Abstract

Thangavelu, Ranjithkumar. Effect of Non-Visual Stimulus on Color Perception (under the direction of David Hinks).

The subjective perception of color and overall quality (age, abrasion, uniformity, etc) of textile products cannot always be characterized by physical measurement of the textile substrate alone. Color perception, for instance, is greatly influenced by factors such as the complexity of the viewing environment, mood, fatigue and stress. It is also known that certain stimuli can influence the subjective judgment of other stimuli.

In view of the critical role that color perception plays in the commercial success of almost all manufactured products, particularly consumer products such as apparel garments, it is important to determine the influence of non-visual stimuli that are not commonly controlled (e.g., tactile response) on the visual response of the average observer. Accordingly, this study is concerned with the possible influence of two non-visual stimuli, tactile response and odor, on the perception of the magnitude of color difference between two dyed fabric samples. It was considered that the ability to influence an observer's color perception by deliberately modifying one or more of the non-visual stimuli could lead to new avenues of research and development into optimized perception of color, wear and overall quality of textile products.

Large samples of 100% knit cotton fabric were dyed with fiber-reactive dyes to six hues of two depths of shade using a cold pad-batch method. Each sample was cut into four pieces and three were subjected to 1, 5 or 10 wash-and-dry

laundering cycles. Each of these samples was after-treated with either stiffening or softening agent. Then 25 - 30 trained observers were trained to visually assess the samples, with and without a tactile sensory input. Also, selected samples were assessed with and without a pleasant odor of lavender or orange oil fragrance.

Statistical analysis showed that color difference perception was influenced by tactile response. Observers rated samples as having a lower color difference when they assessed samples with soft hand compared to equivalent samples that were perceived to be very stiff.

Statistical analysis also showed that color-difference sample pairs with an orange hue exhibited significantly lower perceived color difference in the presence of orange oil fragrance than when no observable fragrance was present. However, the effect of orange oil fragrance on the color difference perception of other hues did not exhibit a statistically significant effect. Also, the presence of a lavender fragrance did not significantly affect the color difference perception of any hues.

Effect of Non-Visual Stimulus on Color Perception

by

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Biography

Ranjithkumar was born on December 25, 1978 in Coimbatore, India, to Thangavelu and Amirthavalli. He obtained his diploma from S.S.M Institute of Textile Technology in June 1997 and entered Shivaji University in August 1997. In June 2000, he received his Bachelor of Science degree, graduating with honors in Textile Chemistry. After graduating from Shivaji University, he worked for K.T.V Exports as a quality controller in the color laboratory. In 2001, he accepted a scholarship to enter the graduate program of the College of Textiles at North Carolina State University for a Master of Science degree in Textile Chemistry. He commenced his graduate studies in January, 2002.

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I. Introduction

A. Subjective Assessment

Subjective analysis or sensory tests have been conducted for as long as there have been human beings evaluating the quality of food, water, and all other materials that can be used in commerce. Increases in trade inspired the development of formal sensory testing. Initially, sensory testing began in earnest due to the need to grade wine, tea, coffee, butter, etc, which led to professional tasters and consultants for the food industry in early 1900's [1]. Scientists began to develop sensory testing as a formalized, structured and confined methodology, via development of new and improved statistically valid methods. The principal uses of sensory techniques are in quality control, product development and fundamental research [1,2]. Valid and meaningful sensory analysis is based on the skill of the sensory analyst in optimizing four factors, governing the measurement.

1. Defining the problem
2. Experimental design
3. Instrumentation
4. Interpretation of results

Study of the relationship between a given physical stimulus and a subject's response requires incorporation of at least three steps in the process shown below. The stimulus affects the sense organ, resulting in a nerve signal which travels to the brain. Using, in part, previous experiences in memory, the brain interprets, organizes, and integrates the incoming sensation into perceptions and elicits a response [1].

Stimulus

$\Downarrow$

Sensation

$\Downarrow$

Perception

$\Downarrow$

Response

The stimuli may be auditory, taste, odor, tactile or visual. Arguably, the most important responses with respect to textile materials are visual and tactile. For instance, often consumers of apparel garments first visually inspect and then touch the product. Hence, retailers and garment manufacturers are concerned with the color originally specified by the product designer, in addition to acceptable hand and technical specifications such as light, wash and rub fastness. Commonly, the material will receive a chemical or mechanical after-treatment to improve the tactile response (hand) of the final product.

In addition to retailer's and manufacturer's desire to control the color and hand of the garment during manufacturing and sale, consumer-care companies are also very much concerned with cleaning technology, via complex detergent systems, that maintain the visual and physical integrity of the garment after multiple washes. Hence, laundry detergents commonly contain surfactants and enzymes to remove oils and particulate matter, softening agents to maintain a pleasant hand and drape, and fragrances to enhance the perception of cleanliness and freshness.

Clearly, product manufacturer and consumer-care technology require the ability to control sensory perception, particularly vision (color), tactile (hand) and olfactory (fragrance), which implies a requirement for fundamental knowledge of each type of stimuli, as well as any cross-modal interactions.

1. Tactile (Hand)

Hand or handle is concerned with an observer's perception of how a fabric drapes around an object or feels to the touch. When the hand of a fabric is made to drape more or feel silkier, the fabric is said to be soft and vice versa when stiff. Sense of touch falls into two main categories, *somesthesis* and *kinesthesis*, both of which are pressure dependent [2,1]. There are several types of nerve endings in the skin surface. The surface nerve endings are responsible for the somesthetic sensations of touch, pressure, heat, cold, itching and tickling. Deep pressure, kinesthesis, is felt through nerve fibers in the muscles, tendons, i.e., the sensation of tension and relaxation in muscles. Ssensitivity is different over different parts of the human body due to the distribution of nerve fibers [1].

2. Color Perception

The conversion of light energy to color names such as red, green, and brown is psychological in nature and is an exceedingly complex process. Psychophysics of vision requires the understanding of optics, psychology, neural processing and cognition and is still not completely understood. Light entering the lens of the eye is focused on the retina (Figure 1). Photoreceptors called rods and cones may absorb the incident light and convert it to neural impulses, eventually interpreted in the cortex of the brain. The quality of the retinal image depends on the absorption, scattering and focusing properties of the cornea, lens, and the fluids within the eyeball. However, the first operation in color perception is absorption of photons in the retina by photoreceptors [15].

