THE EFFECTS OF FLUORESCENT, HALOGEN,
AND XENON WEATHER-OMETER
LIGHTING CONDITIONS
ON 100% COTTON
DYED FABRIC

By

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Thesis Advisor

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PREFACE

This study was conducted to determine if commonly used lamps in retail environments contribute to the fading of merchandise within these environments. Fluorescent and halogen lighting were studied as well as the use of sunlight, tested by carbon-arc lighting conditions.

The American Association for Textile Chemists and Colorists (AATCC) Grey scale and the Datacolor Spectrometer was used to determine the colorfastness of the test specimens. This data was analyzed and compared to the American Society for Testing Materials (ASTM) standards to determine if the samples met the established standard.

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CHAPTER ONE

INTRODUCTION

In today's retail environment countless stimuli have been generated in an effort to promote sales to the consumers. Color and lighting are two elements in this ultra stimulant environment that can not only generate sales, but can also damage merchandise. A combination of high intensity lighting sources combined with colored dyes that may not be colorfast can fade and deteriorate merchandise. With improving technology the perfect combination of light and color can be obtained without counteracting each other's benefits (Kaplan, 1991).

Interior designers can implement designs to stimulate the retail store environment. However, it is the retailer's responsibility to satisfy and attract customers. In order to attract customers into the retail establishment, displays are used within the store. The apparel displayed is often exposed to several types of lighting, which may fade the merchandise. The types of lighting vary in their sources because of lighting design. Lighting may be permanent lamps or accent lighting (Gorman, 1997). Accent lighting will cause more fading because of the proximity of the lamp to the merchandise. Sunlight, the light source frequently recognized in textile product testing, is damaging as are the light sources within the store.

In today's marketplace malls contain a large percentage of stores in the apparel industry. Most of these stores in the malls have little to no sunlight coming in to the store, skylights are an exception to this rule. Therefore, the fading in most retail situations is a result of artificial light sources (DeLaney & Makulec, 1963).

In addition to the merchandise on display, the merchandise inside the store may also be inclined to be damaged by strong lighting. Apparel hanging on the store racks is exposed to at least two lighting sources. These lighting sources may be a combination of halogen, fluorescent, and daylight energy. These lights are often fixed on a particular point on the garment for an extended period of time. This duration of light exposure may lead to fading and deterioration of the merchandise (DeLaney & Makulec, 1963).

By using a combination of textile and lighting research it is possible to simulate the retail setting that produces the maximum results for both the retailer and the customer. Creating a lighting system that is attractive, economical, and saves energy (Energy User News, 1998) can do this. Textile research provides information regarding how different types of fabrics will perform under certain conditions.

Research Design

An experimental factorial design study was used to explore the relationship between lighting and fabric. Three independent variables were manipulated, these were lighting, color, and time. The lighting consisted of general lighting being fluorescent, accent lighting being halogen display, and sunlight as simulated by the carbon-arc tester. The colors to be examined are red, royal blue, and teal. The time of the experiment was

720 hours, this is the stock turn ratio of 10.4 weeks multiplied by the hours most retail stores have their lights turned on.

Problem Statement

The lamps used in artificial lighting sources may damage apparel by fading the colors in the merchandise. Many retail environments use lighting with halogen and fluorescent lamps in close proximity to the merchandise thus causing fading. This problem is amplified when display lighting is used because the merchandise on display is often highlighted with lamps at a short distance.

Objectives

The goal of this study was be to analyze different merchandise fading and the impact of lighting conditions on each other. These factors were fiber content (100% cotton), color, lighting lamps, and duration of light exposure. A combination of interior design, textiles, and apparel merchandising research was used to accomplish this goal. The specific objectives of this study were to:

1. Identify and compare the differences in fading on red, royal blue, and teal women's 100% cotton T-shirts.
2. Identify and compare the differences in fading under general, accent, and sunlight conditions on women's 100% cotton T-shirts.
3. Determine the maximum amount of time lapse before significant fading occurs in general lighting, accent lighting, and sunlight conditions as simulated by carbon-arc testing.

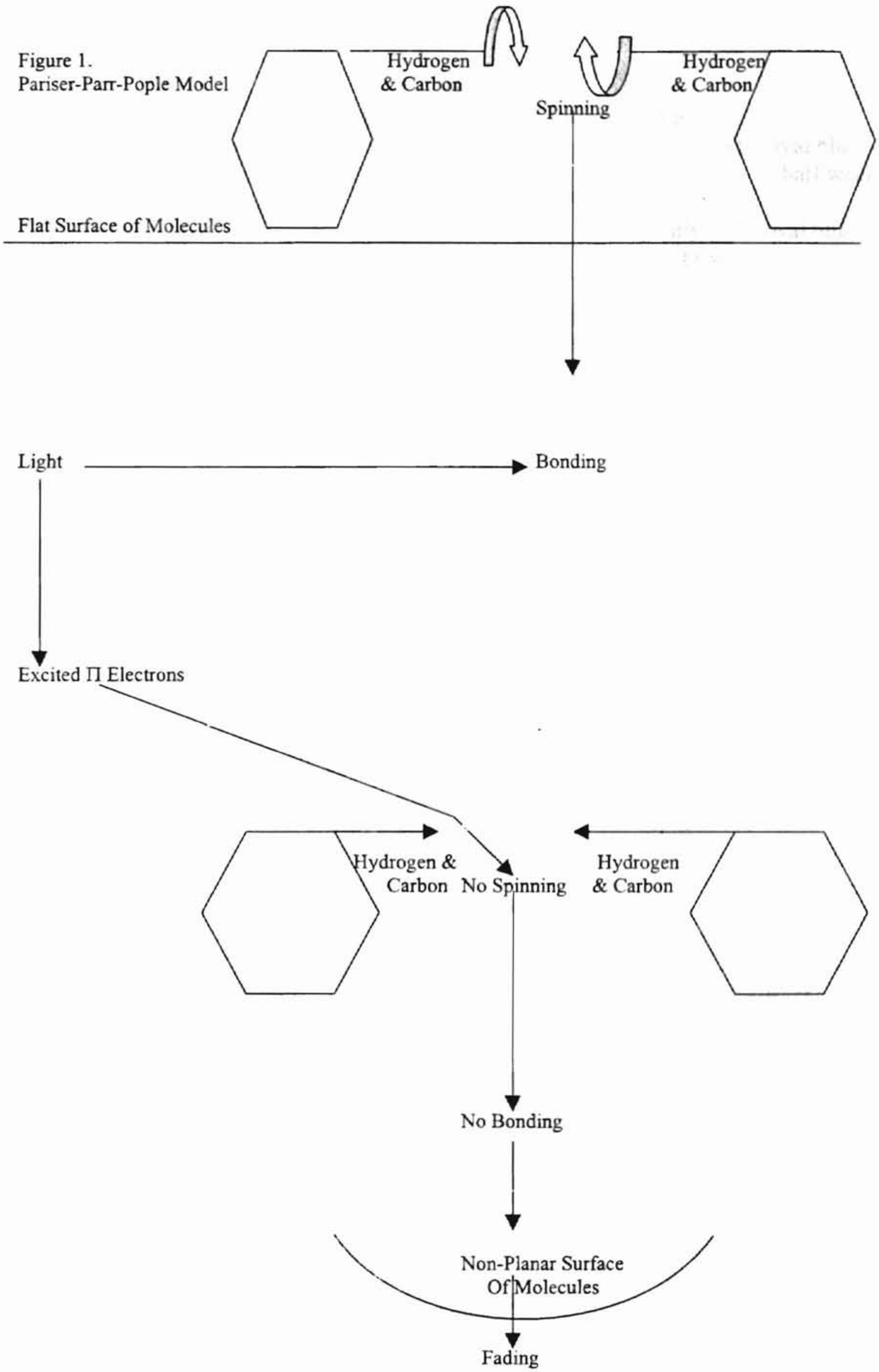
The merchandising area in a retail store is the center of both the lighting scheme and garments. "Research indicates that the amount of light within the space will have a direct influence on the customers' perception of the space and product" (Hegde, 1996, p. 9). This space has objectives that must be met. The merchandising area must attract customers, initiate purchases, facilitate completion of sales, and minimize customer returns. Attractive display and lighting schemes have been shown to initiate traffic patterns of customers into and around stores. Once the customer is inside the store, it then becomes easier to initiate and complete sales. All of these attributes serve to satisfy the customer with the merchandise they purchase. This in turn will reduce the customer returns. The desired end result for any retail store is profit. In order to meet that goal, the retailer must satisfy the needs of their customers. The store lighting and merchandise plays an important role in satisfying those needs.

Theoretical Bases

The Pariser-Parr-Pople (PPP) model and theory predicts and calculates the color and strength of dyes (Gordon & Gregory, 1983). To do this, the theory incorporates Π-electronic make-up of molecules which effects the dyes color and strength. This theory is important to azo dyes because they react with metal ions that can alter the light resistance of these bright dyes.

The PPP theory states that hydrogen and carbon group molecules rotate on a flat surface to form a bond between the dyes and fibers. If light were to strike this rotation of these hydrogen and carbon groups, pi electrons become excited. The excitement of the pi electron will then stop the rotation, which will break the bond between the fiber and the dye. The surface of the dye molecules then becomes curved at which point fading occurs (Gordon & Gregory, 1983).

