighting and school and office lighting. Design practitioners and design educators can constructively utilize the various lighting techniques regarding color temperature, color rendering index and age used as independent variables in this study. Color temperature and color rendering index are excellent parameters for successfully executing the use of many variations available for the color selection, sign readability, visual comfort and lighting preferences in store environments.

Recommendations for Future Studies

This topic of study is worthy of further research since visual stimuli by the lighting environment surrounds humans daily and almost constantly. Areas that could be explored further include replicating of this study to compare lighting perceptions, preferences, sign readability and color descriptors of 1) males to females, 2) additional age groups, 3) subjects from different geographical areas of the country, and 4) subjects from different cultural backgrounds or national origins. Another study on this topic could be devised for comparing different sets of lamp with a more diverse range of color rendering indices and color temperatures, as well as different sets of color samples. Also, comparisons might be more accurate if respondents were evaluated in a real setting, such as different store environments.

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APPENDIXES

Appendix A

Appendix B

Appendix C

APPENDIX A

OKLAHOMA STATE UNIVERSITY
INSTITUTIONAL REVIEW BOARD
HUMAN SUBJECTS REVIEW

OKLAHOMA STATE UNIVERSITY
INSTITUTIONAL REVIEW BOARD
HUMAN SUBJECTS REVIEW

Date: January 30, 1998

IRB#: HE-98-048

Proposal Title: **IMPACT OF DIFFERENT FLUORESCENT LIGHT COLOR TEMPERATURES AND COLOR RENDERING INDICES ON PREFERENCE, VISUAL COMFORT, VALUE DISCRIMINATION AND COLOR MATCHING FOR ELDERLY CONSUMERS**

Principal Investigator(s): Cheryl A. Farr, Nam-Kyu Park

Reviewed and Processed as: Expedited

Approval Status Recommended: Pending Revision

ALL APPROVALS MAY BE SUBJECT TO REVIEW BY FULL INSTITUTIONAL REVIEW BOARD AT NEXT MEETING, AS WELL AS ARE SUBJECT TO MONITORING AT ANY TIME DURING THE APPROVAL PERIOD.

APPROVAL STATUS PERIOD VALID FOR DATA COLLECTION FOR A ONE CALENDAR YEAR PERIOD AFTER WHICH A CONTINUATION OR RENEWAL REQUEST IS REQUIRED TO BE SUBMITTED FOR BOARD APPROVAL.

ANY MODIFICATIONS TO APPROVED PROJECT MUST ALSO BE SUBMITTED FOR APPROVAL

=====

Comments, Modifications/Conditions for Approval or Disapproval are as follows. To receive Approval, the following pending items must be taken care of:

REVIEWER #1:

Although there is minimal risk to the subjects in this study, it does not meet the criteria for exempt status as outlined in the IRB guidelines. It can be approved, though, through an expedited review but with the following considerations:

- 1) The investigators state that the subjects' names will not be asked. This is not true in that their names will go on the consent forms.
- 2) The investigators should briefly describe how they might advise subjects for whom a previously-unknown visual impairment was discovered.

REVIEWER #2:

Since the researcher plans to use an Informed Consent Form, the reviewer would suggest some useful additions:

- 1) Advise the participants that they will be asked to step into a cubicle which will contain lighting very similar to what they would encounter in a store or shop and this will pose no risk greater than what they would encounter there.
- 2) Explain the purpose for the subject code at the bottom of questionnaire.
- 3) Point out that their personal identities or responses will not be disclosed.

PLEASE DO NOT PROCEED WITH THIS STUDY PRIOR TO RECEIVING FINAL APPROVAL

Your study is disapproved in its present format, and you may gain approval by revising your application. You are requested to seek approval by responding to the Comments, Modifications/Conditions for Approval or Disapproval listed above in resubmitting under the same IRB number. If you have any strong disagreements with the reviewer's recommendations, you may respond in writing to the executive secretary (Gay C. Clarkson, 305 Whitehurst, 744-5700) or request a meeting with the full IRB to discuss the recommendations.