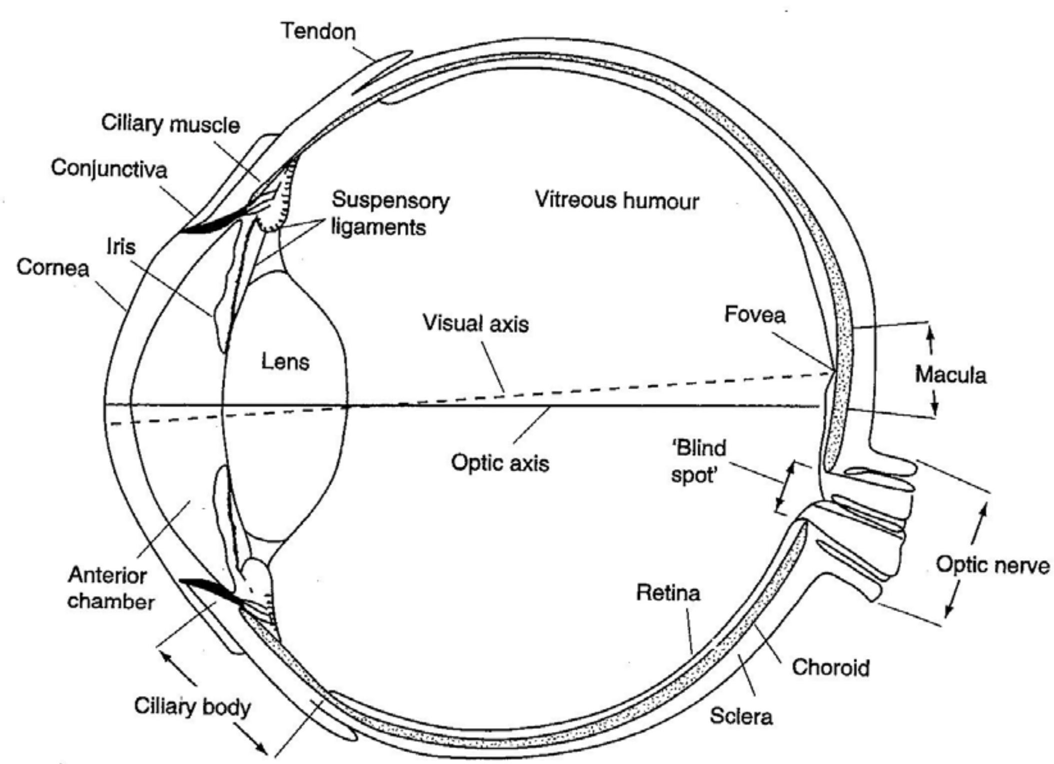


Figure 1. A schematic diagram showing a horizontal cross-section of the human eye.

There are two classes of receptors, rods and cones, named according to their microscopic shape. Rods are extremely sensitive to light and operate under low illumination (scotopic vision). In this case, because there is only one pigment type associated with rods, we only see objects as lightness contrast under scotopic conditions. As the amount of light increases, the rods become desensitized (bleached) and cones are activated. Cones are the second class of receptors in the retina. Our sensations of color are a result of three types of cones that respond differently to light of various wavelengths. Owing to their selective absorption curves, they have lower sensitivity to light than rods. All four receptors have the same pigment, 11-cic-retinal, but each is complexed with a different protein [6,7].

When visible light strikes the chromophore present in the photoreceptors, the chromophore undergoes photo-isomerization, a change in molecular arrangement, to all-trans-retinal. This isomerization is a common occurrence when unsaturated molecules absorb a photon. The molecule's electrons absorb the photo energy and become excited to higher-energy orbitals. In retinal, absorption of a photon promotes a π electron to a higher-energy orbital (a π-π^* excitation). This excitation breaks the π component of one of the double bonds [8]**.** When 11-*cis*-retinal absorbs a photon in the visible range of the spectrum, free rotation about the bond between carbon atom 11 and carbon atom 12 occurs, and the all-*trans*-retinal is formed [8,6].

In rod cells, the protein that binds the chromophore retinal is opsin, and the bound complex of 11-*cis*-retinal plus opsin is known as *Rhodopsin*. Rhodopsin is known as 'Bathorhodopsin' when it contains the all-trans isomer of retinal. This trans isomer does not fit well into the protein. Due to its (trans isomer) rigid and elongated shape. Therefore, a series of changes occur to expel the chromophore from the protein. It is estimated that within nanoseconds (10^{-9} s) [7] the shape of the protein begins to change. This expels the protein and yields free opsin plus free all-trans-retinal. A series of intermediate complexes are also formed during the process. One important intermediate is metarhodopsin II. Metarhodopsin II activates the enzyme transducin. Transducin in turn activates another enzyme, phosphodiesterase, which helps in the hydrolysis of cyclic GMP [6]. Cyclic GMP is responsible for the proper flow of Na^+ ions in the plasma membrane. Hence, hydrolyzing the cyclic GMP hinders the flow of Na^+ and creates a large charge difference across the membrane, known as hyperpolarization. The large potential difference travels as an electrical impulse down the rod cell to a synaptic terminal, and is then transferred to an adjoining nerve cell. The nerve cell carries this impulse to the brain [6,4].

The mechanism of light absorption in the cone cells is almost the same as the monochrome vision in the rod cells. However, the eye only has one type of rod cell, as opposed to three different types of cone cells. Each type of cone cell contains a different protein bound to 11-*cis*-retinal. It also has its own characteristic absorption spectrum that corresponds to the particular pigment protein that it contains [6].

The process by which the neural signals are processed by the brain is not fully understood, but some reviews have recently reported the comet understanding [4]. Most research in color perception is focused on empirical psychological measurement. Often, the primary goal is an improvement of a mathematical model to determine colors or color differences under specified viewing conditions with visual judgment.