Figure 1.
Pariser-Parr-Pople Model



Hypothesis

Fading of Samples by Color X Light X Time

$H_0$1: The effects of general fluorescent lighting will not significantly fade royal blue 100% cotton T-shirt after 360 hours of exposure, the equivalent of 5 and one-half weeks in a retail environment.

$H_0$2: The effects of general fluorescent lighting will not significantly fade royal blue 100% cotton T-shirt after 720 hours of exposure, the equivalent of 11 weeks in a retail environment.

$H_0$3: The effects of halogen display lighting will not significantly fade royal blue 100% cotton T-shirt after 360 hours of exposure, the equivalent of 5 and one-half weeks in a retail environment.

$H_0$4: The effects of halogen display lighting will not significantly fade royal blue 100% cotton T-shirt after 720 hours of exposure, the equivalent of 11 weeks in a retail environment.

$H_0$5: The effects of xenon weather-ometer simulated sunlight will not significantly fade royal blue 100% cotton T-shirt after 40 AATCC Fading Units of exposure.

$H_0$6: The effects of general fluorescent lighting will not significantly fade red 100% cotton T-shirt after 360 hours of exposure, the equivalent of 5 and one-half weeks in a retail environment.

$H_0$7: The effects of general fluorescent lighting will not significantly fade red 100% cotton T-shirt after 720 hours of exposure, the equivalent of 11 weeks in a retail environment.

$H_0$8: The effects of halogen display lighting will not significantly fade red 100% cotton T-shirt after 360 hours of exposure, the equivalent of 5 and one-half weeks in a retail environment.

$H_0$9: The effects of halogen display lighting will not significantly fade red 100% cotton T-shirt after 720 hours of exposure, the equivalent of 11 weeks in a retail environment.

$H_0$10: The effects of xenon weather-ometer simulated sunlight will not significantly fade red 100% cotton T-shirt after 40 AATCC Fading Units of exposure.

$H_0$11: The effects of general fluorescent lighting will not significantly fade teal 100% cotton T-shirt after 360 hours of exposure, the equivalent of 5 and one-half weeks in a retail environment.

$H_0$12: The effects of general fluorescent lighting will not significantly fade teal 100% cotton T-shirt after 720 hours of exposure, the equivalent of 11 weeks in a retail environment.

$H_0$13: The effects of halogen display lighting will not significantly fade teal 100% cotton T-shirt after 360 hours of exposure, the equivalent of 5 and one-half weeks in a retail environment.

$H_0$14: The effects of halogen display lighting will not significantly fade teal 100% cotton T-shirt after 720 hours of exposure, the equivalent of 11 weeks in a retail environment.

$H_0$15: The effects of xenon weather-ometer simulated sunlight will not significantly fade teal 100% cotton T-shirt after 40 AATCC Fading Units of exposure.

Main Effect and Interaction

$H_0$16: Regardless of light, at 360 hours, there will be no significant change in chroma and hue between the colors royal blue, red, and teal.
$H_0$17: Regardless of color, at 360 hours, there will be no significant change in chroma and hue for samples exposed to fluorescent and halogen lighting.
$H_0$18: There will be no significant difference in interaction of light and color at 360 hours.

$H_0$19: Regardless of light, at 720 hours, there will be no significant change in chroma and hue between the colors royal blue, red, and teal.
$H_0$20: Regardless of color, at 720 hours, there will be no significant change in chroma and hue for samples exposed to fluorescent and halogen lighting.
$H_0$21: There will be no significant difference in interaction of light and color at 720 hours.

$H_0$22: There will be no significant change in chroma and hue for samples exposed to 40 AATCC Fading Units.

Assumptions

Several assumptions have been made with this research. These assumptions involve the samples used, the dye type used in the samples, and the conditions under which the testing is preformed.

1. The samples were purchased from a retail establishment, and were assumed to be colorfast at the time of the purchase.
2. The dye class is unknown but assumed to be azo. The dye class was assumed to be azo dyes because it is the most commonly used dye for natural cellulosic fibers.
3. A retail environment was simulated, this retail environment simulation was assumed to be reflective of a typical retail setting.
4. The samples tested, were cut from one purchased garment per color, and were colored in the same dye lot.

Limitations

Some limitations have been found in this research. They are as follows:

1. The dye class assumed in this study was azo dyes. This assumption is a limitation of this study because the theoretical model only applies to the azo dye type.
2. The level of dye penetration was unknown. The Pariser-Parr-Pople (PPP) model was used to analyze the dye penetration. However, this model only deals with planar molecules, and did not consider hydrogen bonding.
3. There was no data available on the air quality of the simulated retail environment, the air quality levels have the potential for influencing textile performance and thus the results of this study.

Definition of Terms

Accent\Display lighting – highlighting or emphasizes lighting for display merchandise (Mills, Paul, & Moormann, 1995).

American Association for Textile Chemists and Colorists (AATCC) – Establishes standard test methods related to performance characteristics and physical parameters of textile products (Glock & Kunz, 2000).

Azo dyes –The most important classification of dyes for natural cellulosic fibers, containing over one-half of the total world dyestuff production. They are readily and economically available for use in production (Gordon & Gregory, 1983).

Carbon-Arc Lamp – The apparatus utilizes a carbon-arc lamp as the source of radiation. The arc is operated from a power supply of 208 to 250 volts (AATCC Technical Manual, 1999).

Cold cathode lamp – An electric-discharge lamp whose mode of operations is that of a glow discharge, and having electrodes so spaced that most of the light comes from the positive column between them (IES Lighting Handbook, 1972).

Color (Hue) – The net response of an observer to visual physical phenomena involving visible radiant energy of varying intensities over the wavelength range 400 to 700 nanometers (nm) (Needles, 1986, p.158).

Daylight factor – A measure of daylight illumination at a point on a given plane expressed as a ratio of the illumination on the given plane at that point to the simultaneous exterior illumination on a horizontal plane from the whole of an unobstructed sky of assumed or known luminance (photometric brightness) distribution. Direct sunlight is excluded from both interior and exterior values of illumination (IES Lighting Handbook, 1972).

Fluorescent lamp – A low-pressure mercury electric discharge lamp in which a fluorescing coating (phosphor) transforms some of the ultraviolet energy generated by the discharge into light (IES Lighting Handbook, 1972).

General/Primary lighting – the all-over level of illumination in an area. It is usually the lights that fills the selling floor from overhead lighting fixtures, but without including accent lights and display highlights lamps (Pegler, 1991, p. 48).

Halogen lamp – a lamp that offers longer life and better energy efficiency. Features a coiled filament a coiled filament and a bulb filled with inert gases (Osram Sylvania Handbook).

High-intensity discharge (HID) lamps – A general group of lamps consisting of mercury, metal halide and high-pressure sodium lamps light (IES Lighting Handbook, 1972).

Incandescence – The self-emission of radiant energy in the visible spectrum due to the thermal excitation of atoms or molecules (IES Lighting Handbook, 1972).

Stock-turn ratio or stock turnover – The number of times during the year that inventory turns; derived by dividing total sales by average value of inventory (Nevenglosky, 1995, p. 115).

Quality level B glass – A flat-drawn sheet glass that is single strength (AATCC Technical Manual, 1999).

CHAPTER TWO

REVIEW OF LITERATURE

The purpose of this review of literature was to explore the previous research preformed in areas related to merchandise fading. These related areas have been identified as lighting, both sunlight and artificial lighting, and fading. In addition literature concerning visual merchandising, color, cotton, and dye research has been summarized.

One of the aspects of textiles that make them attractive to the consumer is the color that is the result of the dyeing process. Sunlight and artificial lighting in the retail environment can fade that color. Textile products must be displayed and merchandised to reduce the amount of fading of the product so that the customers will continue to be attracted to the textile product.

Cotton

One of today's most popular fibers in women's causal apparel is cotton. This is because of the comfort and care properties related to this fiber (Wingate & Mohler, 1984). Different fiber contents of merchandise can contribute to the intensity of color loss.

Cotton is a natural, cellulosic fiber, which has properties conducive to dying. Cotton fiber is very absorbent, and therefore it dyes well. "Cotton takes dyes that are fast to washing and to sunlight" (Wingate & Mohler, 1984, p. 231). The dye penetrating properties of cotton make testing the fiber ideal under different lighting conditions.

Cotton has been chosen as the fiber for this experiment because of two characteristics of the fiber. The fiber structure of cotton is considered to have moderate appearance retention. Also, cotton is oxidized by sunlight, which breaks down the fiber structure and will be a contributor to the deterioration of the merchandise tested.

Cotton is about 94 percent cellulose when picked from the plant and about 99 percent cellulose in the finished fabric form. As with other cellulosic fibers, cotton contains carbon, hydrogen, and oxygen with hydroxyl (OH) groups. The.basic unit of the cellulosic molecule is the glucose unit which consists of the three previously mentioned elements. Cotton's molecular chain is arranged in a long, spiral formation which is a factor in the strength of the fiber. Since cotton is composed of carbon, hydrogen, and oxygen the hydroxyl group readily reacts with moisture and dyes (Kadolph , Langford, Hollen, & Suddler, 1998).

Cotton is frequently used in combination with azo dyes because of their compatibility for colorfastness. The azoic dyes are used primarily for coloring cellulosic fibers. To prepare for the dyeing process, the yarn or fabric should be scoured to remove any oils or starches that may be in the textile. The scouring process should be applied to any textile that is not bleached. If the textile has been bleached, it should be neutralized and rinsed until a pH level of 7 (being the neutral point on the pH scale) has been obtained (Moore, 1981).