Signature: 

Chair of Institutional Review Board

Cc: Nam-Kyu Park

Date: February 3, 1998

1. The purpose of
this study is to

APPENDIX B

INFORMED CONSENT FORM

INFORMED CONSENT

I, _____, voluntarily agree to participate in this study entitled impact of different fluorescent light color temperatures and color rendering indices on lighting preference, visual comfort, value discrimination and color descriptors for elderly consumers.

The purpose of this study is to more fully understand and explore the impact of different fluorescent light color temperatures and color rendering indices on preference, visual comfort, value discrimination and color matching. The experiment is conducted within the Lighting and Technology Laboratory (HES 432) in the College of Human Environmental Sciences at Oklahoma State University. Four different lighting conditions are provided in the cubicles of laboratory. Your perception of each lighting condition is important in understanding differences in preference, visual comfort, value discrimination and color matching. Your honesty in reacting to your lighting condition will help to recommend store lighting techniques which can be used to provide optimum lighting conditions for consumers of all age.

I understand that I need to be available for about 60 minutes to complete four lighting evaluations and the two vision tests. Two vision tests, the color blindness test and the visual clarity test, will be administered.

I understand that participation is voluntary, that there is no penalty for refusal to participate, and that I am free to withdraw from participation in this project at any time without penalty after notifying the project director.

I understand that my name will not be associated with the questionnaire after all parts are completed. A subject code number will be used on the questionnaire rather than my name. I will not be identified by name as a subject in this research.

I may contact Dr. Cheryl A. Farr at telephone number (405) 744-9525. I may also contact Gay Clarkson, IRB Executive Secretary, 305 Whitehurst, Oklahoma State University, Stillwater, OK 74078; telephone number: (405) 744-5700.

I have read and fully understand the consent form. I sign it freely and voluntarily.
A copy has been given to me.

Date: _____ Time: _____ (a.m./p.m.)

Signed: _____
Signature of Subject

I certify that I have personally explained all elements of this form to the subject or his/her representative before requesting the subject or his/her representative to sign it.

Signed: _____
Project Director or his/her authorized representative

APPENDIX C
PART I: DEMOGRAPHIC QUESTIONNAIRE

PART I : DEMOGRAPHIC QUESTIONNAIRE

INSTRUCTIONS: Circle the number of the category that describes you.

1. Are you between 20 and 30 years or over 65 years?

- 1. Yes
- 2. No

(If No) Thank you for your willingness to participate. Participants must be between 20 and 30 years or 65 years old. You do not need to continue answering the remainder of the questions.

2. Do you have any visual impairments (such as color blindness) that can not be corrected by your glasses or contact lenses?

- 1. Yes
- 2. No

(If Yes) Thank you for your time; however, your assistance will not be required. You do not need to proceed.

3. Age:

- 1. 20-30 years old
- 2. 65-75 years old
- 3. Over 75 years old

4. Sex:

- 1. Male
- 2. Female

5. Which term best describes your educational level?

- 1. Have not completed high school or GED
- 2. Have completed high school

6. Do you usually wear glasses or contacts?

- 1. Yes
- 2. No

7. If yes, are you wearing them now?

- 1. Yes
- 2. No

For Researcher Use Only

Subject code number: _____

1) The Color Vision Test: _____

2) The Visual Acuity Test: Right eye: _____ Left eye: _____

APPENDIX D

PART II: STUDY QUESTIONNAIRE

(FLUORESCENT LAMP 730, 830, 741, and 841)

PART II : FLUORESCENT LAMP (730, 830, 741, 841)

1. INSTRUCTIONS: Each of the following word pairs are used to understand your reaction to the lighting in your cubicle. Please indicate your perception of this setting by placing an on the eight point scale that best describes your feelings for the setting. (See the example below)

EXAMPLE:

Stressful | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Relaxing

- 1) Under this lighting, how does your skin appear?