In performing a color assessment, an experimenter should take into account each of the following aspects:

1. Use consistent and neutral background color and relative size of field.
2. Standardized and calibrated illumination conditions
3. Surface properties, gloss and texture of the surface

4. Testing observers for color normal-vision to ensure only color-normal observers are used.

3. Odor

Airborne odorants are sensed by the olfactory epithelium located in the roof of the nasal cavity. Odorant molecules are sensed by the millions of tiny hair-like cilia which cover the epithelium. The anatomy of the nose is such that only a small fraction of inspired air reaches the olfactory epithelium via the nasal turbinates, or via the back of the mouth on swallowing. Optimal contact is obtained by moderate inspiration (sniffing) for 1 to 2 seconds. At the end of 2 seconds, the receptors have adapted to the new stimulus and it takes at least 15 to 20 seconds to de-adapt before a new odor can produce a full-strength sensation [1].

A single receptor recognizes multiple odorants, and a single odorant is recognized by multiple receptors [9]. Olfactory information is the only sensory information that is integrated directly to cortical regions without a primary processing in the thalamus. Olfactory neural transduction, carried out by unmyelinated axons, is considered the slowest of the nervous system [10].

B. Cross-Modal Sensory Correspondence

Interest in cross-modal correspondence between vision and touch dates back to at least 1964. Rock and Victor [12] presented observers with an object whose visual shape, because of optical distortion, differed from its tactual shape. Later, different methodologies were carried out in analyzing cross-modal correspondence between vision and touch. Jones and O'Neil (1985) assessed cross-modal correspondence between vision and touch in texture perception. They concluded that visual and haptic judgments of surface roughness were made with comparable accuracy, although visual judgments, since they were affected rapidly, are described more efficiently [11].

Cross-modal correspondence between vision and olfaction has seldom been considered [10]. In one of the few studies reported, Martin (1909) found that olfactory impressions were among the sensory experiences reported by subjects when shown reproductions of paintings. Simpson and McKellar (1955) reported odor experience was evoked in some subjects by stimulation of other senses following mescaline ingestion. Gilbert et al (1996) [10] performed two different experiments to describe an odor stimulus in terms of color. The first experiment was a replication of studies by Rader (1979) and Rader and Tellegen (1987), using a questionnaire-based protocol to quantify the synesthesthetic relations between color, mood, and line elements. In the second experiment Munsell color chips were used to associate odor with the chips. Both experiments reported to have converging lines of evidence suggesting that odors are associated with specific colors [10]. Morrot et al. (2001) used a panel of 54 tastes to perform a wine-tasting experiment. Observers were presented with white wine artificially colored red with an odorless dye; they described it as smelling like red wine. The visual characteristics dominated the olfactory information in determining the taste. [9]

C. Instrumental Measurement

1. Color

In visual color assessment, the sample, or trial, and standard are simultaneously illuminated by a source. The sample is evaluated and compared with the standard by the observer. In instrumental color measurement, photo detectors replace the observer. The reflectance function of the standard and sample are measured successively using a spectrophotometer. Instead of color perception by eye and brain, the reflectance data are processed by computer to determine the parameters describing the color of an object.

It is impossible to understand how color can be measured, communicated, and controlled without first understanding how color is perceived. Because it is such a common element in our lives, most take color for granted. It is a very complex phenomenon, governed by the interplay of physics, physiology, individual experience, and memory.

In the simplest terms, color is the result of the interaction between light, an object, and a viewer. The specific manner in which light is modified by an object determines the viewer's perception of its color. Objects can modify light in different ways. For example, solid objects reflect light, while transparent objects transmit it. Fibers may scatter light and dyes selectively absorb certain regions of the visible spectrum between 380-750nm. Light sources themselves are highly variable. Daylight, incandescent light, and fluorescent light, for example, each consist of distinctive and highly variable spectral power distributions (SPD). What we see as a given object's color is actually an individualized response to a unique combination of electromagnetic radiation that it transmits and/or reflects following absorption and / or scattering.

Color-measurement instruments attempt to remove subjectivity from color identification by directly measuring the reflected light usually between 380 and 750nm. Unlike a human viewer, instruments are not influenced by human biases, such as fatigue, experience, mood, and pressure to meet commercial deadlines. Consequently, a method to measure and calculate a numerical specification of color requires a standard protocol that incorporates the SPD of the light source (illuminant), the reflectance function of the object, and the color matching functions of an average observer [15,17,35].

In 1931, the Commission Internationale de L'Eclairage (CIE) modified experimental observer data developed by Guild [13] and Wright [14] to produce the CIE 2^{o} standard observer. This standard observer is the set of three color matching functions, $\bar{x}, \bar{y}, \bar{z}$, which represent the average response of a color-normal human observer for matching all colors, as shown in Figure 2.