Azoic dyes are also called naphthols, and they are insoluble dyes that are synthesized by the dyer on the fiber. This method of dyeing consists of applying two small components separately. The components combine inside the fiber to produce a larger, insoluble molecule that is the azoic dye. The first component is called the coupling component which carries the weak acidic hydroxyl group. The acidic hydroxyl group is made soluble by reacting with alkali to form their salt called naphtholate. This salt molecule must be large enough to attach to the cellulosic fibers. Then the second component (diazonium salt) is prepared by reacting with a base (the diazo component) with nitrous acid. The fibers are then treated with the second component, and the coupling occurs to form the dye on the fibers (Rivlin, 1992).

Lighting

The Illumination Engineering Society (1972) states in their Lighting Handbook that there are two approaches for lighting merchandise in retail environments. They are referred to as the specific method and the general pattern method. The specific method involves placing luminaries in areas that emphasize the merchandise. This method is used with display lighting and sometimes referred to as accent lighting. Higher levels of illumination are located in merchandise viewing areas. The increased illumination in these areas has been found to increase merchandise fading (Illumination Engineering Society, 1972). Incandescent lighting is generally used in these situations in an attempt to control the lighting. The general pattern method places the lighting fixtures symmetrically around the building using incandescent, fluorescent, High Intensity Discharge (HID) lighting, or any combination of the three. This method is also referred to as general lighting. General pattern method lighting is known for its pleasant atmosphere that emphasizes the store and creates a desirable shopping environment with an even distribution of the light throughout the store (Illumination Engineering Society, 1972).

Both the specific method and the general pattern method have been used in retail environments; often, a combination of the two has been used. Both of these methods present advantages and disadvantages. The specific method highlights merchandise, which is used to increase sales, while the general pattern method creates a desirable shopping atmosphere. The specific method's high illumination level fades and destroys the merchandise, and the general pattern method uses different lighting types, which also can increase the illumination level.

The various types of lighting and lighting methods play a very important role in retailing. It is important to determine which of these methods will work best in a given retail setting. It becomes important to analyze the different types of retail environments to determine the best combination of lighting and merchandise for the retailer. "A well-lighted retail environment can help make merchandise appeal to target customers and guide them through the store to featured displays and ultimately to the cash register" (Morin, 1998, p. 134).

"The main function of the retail environment is to encourage the sale of products" (Hegde, 1996, p. 9). The lighting of a store is a major factor in how the customer perceives the merchandise and the retail establishment. The customer's evaluation and purchase decision is based on the color, pattern, and texture of the merchandise (Hegde, 1996). All of these factors are influenced by the lighting scheme. The method in which the merchandise is illuminated makes a difference in how that merchandise appears to the customers. "Therefore, lighting should be considered an essential design and building element" (Nuckolls, 1983, preface).

Sunlight

There are two major sources of lighting for apparel retailers, sunlight and electric lighting. Sunlight is very popular with consumers but must be managed effectively to keep from distracting attention from the merchandise. Effective management of sunlight includes rotating merchandise out of the sunlight to prevent fading and choosing colors that will be less prone to fading in sunlight lit areas. Daylight can also vary depending on the geographic location of the retailer. In areas of the United States that receive a large amount of sun, like Florida or Oklahoma, fading is a greater concern than states like Washington that receives limited amounts of sunlight. Generally, the more diffused the daylight is, the easier it is to control and the more uniform the light is (Steffy, 1990). While daylight is a good option, it must be properly managed. This can be done by manipulating the existing light or by designing a lighting concept around the daylight. When the merchandise needs to be manipulated, the other sources of lighting should be reduced or placed so that the merchandise is exposed to fewer lighting sources.

The effects of daylight fading are most obvious in visual merchandising. Displays are frequently used at the entrances of retail stores to entice customers inside to purchase goods. These displays are often the first effected by fading within the retail environment. It then becomes necessary for the retailer to rotate their merchandise in order to prevent fading. Daylight fading then becomes another source of cost for the retailer with damaged merchandise.

<u>Artificial Lighting</u>

The level of illumination and the duration of exposure have been cited as the most important factors in fade prevention (Illuminating Engineering Society, 1972). Research has indicated a reciprocal relationship between time of exposure and the intensity of the illumination in the fading of textiles and textile products. As long as the sample tested for fading remained the same, the fading was dependent upon the illumination and duration of the experiment.

Electric light sources serve as a benefit to retailers by emphasizing merchandise, guiding traffic patterns, or even communicating a message to the consumer. Lighting is necessary and retailers have come to rely on its benefits (Illuminating Engineering Society, 1972). However, a problem arises when the light sources damage the merchandise. Since electric lighting illuminates the entire store, fading may occur in all of the merchandise, as opposed to being limited to merchandise in an isolated display area.

As with the different types of lighting there are different types of retailers who need different types of lighting fixtures. Specialty stores, discounters, mass merchants, and chain stores all have a different image to portray. Steffy (1990) indicated that there are four major classifications of electric light sources. They are incandescent, cold cathode, fluorescent, and high intensity discharge (known as HID). Retailers generally use incandescent, fluorescent and HID lighting within the store environment. Some incandescent lamps have been replaced with halogen lamps (Osram Sylvania Handbook). Incandescent or halogen lamps are most popular in residential areas, they are typically known for the heat they produce. These lamps are typically used for highlighting decorative areas in retail situations such as display areas for accent lighting. Fluorescent lighting is most common in commercial areas. They are very efficient and produce bright lighting if they have high footcandle levels. This type of lighting is referred to as general lighting. Large discount stores are known for using fluorescent lighting in their stores. HID lighting is popular on the retail scene because of its color rendering and efficiency.

Brasier (1997) stated that "The increased efficiency and improved color rendering enable HID lamps to compete with incandescent" (p. 57). The HID lamps are replacing incandescent lamps in the retail environment. The different types of lighting fixtures are used to communicate store image. Specialty stores and chain stores, referred to as Fancy

Box and Shot Gun stores, must attract trend-oriented customers, while discounters and mass merchants, referred to as Big Box stores, attract the price conscious customer (Brasier, 1997). The one consistency within these stores is their merchandise, all of which needs to remain undamaged.

Chain Store Age recently held an executive roundtable to discuss retail lighting. The majority of the participants (including Limited Stores, Saks Fifth Avenue, and Liz Claiborne) expressed that image was their primary concern and the deciding factor in their retail lighting scheme (Anonymous, 1998). While the physical appearance of the store and how that relates to their image was discussed, the quality of their merchandise was also very much related to image. This image is further portrayed to consumers by maintaining the quality level of the merchandise. Colorfast merchandise contributes to the quality level of merchandise and the image of the store.

Fading

Lightfastness has been studied for many years, starting in 1730 in France. (Giles & McKay, 1963). Dufray was the first pioneer who researched lighting tests on a scientific basis. In 1914, the system of study was modified to test exposed areas alongside a set of graded standard patterns. "The principle of evaluation is that the test pattern is equated with the standard that fades at the same rate"(Giles & McKay, 1963, p. 531).

The fading and deterioration of merchandise can pose a costly problem for retailers. The change in hues of textiles is obvious and has everyday importance (Giles & McKay, 1963). The term hue is used to describe an attribute of color in spectral sequence (Nassau, 1998). The fading can be the result of two factors, an extended period of time under certain lighting conditions and high levels of illumination. The fading of merchandise because of exposure to light is of significant interest because of the importance of lighting to the ambiance of the rest of the retail store and the increasing levels of illumination in retail stores.

A good lighting scheme considers the merchandise and its qualities, fading and deterioration of merchandise is one of the merchandising qualities that must be considered. "Fading of colored textiles and other materials upon exposure to light and other radiant energy is of special interest because of the higher illuminants now employed in merchandising" (IES Merchandising Lighting Committee, 1991, p. 205).

Fading is caused by the spectral distribution of radiant energy and appears to require oxygen in a photochemical process. Ultraviolet energy is also a major promoter of fading of textiles, however it is not present in most light sources (Kaplan, 1991). Radiation generally comes from the electric lighting sources within the retail environment. Therefore, radiation is not as much of a concern in daylight as it is in electric lighting. In retail areas where sunlight is used in the lighting scheme, ultraviolet light is more of a concern for the fading of textiles, due to the rapid nature of fading associated with ultraviolet lighting (Kaplan, 1991). "Skylights are often used in retail stores that track the sun and store sunlight that is then emitted into a steady stream" (Pete, 1996, p.3). Steve Milby, Wal-Mart's City of Industry store manager is quoted by Pete (1996, p.3) as saying "skylights offer an advantage, they're easier on the apparel and cause less fading of colors than traditional light. With natural lighting, merchandise looks better to the customer because they are seeing true colors and fading is minimized" (Pete, 1996, p.3).

The most notable examples of merchandise color deterioration are instances when folded merchandise is placed under high illumination lamps. This is most frequently used in retail settings where men's ties and scarves are folded and placed in display cases with high level lamps shining on the merchandise. The exposed area is then faded while the area not exposed retains its original color. The merchandise is then noticeably faded because half of the merchandise is faded while the other half is not. To prevent this from occurring, retailers should rotate their merchandise every week to ten days (IES Merchandising Lighting Committee, 1991).