Healthy | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Unhealthy

- 2) Would you describe this lighting as being warm or cool?

Warm | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Cool

- 3) Is this light too bright or too dim?

Too bright | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Too dim

- 4) How would you describe this light?

Glaring | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Not glaring

- 5) Would you describe this lighting as being visually comfortable or uncomfortable?

Comfortable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Uncomfortable

- 6) How do you feel about this lighting?

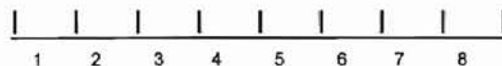
Like | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Dislike

2. INSTRUCTIONS: Please identify the difficulty or ease you find reading each of these "signs" by placing an X on the scale.

1)



Very easy
to read

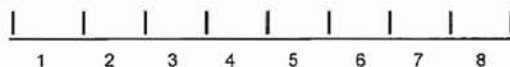


Very difficult
to read

2)



Very easy
to read

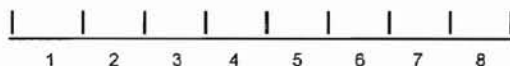


Very difficult
to read

3)



Very easy
to read

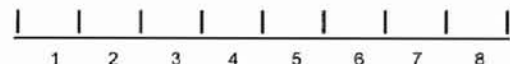


Very difficult
to read

4)



Very easy
to read

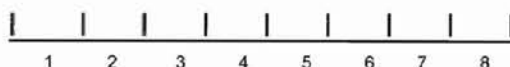


Very difficult
to read

5)



Very easy
to read



Very difficult
to read

6) From the above, which one do you most prefer? Please circle the number.

1 2 3 4 5

3. INSTRUCTIONS: Please identify the difficulty or ease you find reading each of these "signs" by placing an X on the scale.

1)



Very easy to read | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Very difficult to read

2)



Very easy to read | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Very difficult to read

3)



Very easy to read | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Very difficult to read

4)



Very easy to read | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Very difficult to read

5)



Very easy to read | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Very difficult to read

6) From the above, which one do you most prefer? Please circle the number.

1 2 3 4 5

4. Which color BEST describes each color sample. (circle number)

1

See card # 1
on the podium

1. red
2. tomato red (orange red)
3. cherry red (blue red)
4. other (please describe) _____

2)

See card # 2
on the podium

1. yellow
2. citrus yellow (green yellow)
3. orange yellow
4. other (please describe) _____

3)

See card # 3
on the podium

1. green
2. kelly green (blue green)
3. lime green (yellow green)
4. other (please describe) _____

4)

See card # 4
on the podium

1. blue
2. green blue
3. purple blue
4. other (please describe) _____

5)

See card # 5
on the podium

1. purple
2. violet (red purple)
3. bluish purple
4. other (please describe) _____

APPENDIX E
MUNSELL COLOR CHART

11

MUNSELL COLOR CHART¹

1)



2)



3)



4)



5)



¹ Representation of the card used for question #4 reproduced by scanning and color printing
(Colors not exact as used in original)

VITA

Nam-Kyu Park

Candidate for the Degree of
Master of Science

Thesis: IMPACT OF DIFFERENT FLUORESCENT LIGHT COLOR TMPERATURES AND
COLOR RENDERING INDICES ON LIGHTING PREFERENCE, VISUAL COMFORT,
VALUE DISCRIMINATION AND COLOR DESCRIPTORS FOR ELDERLY
CONSUMERS

Major Field: Design, Housing, and Merchandising

Biographical:

Personal Data: Born in Chung-Ju, Korea, On May 20, 1967, the daughter of Ro-Sung
Park and Sung-Hwa Park (Kim). Married to Byung-Ok Im on April 28, 1991.

Education: Graduated from Chung-Ju Women High School, Chung Cheong Buk
Province, Korea, in February 1985; received Bachelor of Science degree in Home
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Professional Experience: Teaching assistant, Department of Home
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Professional Membership: Illuminating Engineering Society of North America (IESNA).