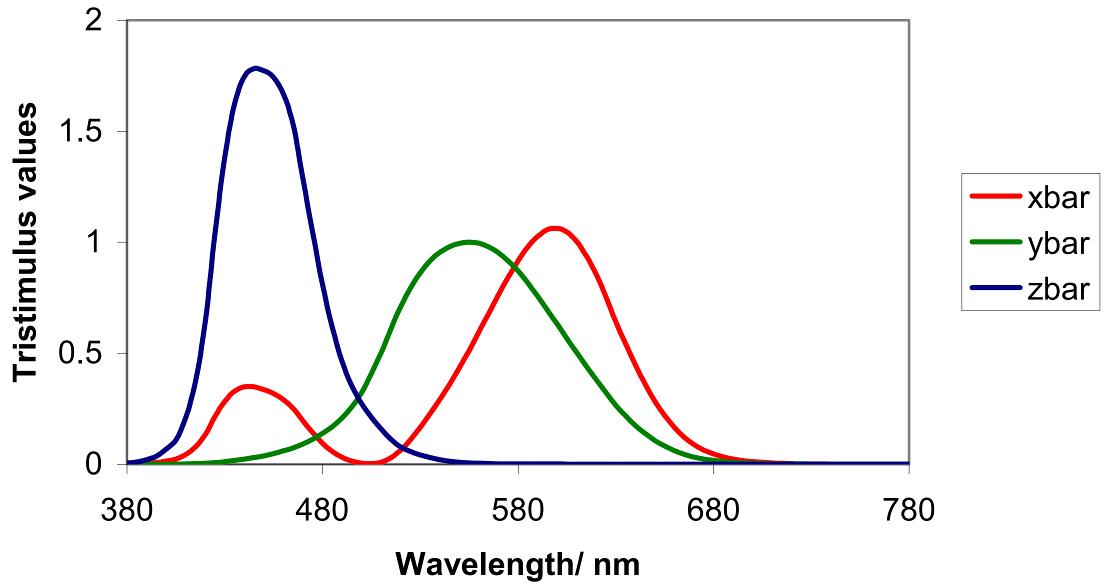


Figure 2. The CIE 1931 Standard 2^{o} observer color matching functions

Hence, no less than three numbers are required to specify the color of any object or light, according to the tristimulus values given in equations 1 - 4

$$X = k\sum_{380}^{750} S.R.\bar{x} \quad (1)$$

$$Y = k\sum_{380}^{750} S.R.\bar{y} \quad (2)$$

$$Z = k\sum_{380}^{750} S.R.\bar{z} \quad (3)$$

$$k = 100/\sum_{380}^{750} S.\bar{y} \quad (4)$$

Where
S = Spectral power distribution of light source.

R = Reflectance (or transmittance) of sample.

$\bar{x}, \bar{y}, \bar{z}$ = color matching functions of standard observer (2^{o} or 10^{o}).

The importance of precise color control is widely acknowledged today by formulation and quality-control professionals throughout numerous industries. In formulation applications, the ability to control color mathematically permits manufacturers to hit target colors with minimal trial and error. In quality control, numeric color control enables the manufacturers to check parts, components and assemblies for conformance to color-tolerance specification.

Mathematical color-difference assessments is achieved using an approximately perceptually uniform color space developed by the CIE, known as the CIELAB or CIE L* a* b*. CIELAB is a non-linear transformation of XYZ tristimulus space (equations 1 - 4) as shown in equations 5 - 7.

$$L^* = 116(Y/Y_n)^{1/3} - 16 \tag{5}$$

$$a^* = 500\,[(X/X_n)^{1/3} - (Y/Y_n)^{1/3})] \tag{6}$$

$$b^* = 200\,[(Y/Y_n)^{1/3} - (\,Z/Z_n)^{1/3})] \tag{7}$$

L* represents visual correlate of lightness (L*=0 = black, L*= 100= perfect white), positive a* indicated redness and negative a* indicates greenness, and positive b* indicate yellowness and negative b* indicates blueness.

The main utility of CIELAB is in the ability to calculate color differences that (approximately) correlate with perceived magnitude of color difference by the average observer. Hence, the following equations are commonly used [17,36,15].

$$DL^* = L^*_{batch} - L^*_{standard} \tag{8}$$

$$Da^* = a^*_{batch} - a^*_{standard} \tag{9}$$

$$Db^* = b^*_{batch} - b^*_{standard} \tag{10}$$

$$DC^* = C^*_{batch} - C^*_{standard} \tag{11}$$

$$DE^*_{ab} = [(DL^*)^2 + (Da^*)^2 + (Db^*)^2]^{1/2} \quad (12)$$

$$DH^* = [(DE^*_{ab})^2 - (DL^*)^2 - (DC^*)^2]^{1/2} \quad (13)$$

2. Hand

Agreement between objective measurement and subjective hand assessment has been reported over the years. Peirce [18] set out detailed theoretical reasons to expect a positive correlation between flexural rigidity and hand results. Kim and Vaughn [19] reported such a correlation, as did Paek [20]. Perhaps the most important study, however, given the number of samples involved (reported to be 1000), was by Kawabata who reported a positive correlation of subjective assessment to objective measurement [21]. The purpose of instrumental analysis of hand was to quantify the relationship between subjective magnitude estimations to objective measurements. Today, the Kawabata methodology and instruments are still widely used for these purposes.

Kawabata methodology is based on two key assumptions: 1) that fabric hand derives from a combination of primary sensory factors such as softness, stiffness, or roughness, and 2) that the ultimate judgment of fabric hand is biased according to the specific apparel end use. Hence, the set of primary sensory components that are appropriate, and the weight of individual sensory factors in the overall hand, are determined by end-use function. This means that the set of primary factors for fabrics that are intended for a particular type of garments. For example, men's suiting is specific and unique to that end use and would not necessarily be valid for other materials or end uses.

The feature of Kawabata’s devices lies in their ability to measure a fabric‘s mechanical properties at small strains with high sensitivity. The instruments provide an unprecedented capability to isolate the contribution of individual fabric properties and to define the role played by tensile, bending, compression, shear and surface properties on tactile sensation. This analytical power, when combined with the capability to characterize energy loss in mechanical deformation and recovery loss, provide an unparalleled tool for use in fabric-hand analysis [27].

D. Dye application and Finishing

1. Cotton Fiber

Cotton, the most important textile fiber along with polyester, contains approximately 95% cellulose. Cellulose is a linear, nonionic polymer of glucose units and can be described as 1,4-β-D-glucan. As shown in Figure 3 the repeat units are linked together by 1,4-glycosidic bonds, and the number of repeating units or degree of polymerization ranges from 1200-3000 [30].

Cotton is a hydrophilic fiber as there are three hydroxyl groups in each repeating unit, specifically in positions 2, 3 and 6 (Figure 3). The standard moisture regain for cotton is 7-11%, and the tenacity of both wet and dry cotton is the same. Dry cotton has a density of 1.05, which indicates a fairly open structure and facilitates diffusion of the dye molecules and chemicals for effective dyeing and finishing applications. However, cotton fibers have areas of high crystallinity that are not accessible to most diffusing process chemicals [30].