To counteract the problems of fading merchandise, improvements in the dyeing of textiles have been made (IES Merchandising Lighting Committee, 1991). Chemical processes have been developed to increase the colorfastness of textiles. While these process have helped prevent fading in merchandise, the optimal situation occurs when treated textiles and the proper lighting pattern are used concurrently.

Visual Merchandising

The purpose of displays is to show and explain the merchandise to the customers in order to sell it (Pegler, 1991). Displays are placed in the exterior and interior of stores. The displays that are exterior are generally window store related and so have daylight as the illumination source. Those displays that are inside are highlighted with accent lighting, often at a close proximity to the merchandise (Pegler, 1991).

These visual merchandising techniques are necessary to promote sales for the retailers. This clothing is frequently closer in proximity to the lighting fixtures (Pegler, 1991), than the other merchandise like accessories which are frequently located in glass cabinets or at the cashier stand, away from the lighting fixtures. The result of which can be faded merchandise if the apparel remains on display over an extended period of time.

A successful merchandising strategy will have a high stock-turn ratio, the number of times during the year that the merchandise is replaced (Nevenglosky, 1995). Retailers desire a high stock-turn ratio, the result of which is increased sales and profits. To achieve this increase in sales, promotion is necessary to attract customers. The attraction leads to increased traffic in the store and increased sales. The sales decrease the stock inventory, which allows the store to buy new merchandise. This movement will rotate the merchandise, thus limiting the amount of time the garment is under the lighting.

In 1994, the women's clothing stores reported an average stock-turn ratio of 4.9 times annually (Nevenglosky, 1995). This indicated that a garment spent an average of 10.6 weeks in a retail store before being sold. It is the job of the retailers to increase this statistic yearly. The higher the stock-turn ratio, the more fashion merchandise that moves out of the store, the more profit the company sees. This may result in higher sales and less damage to the merchandise from lighting sources.

Color

Color in itself has been noted for selling merchandise and as being as important to the consumer as size and price (Pegler, 1991). Color is one of the first things that attracts the customer to a piece of merchandise they are considering for purchase. If the color meets the customer's satisfaction, either by preference or trend factors, the customer will be happier. If the color has somehow been lightened through light deterioration, or some other factor, the merchandise is damaged and cannot be sold at regular price.

Color theory says observed color is a combination of three factors; the nature of the light source, the light absorption properties of the object observed, and the response of the eye to the light reflected from the object (Needles, 1986). The nature of the light source and the absorption properties of the object directly effect the colorfastness of the cotton T-shirts. When a light source strikes a dyed textile, different portions of light are absorbed by the dye which is dependant on the structure and light absorption characteristics of the dye (Needles, 1986).

"Color, as color, means little unless it is considered in relation to the type of light in which the color is seen. It is light that makes things visible. Visible light is between 400-750 namometers on the light spectrum for color. All colors depend on light" (Pegler, 1991, p. 45). The type of lighting within the retail environment effects the way in which the customer perceives color. This holds true for all merchandise, but can be a more significant factor when dealing with faded merchandise. Lighting alone, is a factor in the retail environment, like color, it serves as a stimulant and has been effectively used to increase sales. The proper lighting scheme can be designed to attract customers and highlight merchandise. Light and color must be used together to compliment, not damage the merchandise.

Color is initiated by light energy and has two primary dimensions, intensity and wavelength. The intensity is specified by the number of photons that fall on the cross-section area in a period of time (Lamb, T & Bourriau, J, 1995). The wavelength is the "distance between successive crests in the electromagnetic wave train" (Lamb, T & Bourriau, J, 1995, p.6). It is the wavelength that determines if light can be seen and the sensation of color. Wavelengths between 400 and 750 namometers are the color that we see because of absorption in the photoreceptor in our eyes (Lamb, T & Bourriau, J, 1995).

Three attributes are frequently used to describe color, the first of which specifies one of the colors of the spectral sequence or one color of the non-spectral sequence. This attribute is more commonly known as hue, dominant wavelength, or chromatic color. The second attribute is known as saturation, chroma, tone, or intensity. These terms measure the absence of white, gray, or black colors that may be present. The final attribute of color is designated as brightness, value, lightness, or luminance. These are levels of a given hue and saturation level (Nassau, 1998).

Dyes

Azo dyes are very important classification of dyes because they account for the majority of the dyes used today (Gordon & Gregory, 1983). These dyes are stronger and brighter than natural dyes. Azo dyes contain hydroxy and carboxy groups, which react with metal ions. This metal ion alters the properties of the dyes that can in turn alter the light resistance of the dyes. The ∏-electronic make-up of molecules effects the color and strength of the dyes. The Paruser-Parr-Pople (PPP) model and theory incorporated ∏-electrons to explain, predict, and calculate the color and strength of dyes (Gordon & Gregory, 1983). This theory stated that the hydrogen and carbon group molecules, on a flat surface rotate to form a bond. When light strikes the molecules, pi-electrons become excited. This excitement stops the rotation of the molecules, which causes the bond to break. When this bond is broken, the surface of the molecules becomes curved. The curving of the surface, or breaking of the flat plane results in fading. To calculate the intensity of the dyes before or after the change in the surface of the molecules, the PPP model used a complex scientific computer generated system to measure the wavelengths and analyze the color and intensity of the dyes (Gordon & Gregory, 1983).

The loss of color in dyes is due to a photochemical reaction. This happens when a molecule absorbs light energy and is raised to an excited state. While the molecule is in this state, it can lose energy and return to its original ground state or it might decompose before reaching the ground state (Gordon & Gregory, 1983). When the later occurs, that process is termed as a photochemical reaction. This photochemical reaction can be measured with the following formula.

$$\Phi = \frac{\text{The number of molecules reacted}}{\text{The number of quanta absorbed}}$$

$\Phi < 1$ indicated a low efficiency in which other processes are preferred to the chemical reaction, this applies to the photofading process of dyes. Some factors have been identified as effecting the reaction of the dye. These factors are the nature of the light source, absorption characteristics, and the nature of the solvent and the presence or absence of air and moisture. The longer these molecules are in the excited state, the greater the chance it has of reacting and fading.

Giles and McKay (1963) stated when radiation falls on an absorbing molecule, some of the energy increases the vibration and the rotation energy of the molecule. Also, it can excite the electron to a higher energy level. Again, this excited state will lead to the fading of the dyed textile.

Four factors have been identified as influencing photochemical degradation; they are the wavelength of irradiation, the moisture in the textile, the absorption characteristics of the dyes, and the composition of the atmosphere surrounding the textile during exposure. These factors contribute to the process of photochemical degradation of the cotton cellulosic fiber. Oxygen and water vapor are constantly in our atmosphere at varying levels and effect the identified four factors. The wavelength can range from 400-750 namometers (Gavor, 1990), while the moisture in the textile reacts with the water vapor. The absorption characteristics of the dyes also react with the water vapor level, and the atmosphere is a combination of both oxygen and water vapor levels. It is necessary to consider all of these factors when evaluating the color change of dyes.

CHAPTER THREE

METHOD

This chapter describes the American Association of Textile Chemists and Colorists (AATCC) test methods to test sunlight, fluorescent, and halogen resistance to fading. The sunlight resistance was tested using the test method number16A-1988 from the AATCC Technical Manual. The sunlight testing procedure followed the AATCC guidelines for Xenon Weather-Ometer colorfastness testing as specified in option E. The fluorescent and halogen test methods were an adaptation from the AATCC test method 16-1988. The evaluation procedures utilized the AATCC Gray Scale and color level readings from a color spectrometer.

Lightfastness must have some method of measurement in research. Colorfastness to light is usually evaluated using a reference standard. This standard was necessary for both sunlight and artificial light sources. It was important to use this standard when communicating information regarding the test results. Comparative lightfastness results were acquired by testing all of the samples to the same light sources, simultaneously, for the same amount of time. With these types of testing conditions, the reference standard may be omitted. However, when this method is used, the lightfastness value is only relative to the samples exposed in that particular test (Mehta, 1992).

For this research nine samples from each selected color of dyed 100% cotton T-shirts were cut and used for testing for lightfastness. Three samples of each color were exposed to each type of lighting. Every sample was read in three different locations for color levels. The samples of a color were cut from one shirt to ensure that the samples are from the same dye lot. The samples were cut from different areas of the shirt to ensure a representative sample. The samples were exposed to light for 720 hours to match the retail stock turn-rate of 10.4 weeks. Each sample was monitored for fading every 72 hours at which time color levels were checked using the Datacolor Spectrometer.

The size of the sample was also an important consideration. "Ideally, a sample should be small enough to be handled easily and readily presented to an instrument" (Celikiz & Kuehni, 1983, p. 50). The sample should also be large enough to cover the area of the port on measuring instrument. The size of the sample was also dependent upon the type of measuring instrument used, in this case the color spectrophotometer. The samples were cut at least 2.75 X 4.7 inches, with the exposed area measuring at least 1.2 X1.2 inches. The specimens that were tested in the Xenon Weather-Ometer for continuous light must be secured inside the frame to be placed in the machine for testing. All samples were mounted on white card stock for labeling.

The thickness and texture of the sample also contributed to the testing procedure. The general rule for thickness of samples indicated that one additional layer of fabric would not result in a change of results. This can be a potential problem for lightweight fabrics, which should be addressed. If too many layers are added, then excess thickness may result which will produce inaccurate edge measurements. Texture refers to any nonuniformity in the surface of the textile sample. The appearance is different when viewed from different angles, and so the light will not strike the surface evenly.

Therefore, a flat, even sample must be obtained for testing of the sample (Celikiz & Kuehni, 1983).

Testing Procedure

Sunlight Testing

The first test to be preformed used the Xenon Weather-Ometer machine for testing continuous light, simulating sunlight. Before this test was preformed the machine was operated for twenty-four hours to ensure the equipment was fully operational. The samples were mounted in the frames to be placed on the specimen rack. All materials were securely supported on top and bottom and properly aligned. The face side of the fabric was directly exposed to the radiant source. The specimen rack was completely filled; card stock was used to fill an empty rack (AATCC Technical Manual, 1999).

The testing apparatus was operated on a daily basis until the preferred hours of simulation were completed. The test specimens were exposed for 40 fading units to determine if the samples meet the minimal standards for women's and girls knitted sportswear established by the American Society for Testing Materials (ASTM). The exposure and testing conditions were monitored and the controls were readjusted as necessary (AATCC Technical Manual, 1999).

Fluorescent and Halogen Lighting Testing

The back of the test specimens were mounted to white card stock, with an solid cover to mask one-half of the sample. Three specimens in each color were exposed to both a fluorescent and a halogen lamp. The halogen lamp was closer in proximity to samples since it is testing accent lighting in accordance with the Illuminating Engineering Society standards for display lighting footcandles.

The samples remained exposed for twenty-four hours a day for 720 hours in a lighting laboratory, and were removed for inspection every 72 hours. Each specimen was evaluated against the covered control or an unexposed original for evaluation.

Evaluation

To evaluate the colorfastness of the samples, the exposed area of the sample was compared to the masked portion of the sample or to an unexposed original. This evaluation was preformed during the stages of the exposure process and after the exposure was completed. To quantify the color changes, the AATCC Gray Scale of Color Change and color spectrometer readings were used (AATCC Technical Manual, 1999). The AATCC Gray Scale is a numerical rating ranging from one to five. A rating of five is considered to have no color change at all, while a rating of one is considered to have extreme color change. To determine which rating a sample will receive the intensity in change between the original sample and the exposed sample will be compared to the intensity changes of each step of the AATCC Grey Scale. The rating of the closest matching intensity will be assigned to the samples as its rating. This data was compared to the American Society of Testing Materials (ASTM) standards for women's knitted T-shirts to determine if the colorfastness of the samples is satisfactory. A maximum of a class 4 color change will comply with ASTM standards.

Datacolor Spectrometer readings were taken before and after the exposure to light, as well as every 72 hours. Chroma and hue color levels were displayed on the spectrometer screen and recorded. Statistics were then used to analyze the data.

After determining the satisfactory/unsatisfactory status of the samples using the AATCC Gray Scale, the data from the color spectrometer and gray scale ratings were analyzed. T-tests were preformed to determine if the samples had significantly faded by color by light by time. Analysis of variance (ANOVA) and Univariate Analysis of Variance statistics was used to analyze the variance. This statistic allowed for detection of interaction between main effect variables and allowed the data to be interpreted with assurance that any difference was the result of the means and not random error. Where a significant difference was found, the hypothesis was not rejected (Statistica Enterprise System, 1999).

The ANOVA statistics were preformed on the main effect hypotheses to analyze the variance within the samples and to determine significance levels. The Univariate Analysis of Variance was preformed on the interaction hypotheses. When a significant change in hue or chroma was found when controlling for the light source, then a post-hoc statistic the Scheffe test, was preformed. When a t-test was used to examine the points of interaction, between color and light the means were plotted. Finally, the main effect hypotheses concerning carbon-arc testing were also analyzed using one-way ANOVA tests.

CHAPTER FOUR

FINDINGS

The American Association of Textile Chemists and Colorist (AATCC) Gray scale rating system was used to determine if the test specimens were in compliance with the American Society of Testing Materials (ASTM) standards. The AATCC Gray Scale is a system of rating color changes that ranges from a 5.0 to a 1.0. On this scale a 5.0 is considered perfect, with no color change. There are half-steps between each whole number on the scale. Each step (including half-steps) on the scale represents a different level of color change intensity. To determine which rating a sample will receive the intensity in change between the original sample and the exposed sample will be compared to the intensity changes of each step of the AATCC Gray Scale. The rating of the closest matching intensity will be assigned to the samples as its rating. A minimum of a class 4 rating is required to be satisfactory for women's sportswear apparel. The minimum rating is determined by ASTM. Table 1 identifies each sample's rating on the AATCC Gray scale.

All of the samples exposed to fluorescent and halogen lighting were considered satisfactory by ASTM standards after 720 hours of exposure. Each sample had a rating higher than a 4.0. However, the same was not true for samples exposed to Xenon

Weather-Ometer lighting conditions. All of the red samples received a rating of 3.5, below the 4.0 minimum established by ASTM. Two of the teal samples received a 3.5 rating, while one sample passed at a 4.0 rating. The blue samples passed with a 4.5 rating.

Table 1
Individual Exposure Sample Rating Table for all Fabric Samples

Sample #	Sample Color	Time of Exposure	AATCC Gray Scale Rating
Fluorescent 1	Blue	720 Hours	4.5
Fluorescent 2	Blue	720 Hours	4.5
Fluorescent 3	Blue	720 Hours	5.0
Fluorescent 4	Red	720 Hours	4.5
Fluorescent 5	Red	720 Hours	5.0
Fluorescent 6	Red	720 Hours	4.5
Fluorescent 7	Teal	720 Hours	5.0
Fluorescent 8	Teal	720 Hours	4.5
Fluorescent 9	Teal	720 Hours	5.0
Halogen 1	Blue	720 Hours	4.5
Halogen 2	Blue	720 Hours	4.5
Halogen 3	Blue	720 Hours	4.5
Halogen 4	Red	720 Hours	4.5
Halogen 5	Red	720 Hours	5.0
Halogen 6	Red	720 Hours	5.0
Halogen 7	Teal	720 Hours	5.0
Halogen 8	Teal	720 Hours	5.0
Halogen 9	Teal	720 Hours	4.5
Xenon 1	Blue	40 Fading Units	4.5
Xenon 2	Blue	40 Fading Units	4.5
Xenon 3	Blue	40 Fading Units	4.5
Xenon 4	Red	40 Fading Units	3.5
Xenon 5	Red	40 Fading Units	3.5
Xenon 6	Red	40 Fading Units	3.5
Xenon 7	Teal	40 Fading Units	3.5
Xenon 8	Teal	40 Fading Units	4.0
Xenon 9	Teal	40 Fading Units	3.5

Although the AATCC Gray scale system showed minimal levels of fading, the Datacolor Spectrometer statistics showed very different results. Statistical analysis were preformed using the Datacolor Spectrometer output readings to determine significant levels of fading. Datacolor readings were taken before and after exposure to obtain the data for analysis because the focus of this experiment was on the change in chroma and hue. Each sample was analyzed by color, light source, and time. The statistical software program, Statistical Package for the Social Sciences (SPSS) was used in this data analysis.

$H_0 1$: The effects of general fluorescent lighting will not significantly fade royal blue 100% cotton T-shirts after 360 hours of exposure, the equivalent of 5 and one-half weeks in a retail environment.

This hypothesis was rejected because of a significant change in chroma ($t=4.819$, $p \leq .001$). The change in hue was also significant ($t=-30.389$, $p \leq .001$). Therefore, this hypothesis was rejected. (See Table 2.)

$H_0 2$: The effects of general fluorescent lighting will not significantly fade royal blue 100% cotton T-shirts after 720 hours of exposure, the equivalent of 11 weeks in a retail environment.

Results of a t-test indicated that there was a significant change in chroma ($t=8.751$, $p \leq .001$) and a significant change in hue ($t=3.937$, $p=.004$) when the royal blue samples were exposed to 720 hours of general fluorescent lighting. Therefore this hypothesis was rejected. (See Table 2.)

$H_0 3$: The effects of halogen display lighting will not significantly fade royal blue 100% cotton T-shirts after 360 hours of exposure, the equivalent of 5 and one-half weeks in a retail environment.

Results of a t-test indicated that there was a significant change in chroma ($t=16.709$, $p \leq .001$) and a significant change in hue ($t=-20.752$, $p \leq .001$) when the royal blue samples were exposed to 360 hours of halogen display lighting. Therefore this hypothesis was rejected. (See Table 2.)

$H_0$4: The effects of halogen display lighting will not significantly fade royal blue 100% cotton T-shirts after 720 hours of exposure, the equivalent of 11 weeks in a retail environment.

Results of a t-test indicated that there was not a significant change in chroma (t=1.139, p = .288) and a significant change in hue (t=.053, p = .789) when the royal blue samples were exposed to 720 hours of halogen display lighting. Therefore this hypothesis failed to be rejected. (See Table 2.)

$H_0$5: The effects of xenon weather-ometer simulated sunlight will not significantly fade royal blue 100% cotton T-shirts after 40 AATCC Fading Units of exposure.

Results of a t-test indicated that there was a significant change in chroma (t=2.637, p =.030) and a significant change in hue (t=12.810, p ≤ .001) when the royal blue samples were exposed to 40 AATCC Fading Units of carbon-arc lighting. Therefore this hypothesis was rejected. (See Table 2.)

H_0 6: The effects of general fluorescent lighting will not significantly fade red 100% cotton T-shirts after 360 hours of exposure, the equivalent of 5 and one-half weeks in a retail environment.