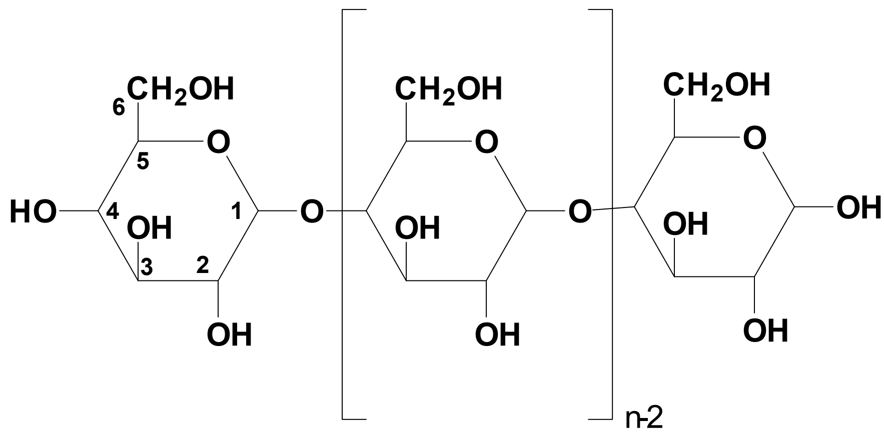


Figure 3. The Haworth projection formula with numbering.

Cotton can be dyed with a number of different classes of dye: direct, sulfur, azoic, vat, and fiber reactive, all of which require specific process conditions.

2. Fiber-Reactive Dyes

One of the most important classes of dye for cotton fiber is the fiber-reactive dye class, developed in 1956 by Rattee and Stephen. Fiber-reactive dyes are water-soluble dyes that are used extensively for dyeing cotton and other fibers. The primary hydroxyl groups in cotton (Figure 3) can be ionized under alkaline conditions (pH ~ 11), and thereby undergo nucleophilic attack of electron-deficient groups in fiber-reactive dyes, as shown in the generalized reaction in Figure 5. Consequently, these covalently bonded dyes have good to excellent wet fastness and also moderate - good light fastness. Fiber-reactive dyes can be represented schematically as a composite of up to five different interlocking features, as shown in Figure 4.

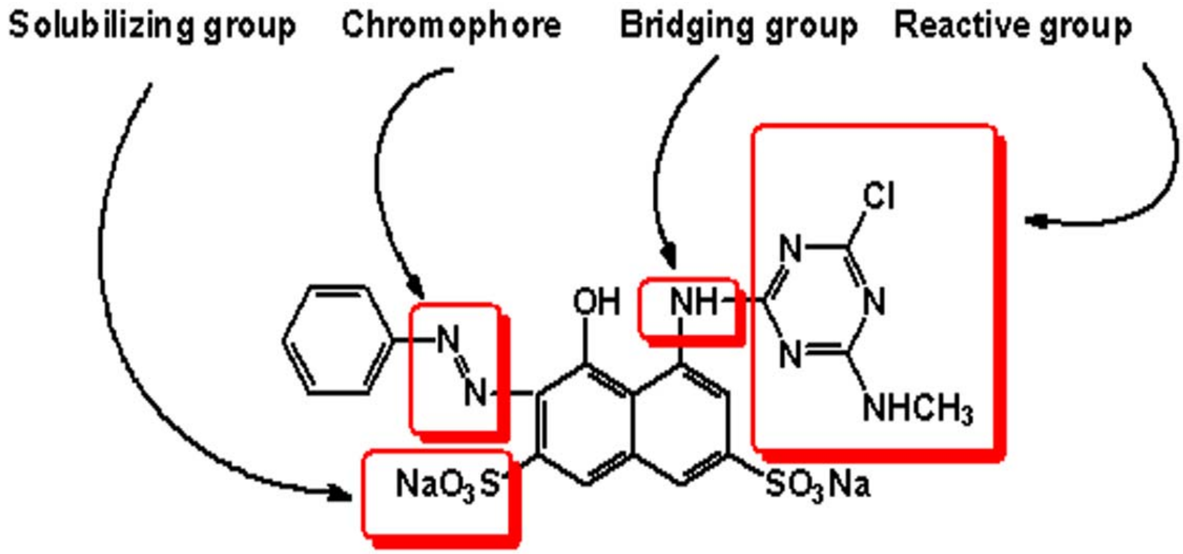


Figure 4. Key features of fiber-reactive dyes.

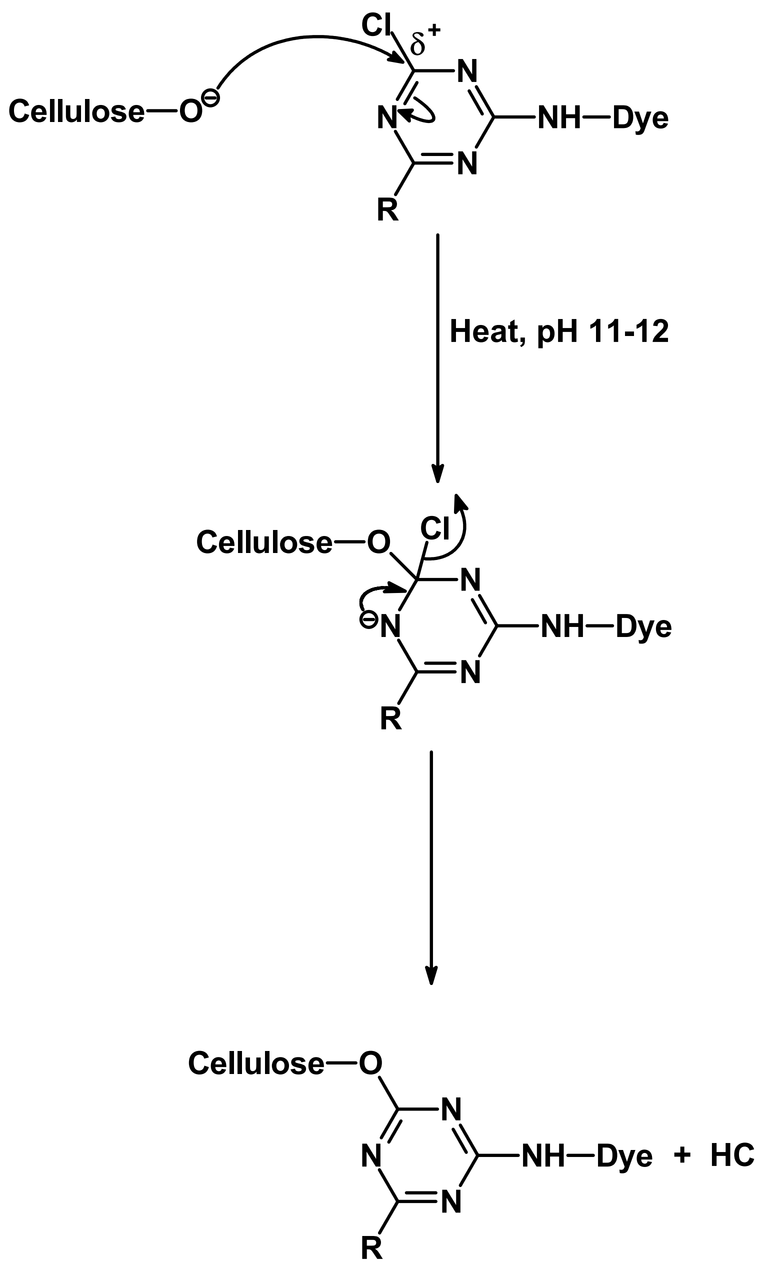
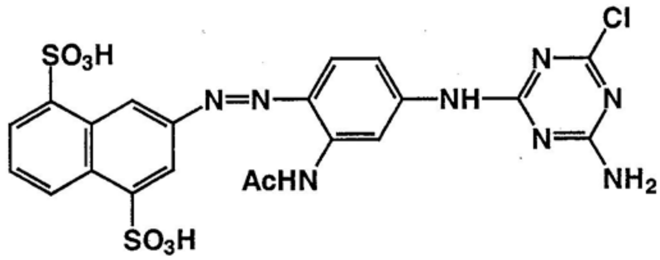