Results of a t-test indicated that there was not a significant change in chroma (t=.704, p = .501) and there was a significant change in hue (t=35.909, p ≤.001) when the red samples were exposed to 360 hours of general fluorescent lighting. The change in chroma and the change in hue were not both significant. The AATCC Gray Scale was the first method of evaluation of change used in this study and it is based on changes in intensity and perceived color. A change in intensity (chroma) and a change in perceived color (hue) is necessary to be penalized on the AATCC Gray Scale. The change in chroma was not significant and it is the component of color associated with intensity. Therefore, following the guidelines of the industry standard AATCC Gray Scale as an evaluation tool, this hypothesis failed to be rejected (See Table 2.)

H_0 7: The effects of general fluorescent lighting will not significantly fade red 100% cotton T-shirts after 720 hours of exposure, the equivalent of 11 weeks in a retail environment.

Results of a t-test indicated that there was not a significant change in chroma ($t=.219$, $p = .832$) but there was a significant change in hue ($t=26.317$, $p \leq .000$) when the red samples were exposed to 720 hours of general fluorescent lighting. The change in chroma and the change in hue were not both significant. The AATCC Gray Scale was the first method of evaluation of change used in this study and it is based on changes in intensity and perceived color. A change in intensity (chroma) and a change in perceived color (hue) were necessary to be penalized on the AATCC Gray Scale. The change in chroma was not significant and it is the component of color associated with intensity. Therefore, following the guidelines of the industry standard AATCC Gray Scale as an evaluation tool, this hypothesis failed to be rejected (See Table 2.)

$H_0$8: The effects of halogen display lighting will not significantly fade red 100% cotton T-shirts after 360 hours of exposure, the equivalent of5 and one-half weeks in a retail environment.

Results of a t-test indicated that there was a significant change in chroma ($t=10.523$, $p \leq .001$) but there was not a significant change in hue ($t=1.254$, $p = .245$) when the red samples were exposed to 360 hours of halogen display lighting. The AATCC Gray Scale was the first method of evaluation of change used in this study and it is based on changes in intensity and perceived color. A change in intensity (chroma) and a change in perceived color (hue) were necessary to be penalized on the AATCC Gray

Scale. The change in hue was not significant and it is the perceived color. Therefore, following the guidelines of the industry standard AATCC Gray Scale as an evaluation tool, this hypothesis failed to be rejected. (See Table 2.)

$H_0$9: The effects of halogen display lighting will not significantly fade red 100% cotton T-shirts after 720 hours of exposure, the equivalent of 11 weeks in a retail environment.

Results of a t-test indicated that there was a significant change in chroma ($t=15.482$, $p \leq .001$) and a significant change in hue ($t=10.276$, $p \leq .001$) when the red samples were exposed to 720 hours of halogen display lighting. Therefore this hypothesis was rejected. (See Table 2.)

$H_0$10: The effects of xenon weather-ometer simulated sunlight will not significantly fade red 100% cotton T-shirts after 40 AATCC Fading Units of exposure.

Results of a t-test indicated that there was a significant change in chroma ($t=16.073$, $p\leq .001$) and a significant change in hue ($t=8.115$, $p \leq .001$) when the red samples were exposed to 40 AATCC Fading Units of carbon-arc lighting. Therefore this hypothesis was rejected. (See Table 2.)

$H_0$11: The effects of general fluorescent lighting will not significantly fade teal 100% cotton T-shirts after 360 hours of exposure, the equivalent of 5 and one-half weeks in a retail environment.

Results of a t-test indicated that there was a significant change in chroma ($t=7.672$, $p \leq .001$) and a significant change in hue ($t=-7.015$, $p \leq .001$) when the teal samples were exposed to 360 hours of general fluorescent lighting. Therefore this hypothesis was rejected. (See Table 2.)

$H_0$12: The effects of general fluorescent lighting will not significantly fade teal 100% cotton T-shirts after 720 hours of exposure, the equivalent of 11 weeks in a retail environment.

Results of a t-test indicated that there was a significant change in chroma ($t=7.833$, $p \leq .001$) and a significant change in hue ($t= -1.6722$, $p \leq .001$) when the teal samples were exposed to 720 hours of general fluorescent lighting. Therefore this hypothesis was rejected. (See Table 2.)

$H_0$13: The effects of halogen display lighting will not significantly fade teal 100% cotton T-shirts after 360 hours of exposure, the equivalent of 5 and one-half weeks in a retail environment.

Results of a t-test indicated that there was a significant change in chroma ($t=8.760$, $p \leq .001$) and a significant change in hue ($t= -6.363$, $p \leq .001$) when the teal samples were exposed to 360 hours of halogen display lighting. Therefore this hypothesis was rejected. (See Table 2.)

$H_0$14: The effects of halogen display lighting will not significantly fade teal 100% cotton T-shirts after 720 hours of exposure, the equivalent of 11 weeks in a retail environment.

Results of a t-test indicated that there was a significant change in chroma ($t=7.429$, $p \leq .001$) and a significant change in hue ($t=17.999$, $p \leq .001$) when the teal samples were exposed to 720 hours of halogen display lighting. Therefore this hypothesis was rejected. (See Table 2.)

$H_0$15: The effects of xenon weather-ometer simulated sunlight will not significantly fade teal 100% cotton T-shirts after 40 AATCC Fading Units of exposure.

Results of a t-test indicated that there was a significant change in chroma ($t=54.931$, $p \leq .001$) and a significant change in hue ($t= -74.456$, $p \leq .001$) when the teal samples were exposed to 40 AATCC Fading Units of carbon-arc lighting. Therefore this hypothesis was rejected. (See Table 2.)

Table 2

T- Tests of Fading of Samples by Color X Light X Time (Hours)

Hypothesis #	Color	Light Source	Hours	Chroma Mean Difference	Hue Mean Difference
$H_0 1$	Blue	Fluorescent	360	1.0556***	-2.2789***
$H_0 2$	Blue	Fluorescent	720	0.3589***	0.2556**
$H_0 3$	Blue	Halogen	360	.9722***	-1.5678***
$H_0 4$	Blue	Halogen	720	.0533	.00778
$H_0 5$	Blue	Xenon	40†	1.7456*	1.4511***
$H_0 6$	Red	Fluorescent	360	0.6733	.8400***
$H_0 7$	Red	Fluorescent	720	0.2489	1.2100***
$H_0 8$	Red	Halogen	360	2.7411***	0.1711
$H_0 9$	Red	Halogen	720	2.8067***	.6933***
$H_0 10$	Red	Xenon	40†	4.0278***	-0.222***
$H_0 11$	Teal	Fluorescent	360	.9044***	-.6456***
$H_0 12$	Teal	Fluorescent	720	1.0200***	-1.6722***
$H_0 13$	Teal	Halogen	360	.9211***	-.6922***
$H_0 14$	Teal	Halogen	720	.8756***	-1.4433***
$H_0 15$	Teal	Xenon	40†	3.9711***	-3.5911***

p * < .05
p ** < .01
p *** < .001
† =AATCC Fading Units

Main Effect and Interaction Effects

$H_0$16: Regardless of light, at 360 hours, there will be no significant change in chroma and hue between the colors royal blue, red and teal.
$H_0$17: Regardless of color, at 360 hours, there will be no significant change in chroma and hue for samples exposed to fluorescent and halogen lighting.
$H_0$18: There will be no significant change in interaction of light and color at 360 hours.

The data for $H_0$16, $H_0$17, and $H_0$18 were analyzed using an Analysis of Variance (ANOVA) at the 360 hour midpoint time interval. This test allowed for an examination of the main effect of one variable (color or light) while controlling for the effect of the second variable and the interaction effect of color and light (color X light).

When a significant main effect for color was found, a post hoc Scheffe test was used to determine which color caused the changes within the main effect. When a significant main effect for light was found, a t-test was used to determine which light source caused the changes within the main effect.

The ANOVA indicated that there was a significant change in chroma by color ($F=5.781$, $p=.006$). A significant difference or change in hue was also found by color ($F=348.416$, $p \leq .000$). These results indicated that there were significant differences in fading depending on the color of the samples. (See Table 3.) Therefore, it was necessary to reject hypothesis $H_0$16 because there was significant change in chroma and hue after 360 hours by color.

Table 3

Main Effects and Interaction Effect for Color and Light after 360 Hours of Exposure

Source	Chroma		Hue	
	Mean	F	Mean	F
Color		5.781*		348.416***
Royal Blue	1.0139		-1.9233	
Red	2.3506		.5056	
Teal	.8439		-.6689	
Light		.235		.000
Fluorescent	1.3067		-.6948	
Halogen	1.4989		-.6963	
Color X Light		.553		28.198***

p. * < .05
p ** < .01
p *** < .001

An analysis using the Scheffe revealed that the color red had a larger, significant change in chroma than the colors blue and teal. The biggest change occurred between the color red and teal at (p = .012) with a mean of 1.5067. Whereas, red changed more significantly than the color blue (mean difference of 1.3367, p = .303), blue did not change significantly more than teal (mean difference of .1700, p=.941) Table 4 displays the individual significance levels at 360 hours.