Figure 5. Reaction between a monochlorotriazine dye and ionized cellulose.

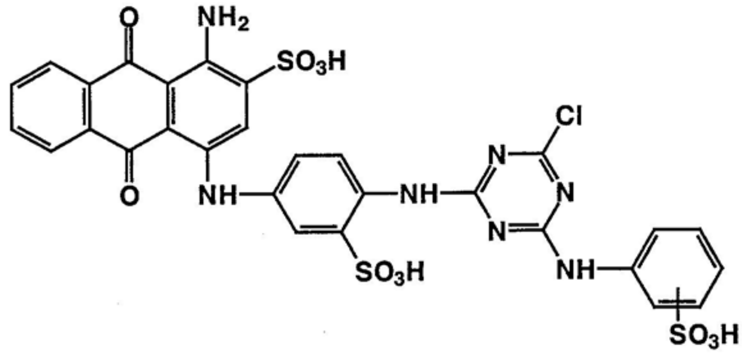
Over the last 50 years, many reactive groups have been introduced commercially [28]. Figure 6 Shows examples of yellow, blue and red dye based on a monochlorotriazine reactive group. However, the reaction mechanisms can be classified as nucleophilic substitution or nucleophilic addition [30]. Unfortunately, in both cases fiber-reactive dyeings are performed in aqueous alkaline conditions and a competing nucleophilic reaction exists owing to the presence of high levels of hydroxyl anions, OH^-, in the dye bath. Thus, fiber-reactive dyes can undergo hydrolysis to a non-reactive form, which significantly reduces the efficiency of the dye-fiber reaction [29]. Hence, the application method must be optimized to reduce hydrolysis and maximize levelness and wash fastness.

2.1 Application of Fiber-Reactive Dyes

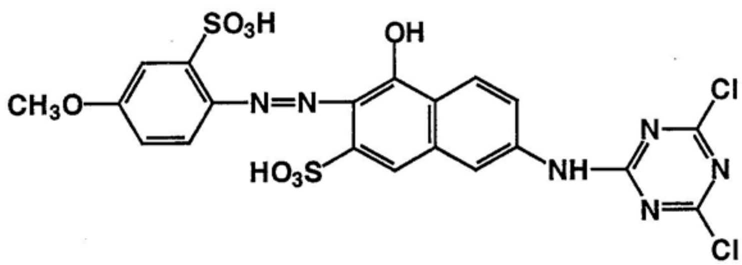
Fiber-reactive dyes can be applied to cotton in a number of ways, including exhaustion [30], pad-steam, and pad-batch. In the case of pad-batch the dye bath is prepared containing electrolyte, alkali, dye, wetting agent and anti-migrating agent. The pre-scoured and/or bleached fabric [28] is passed through the mixture and excess solution is removed to constant wet pick-up through a padder under calibrated and uniform pressure [29]. The reactive dyes are selected such that dye-fiber reaction proceeds at room temperature (cold-pad-batch) over a certain time period, typically 24 hours. The dyed fabric is then thoroughly rinsed and washed in detergent (soaping) to remove unfixed, hydrolyzed dye. At this point, any required finishes are applied, such as water repellent agents, flame-retardants and softening agents.



C.I. Reactive Yellow 3



C.I. Reactive Blue 2



C.I. Reactive Red 8

Figure 6. Fiber-reactive dye structures.

3. Softeners

A softener is a chemical that when applied to a textile material alters the tactile response, or hand, experienced by an observer, thereby making it more pleasing to touch. The softened fabric is fluffier and has better drape compared with fabric without softener applied. In addition to aesthetics (drape and silkiness), softeners improve abrasion resistance, tearing strength and reduce sewing thread breakages and needle cuts by reducing friction. Because of these functional advantages, softener chemicals are included in nearly every textile finish formulation. Also, consumers apply softeners to fabrics during home laundering, in the rinse cycle or as dryer-added sheets, demonstrating the importance of fabric hand to consumer satisfaction.

3.1 Mechanism

Softeners act as a fabric lubricant and reduce the coefficient of friction between two fibers or yarns and between fabric and contacting object. When yarns slide past each other more easily, fabric will be more pliable and have better drape. Also, when we slide our hand over a lubricated fabric, it gives rise to a lower coefficient of friction and hence the silky/soft feel [32].