Table 4
Post Hoc Scheffe Tests for Chroma Change Between Colors at 360 Hours

Color		Mean Difference
Blue	Teal	.1700
Red	Blue	1.3367*
Red	Teal	1.5067*

* $p < .05$

Every combination of colors were found to have significant changes in hue at p≤.001. The Sheffe test to compare the differences between the color means after exposure to fluorescent and halogen light revealed that the largest hue color change occurred between the red and blue (p≤.001) with a mean of 1.1744, followed by teal to blue (p≤.001) with a mean of 1.2544, and then red to teal at (p≤.001) with a mean of 1.1744 . Table 5 displays the individual significance levels at 360 hours.

Table 5
Post Hoc Scheffe Tests for Hue Change Between Colors at 360 Hours

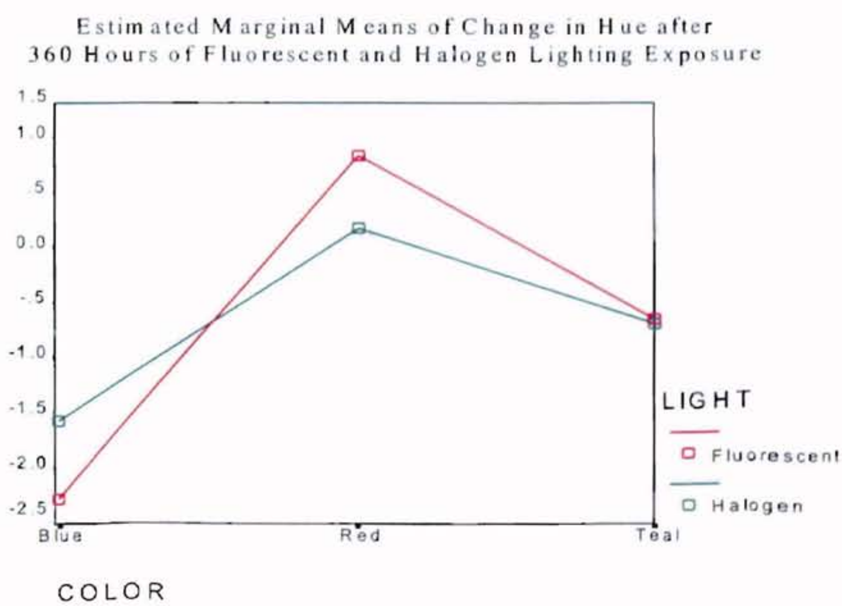
Color		Mean Difference
Red	Blue	2.4289***
Red	Teal	1.1744***
Teal	Blue	1.2544***

** $p < .001$

When testing for the main effect of light, no significant difference for change in chroma or change in hue was found after the samples were exposed to 360 hours of fluorescent or halogen light (F=.235, p=.630 and F=.000, p=.984 respectively). Hypothesis $H_0 17$ was not rejected because there was no significant change in chroma or hue after 360 hours of exposure to fluorescent or halogen lighting. Table 3 displays these findings.

The interaction between light and color was also not significant for change in chroma (F=.553, p>.579). However, for change in hue there was a significant interaction at F=28.198, (p≤.000). This indicated that the perceived color (hue) was greater for some colors exposed to fluorescent light while the change in perceived color was greater for other colors exposed to halogen light. $H_0 18$ addresses the interaction between light and color. To determine which colors faded more under which lighting condition, the mean changes were plotted on a graph. The difference in the change of hue means were plotted vertically, while the colors were plotted horizontally. The graph (see Figure 2) indicates that blue faded more when exposed to halogen light, while red faded more when exposed to fluorescent light. Teal samples faded equally under fluorescent and halogen lighting conditions. The interaction between color and light was not significant for chroma, but was significant for hue. Therefore, $H_0 18$ was rejected. (See Figures 2 and 3.)

Figure 2



$H_0$19: Regardless of light, at 720 hours, there will be no significant change in chroma and hue between the colors royal blue, red, and teal.
$H_0$20: Regardless of color, at 720 hours, there will be no significant change in chroma and hue for samples exposed to fluorescent and halogen lighting.
$H_0$21: There will be no significant change in interaction of light and color at 720 hours.

An ANOVA was used to analyze the readings collected to test $H_0$19, $H_0$20, and $H_0$21.

The ANOVA indicated that there was a significant change in chroma by color ($F=3.891$, $p=.027$) and change in hue by color ($F=1025.007$, $p=.000$). (See Table 6.) Therefore, it was necessary to reject hypothesis $H_0$19 because of significant changes in chroma and hue by color.

Table 6
Main Effects and Interaction Effect for Color and Light after 720 Hours of Exposure

Source	Chroma		Hue	
	Mean	F	Mean	F
Color		3.891*		1025.007***
Royal Blue	.2061		.1317	
Red	1.5278		.9517	
Teal	.9478		-1.5578	
Light		3.283		14.963**
Fluorescent	1.2452		-.2474	
Halogen	.5426		-.0689	
Color X Light	5.736**		22.312**	

* p < .05
** p<.01
***p < .001

A post hoc Scheffe test was preformed to identify which colors faded the most in chroma after 720 hours of exposure. Table 7 indicates that regardless of light source (fluorescent or halogen), the red samples changed significantly more than the blue samples (mean difference of 1.3217, $p = .028$). This was the only significant change in chroma by color. The color change in blue was not significantly greater than the change in teal (mean difference of .7417, $p=.304$). Finally, red did not change significantly compared to teal (mean difference of .5800, $p =.480$).

Table 7
Post Hoc Scheffe Test for Chroma Change Between Colors at 720 Hours

Color		Mean Difference
Red	Blue	1.3217*
Red	Teal	.5800
Teal	Blue	.7417

p * < .05

A post hoc Scheffe test was also performed to identify significant changes in hue by color after 720 hours of exposure. The results are shown in Table 8. Hue changed in the red samples more than the hue changed in the teal samples ($p\leq.001$) with a mean difference of 2.5094, the hue for the teal samples change significantly more than hue for the blue samples changed ($p\leq.001$) with a mean of 1.6894. The red samples changed in hue significantly more compared to the blue samples ($p\leq.001$) with a mean of .8200. (See Table 8.)

Table 8

Post Hoc Scheffe Tests for Hue Change Between Colors at 720 Hours

Color		Mean Difference
Red	Blue	.8200***
Red	Teal	2.5094***
Teal	Blue	1.6894***

p *** < .001

Results from the ANOVA indicated no main effect for light for change in chroma after 720 hours of exposure ($F=3.283$, $p>.076$). However, a main effect for light was found for change in hue, ($F=14.963$, $p\leq.001$) after 720 hours of exposure. (See Table 6.)

Hypothesis H_020 failed to be rejected because the change in chroma and the change in hue were not both significant. The AATCC Gray Scale was the first method of evaluation of change used in this study and it is based on changes in intensity and perceived color. A change in intensity (chroma) and a change in perceived color (hue) were necessary to be penalized on the AATCC Gray Scale. The change in chroma was not significant and it is the component of color associated with intensity. Therefore, following the guidelines of the industry standard AATCC Gray Scale as an evaluation tool, this hypothesis failed to be rejected.

Although hypothesis H_020 was not rejected, a post-hoc t-test was preformed for change in hue at 720 hours. The t-test reveal that halogen light (mean .-2474) did not fade the samples more than fluorescent light (mean .-0689) ($t=.603$, $p=.549$). (See Table 9.)

Table 9
Post Hoc T-Test Table for Light at 720 Hours of Exposure

Source	Mean	t
Light	3.809	.603
Fluorescent	.0689	
Halogen	.2474	

The interaction effect of color and light was significant for change in chroma at F=5.736, p>.006 and for change in hue at (F=22.312, p=.000). The results of the interaction effect indicate that the changes in chroma and hue were greater for some colors exposed to fluorescent light while the changes in chroma and hue were greater for other colors exposed to halogen light. Once again, to determine which colors faded more under which lighting condition, the mean changes were plotted on a graph. For change in chroma, the graph (see Figure 3) indicates that blue fades more when exposed to fluorescent light, while red fades more when exposed to halogen light. The teal samples faded equally under fluorescent and halogen lighting conditions. For change in hue, the graph (see Figure 4) indicates that both blue and red fade more when exposed to fluorescent light. Teal samples, however, fade more when exposed to halogen light. Therefore, $H_0$21was rejected because there was interaction between light and color for both chroma and hue.