3.2 Classification

Softeners are divided into three major chemical categories describing the ionic nature of the molecule: Anionic, cationic and nonionic.

<u>Anionic</u>

Anionic softeners possess negative charges on the molecule due to the presences of a carboxylate ($-COO^-$), a sulfate ($-OSO_3^-$) or a phosphate group ($-PO_4-$). Sulfates and sulfonates make up the bulk of the ionic softeners. The advantages of anionic surfactants are that they are resistant to heat and yellowing. A disadvantage is that the degree of softness is inferior when compared with cationic and some nonionic softeners and has limited durability to washing.

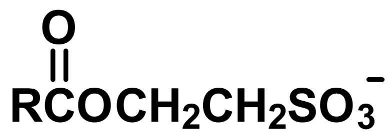


Figure 7. Structure of a sulfonate (isothionate) based anionic softener (R= alkyl or alkoxy).

Cationic

Cationic softeners possess positive charges, commonly based on nitrogen, either in the form of an amine or in the form of quaternary ammonium salt. The amine becomes positively charged under acidic pH and may be considered to carry a temporary ionic charge. Quaternary ammonium salts retain their cationic nature at all pH values. The main advantage of cationic softeners is that they exhaust from solution into the fiber making them generally more durable. These softeners impart higher softness to the fabric than anionic softeners [31,34]. A disadvantage is that they have poor resistance to yellowing and poor light fastness [34]. Figure 8 shows an example of a cationic softener.

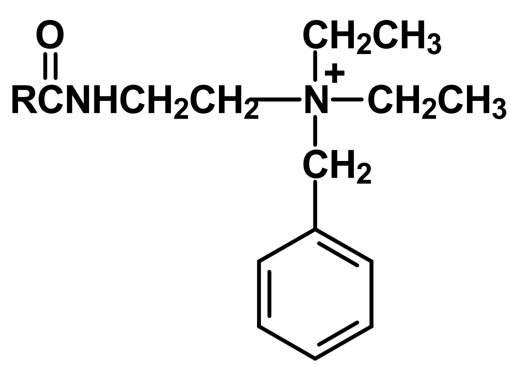


Figure 8. Structure of an Amide based cationic softener.

Nonionic

Nonionic softeners can be divided into three subcategories, ethylene oxide derivatives, silicones and hydrocarbon waxes. Figure 9 shows an example of a silicone softener. The advantages of nonionic softeners are that silicones are water-soluble that are stable to heat and light, produce a silky hand, and are preferred in white goods. A disadvantage is that silicones are water repellent and therefore unsuitable for use in towels or other applications requiring absorbency. They are also expensive [34].

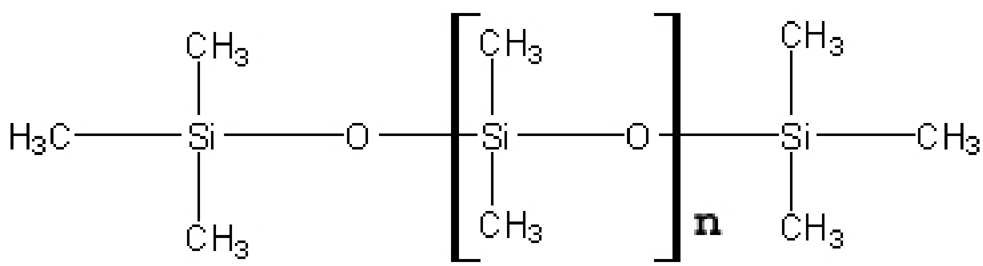
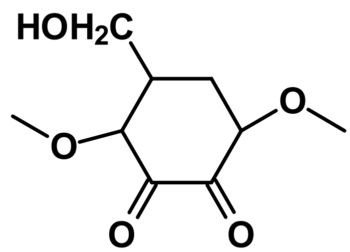


Figure 9. A silicone-based non-ionic softener (dimethyl siloxane silicone)

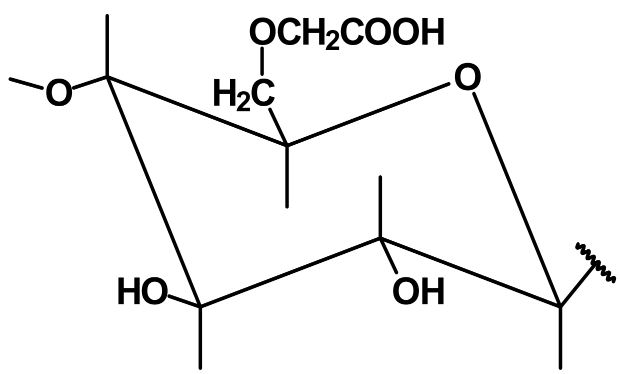
4. Stiffeners

Just as in many instances it is necessary to make fabrics and garments softer, so it is in other cases desirable to make them stiffer, for instance to improve the crisp appearance of a shirt collar and cuffs. Stiffening agents are also used to protect the warp yarns during weaving, a process known as splashing.

The most common stiffening agent is starch. There are numerous types of starch which may be obtained from seeds of wheat, rice, and maize, from the pith of certain plants (sago) or from roots (tapioca). Starch is insoluble in cold water and only dissolves in hot water with agitation. However, modified starches are available, which are cold water soluble (see Figure 10) a chemical modification of natural starch [33]. In addition, a number of synthetic stiffening agents have been developed to overcome some of the processing disadvantages of starch.



(a)



(b)

Figure 10. Structures of (a) Oxidized starch (amylase α 1,4) (b) Carboxymethyl cellulose.

Polyvinyl alcohol (PVA) was first synthesized in Germany by Hermann and Haehnel in 1924 [33]. During the 1930's the DuPont Company introduced polyvinyl alcohol commercially in the United States. PVA comes in several grades, differing in molecular weight and solution viscosity, is highly water soluble, can be easily applied and removed from textile substrates, and can be recycled [31].