Figure 3

Estimated Marginal Means of Change in Chroma after 720 Hours of Fluorescent and Halogen Lighting Exposure

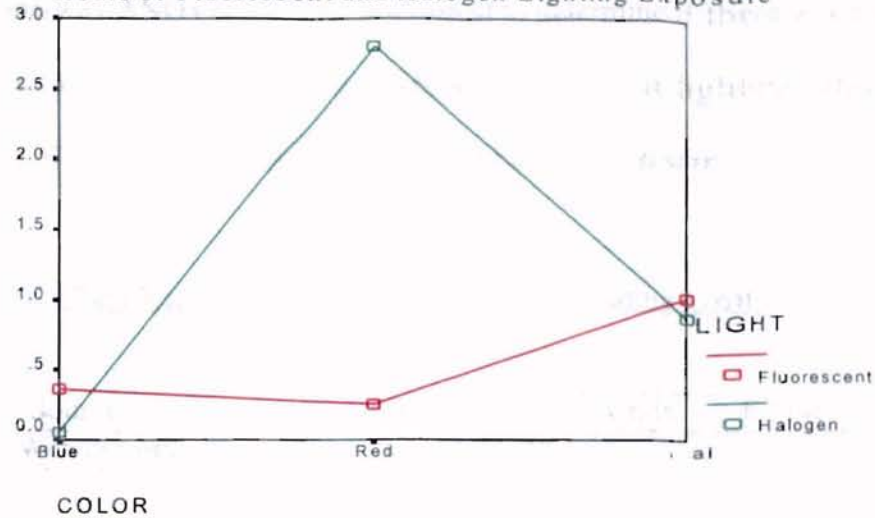
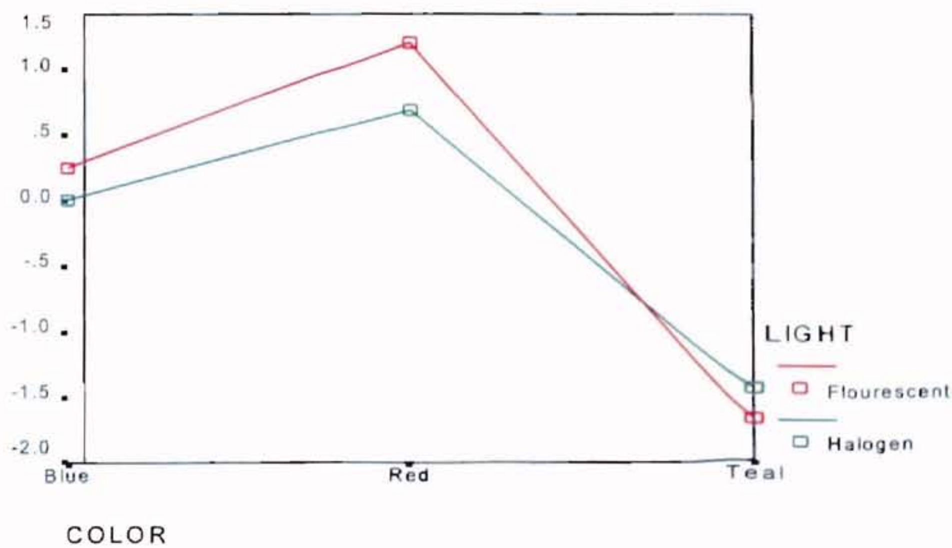


Figure 4

Estimated Marginal Means of Change in Hue after 720 Hours of Fluorescent and Halogen Lighting Exposure



$H_0$22: There will be no significant change in chroma and hue for samples exposed to 40 AATCC Fading Units.

A one-way ANOVA test was preformed to determine if there was a significant change in chroma and hue for samples exposed to carbon-arc lighting. This test analyzed the variance of the changes in both chroma and hue for each sample tested.

Table 10
ANOVA Test Xenon Weather-Ometer Lighting Fading Units Significance Levels

Source	F-Chroma @ 40 Fade Units	F-Hue @ 40 Fade Units
Xenon Weather-ometer	10.043**	891.563**

p * < .05
p** < .05

Hypothesis $H_0$22 was rejected because there was a significant change in chroma (F=10.043, p>.001) and for change in hue (F=891.563, p=.000) after exposure to 40 AATCC Fading Units.

CHAPTER FIVE

Summary and Conclusions

The AATCC Gray Scale ratings for the samples tested indicated that all of the test specimens exposed to fluorescent and halogen lighting were considered to be satisfactory. To the human eye, little or no fading was evident in the samples after 720 hours of exposure to fluorescent and halogen light. This was not the case for the xenon weather-ometer simulated sunlight test, when evaluated using the AATCC Gray Scale those samples did show visible amounts of fading; only the royal blue samples and one of the three teal samples were considered satisfactory by the American Society for Testing Materials (ASTM) standards.

The statistical analysis of the Datacolor Spectrometer readings did not agree with the AATCC ratings. The Datacolor Spectrometer is a highly sensitive piece of equipment, intended for matching colors in dye lots. The discrepancy in the AATCC ratings and statistical analysis using the Datacolor Spectrometer readings indicated the possibility that the Datacolor Spectrometer may be too sensitive for this type of research study.

T-tests were preformed to determine if significant changes occurred in chroma and hue after both 360 and 720 hours of exposure to fluorescent or halogen light. At 360 hours, light did not effect the fading at significant levels. When comparing fluorescent and halogen lighting for chroma fading, the halogen light caused the most fading at 360 hours. The color red faded the most regardless of lighting source when analyzing the difference in chroma and hue at 360 hours. This experiment was continued until the 720^{th} hour of exposure was reached in order to determine if time of exposure contributed to fading.

After 720 hours, only one sample did not change significantly at the .05 level in chroma or hue. This was enough evidence to warrant testing for main effects and interaction effects. When comparing changes in chroma after exposure to fluorescent and halogen light, halogen lamps caused the most fading at 720 hours. At 720 hours, halogen light faded the samples the most when comparing the lighting sources. In analyzing the difference in hue, at 720 hours, the color red faded the most.

The time of exposure was found to contribute to the amount of fading of the samples. A post experiment t-tests revealed that all of the samples continued to have significant changes in hue during the time lapsed between 360 and 720 hours. However, the change in chroma were not significant between 360-720 hours for the red and teal samples. Only the royal blue samples had a significant change in chroma for this time frame.

Discussion of Research Findings

In chapter three, it was noted that the fluorescent and halogen lighting test method was an adaptation of several existing colorfastness test methods. This was done because there was no specific test method for fluorescent and halogen lighting colorfastness. Because changes in chroma and hue were found in this experiment, it is believed that using this new test method was a reliable form of evaluation.

Another result from this study was a difference in the fading of chroma and hue levels. In four cases, the chroma and hue levels faded differently. Three out of the four samples had significant changes in chroma but not hue. To clarify this finding, it should be recalled that hue is the trait most commonly recognized as the actual perceived color. Chroma is the saturation or intensity level of the perceived color.

It may be possible to prevent future changes in chroma and hue. The lowering of footcandles on halogen display lighting, careful selection of display colors, and the frequent rotation of merchandise out of displays can prevent some of the change in chroma and hue. By lowering the footcandles of a halogen display lamp, the retailer may be able to increase the spinning of the molecules (Gordan & Gregory, 1983) which should prevent the excited the electrons from ceasing their rotation which leads to fading.

By selecting textile products which are lightfast for display purposes, the chance of fading is decreased. The nature of the light source and the absorption properties of the object directly effect the colorfastness of the cotton T-shirts. When a light source strikes a dyed textile, different portions of light are absorbed by the dye which is dependant on the structure and light absorption characteristics of the dye (Needles, 1986).

Rotation of merchandise and the careful display of merchandise can also decrease the chance of fading. The exposed area of merchandise is faded while the area not exposed retains its original color. The merchandise is noticeably faded because half of the merchandise is faded while the other half is not. To prevent this from occurring, retailers should rotate their merchandise every week to ten days (IES Merchandising Lighting Committee, 1991).

Conclusions and Recommendations

In conclusion, it was found that the literature review and theoretical bases were accurate in assuming that artificial light sources would fade textile products. The statistical analysis of the data collected using the Datacolor Spectrometer confirmed the findings reported in the literature. However, the AATCC Gray Scale ratings did not concur with the literature and statistical findings from the Datacolor Spectrometer data.

A more reasonable way of evaluating colorfastness levels may be needed. While the AATCC Gray Scale is subject to the human eye and can be considered biased, it was the best analysis tool of the two utilized in this study. It is not economical for an apparel manufacture to the Datacolor Spectrometer for lightfastness levels of merchandise. The Datacolor Spectrometer readings were too harsh for this study. However, with the appropriate software, the AATCC Gray Scale can be programmed into the Datacolor Spectrometer. With this software a computer can determine which AATCC Gray Scale color change class the sample falls into. This would reduce the subjectivity and bias of the human eye.

If the fading is not visible to the human eye, then the retailer is not disadvantaged in anyway; however, the consumer may be disadvantaged later when their merchandise fades from previous exposure to light because the fading process has already begun. While the merchandise was in the retail store, the hydrogen and carbon molecule have absorbed light, thus exciting the electrons. The molecules will loose energy, stop spinning and return to the ground state, which leads to fading. It may be assumed that further exposure and care cycles will continue the fading process. Further exposure can occur in any lit environment, not exclusively in sunlight. This study suggests that fading is a continuous process since textile products are continuously exposed to light. Care cycles will likely continue to deteriorate the dyes, since the molecular bonds would have been broken prior to the purchase of the merchandise.

It would be helpful to expand this research by including a larger variety of colors of samples and fiber contents. A true retail setting instead of a simulated setting would also be beneficial. The testing of sunlight by actual daylight instead of simulated sunlight would provide a more accurate analysis of sunlight fading.

Implications

Consumers are disadvantaged because they are purchasing merchandise that has begun to fade prior to purchasing. However, retailers are also disadvantaged because they too purchase textile products for their stores. Display cases and floor coverings are textile products, and are increasingly being made of natural fibers. Therefore retailers should be careful in their selection of colors for these products to prevent their own products from fading. As stated in this study, red would be a poor color choice for these textile products, and blue would be a better color choice.

Apparel and interior designers are also subject to the implications of fading. Apparel design and manufacturing facilities contain large quantities of fabric that is continuously exposed to light from their indoor lighting. Interior designers frequently use upholstery and flooring materials that contain natural fibers that is exposed to indoor and outdoor lighting. In these situations, the textile products can be exposed for extended periods of time surpassing 720 hours resulting in a lower life of the color of the textile product.

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