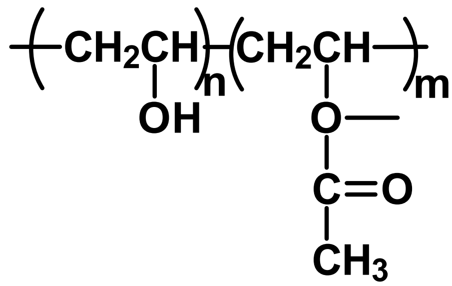


Figure 11. Polyvinyl Alcohol (approximately 90% hydrolyzed).

4.1 Chemical reaction / Structure

Their basic properties include water solubility. The solution viscosity and film-forming properties are key attributes and depend on molecular weight and degree of hydrolysis. Solubility increases with temperature. Polyvinyl alcohol is widely used as a sizing agent in weaving and also in non-durable hand builders. Two types of approach are practiced while used as a hand builder:

1. Higher molecular weight polymers with low add-ons are used to obtain fabric stiffness.
2. Lower molecular weight polymers at higher add-ons to achieve increased bulk and weight.

While PVA is (technically) more attractive than starch, it is more expensive.

Today, commercial processing of the fibers is performed to very high specifications. In particular, the color of the dyed substrate (the trial) must be accurate and precise to a target color (the color standard). As discussed in section B.1., the production trial must be a close visual match to the standard. One of the challenges in textile processing is the influence of required finishes, such as softening and stiffening agents, on color appearance of the product. Hence standard visual color assessment and measurement is important in quality control of commercial textile products.

E. Statistical Analysis

Subjective analysis implies significant variability between observers for a given experiment. Research in sensory perception is particularly susceptible to variance in response. Therefore, a relatively large number of observers may be required for statistical reliability.

The goal of applied statistics is to draw valid conclusions about a population based on the information contained in a sample of the entire population. The types of conclusions fall into two general categories: estimates and inferences. Furthermore, the size and manner in which a sample is drawn from a population affects the precision and accuracy of a sensory study.

1. Calculating Sample Size

The sample size required for a discrimination test is a function of the test sensitivity parameters, α, β and p_d, or in the case of directional difference tests, P_{max}. A 'Test Sensitive Analyzer' incorporated in software packages can be used to determine how various choices of α, β and p_d (or P_{max}), affect the sample size and the number of correct responses necessary to claim that differences exist or that the samples are similar.

The binomial distribution, upon which discrimination tests are based, is a discrete probability distribution. Only integer values for sample size, n, and the number of correct responses, x, are valid. Small changes in n and x can have a large impact on the probabilities α and β, particularly for small values of n. Generally, it is not possible to select values of n, x, and P_d (or p_{max}) which yield values of α and β that are exactly equal to their target values. Instead, the researcher must select values for n, x, and P_d (or p_{max}) that yield values of α and β that are close to their targets [1]

2. Randomized Block Design

The randomized block design is research design's equivalent to stratified random sampling. Like stratified sampling, randomized block designs are constructed to reduce noise or variance in the data. They require that the researcher divide the sample into relatively homogeneous subgroups or blocks. The experimental design is then implemented within each block or homogeneous subgroup. The idea is that the variability within each block is less than the variability of the entire sample. Thus, each estimate of the treatment effect within a block is more efficient than estimates across the entire sample. When these more-efficient data are collected across blocks, a more efficient overall estimate is obtained than when no blocking is used.

The null hypothesis is that the mean ratings of the samples are equal versus the alternative hypothesis that the mean ratings of at least two of the samples are different. If the value of the F-statistic calculated exceeds the critical value of F, then the null hypothesis is rejected in favor of alternative hypothesis [37].

3. Comparing Two Means (Paired-Sample Case)

Sensory analysis often deals with comparison of two sample sets by having a single panel evaluate both sets; the paired t-test is appropriate for these kinds of study. In general, the null hypothesis can specify any difference of interest. The alternate hypothesis can be two-sided or one-sided. In many cases, the form of the paired t-statistic is

$$t = \frac{\sigma - \sigma_0}{S_\sigma / \sqrt{n}}$$

Where σ is the average of the difference between the two samples and s_σ is the sample standard deviation of the differences [38].

D. Proposed Research

Knowledge of the effects of non-visual stimuli on the color perception of objects is important in two key areas of color technology, particularly in relation to apparel garments: The development of controlled laboratory evaluation procedures for the perception of color by observers, and optimization of the perception of color (and overall quality) of products by consumers. A cursory examination of the open literature indicates that no work has been dedicated to the effect of non-visual stimuli on the color perception of garments or fabrics. Hence, this work was undertaken to determine the possible influence (positive or negative) that tactile response and odor would have on the color perception of textile materials.

Bleached 100% cotton knit fabric was used, as this is a common substrate for apparel. This fabric was dyed to six hues (red, orange, green, blue, purple and yellow) at two depths of shade (pale and medium) and treated with hand modifiers (stiff and soft). Furthermore, a statistical experimental design was established to test the influence of tactile response and odor on perceived color after multiple washings to simulate multiple home launderings. Each dyed sample was washed 1, 5 and 10 times in a standard wash method. Then each sample was after-treated with two concentrations of a cationic softener and two concentrations of stiffening agent (PVA).

Visual observations were performed using 25 – 30 trained color-normal observers. Observers estimated color differences of each sample against a dyed, untreated control. The effect of tactile response and two odors, lavender and orange-oil fragrance was determined, using a cross-modal Procedure. Statistical significance of the data was determined using paired t - test.

The ultimate goal was to determine if a human observer could be influenced positively or negatively in his/her perception of color by non-visual stimuli. These cross-modal experiments will have value to fundamental sensory science, as well as to industrial psychologists and consumer-care companies that produce laundry detergents for laundering garments.

II. Experimental

A. General

Scoured and bleached 100% cotton jersey knit fabric (Test Fabrics, North Carolina, USA) was used throughout the study. Six basic colors were obtained at two different depths of shade using Fiber-reactive dyes (Lavafix, Dystar, Charlotte, USA):

1- Yellow (Levafix Brilliant Yellow E-3G).
2- Red (Levafix Red CA).
3- Blue (Levafix Royal Blue E-FR).
4- Green (3 parts of Lavafix Yellow E-3G + 1 part Lavafix Royal Blue E-FR)
5- Orange (1 part Lavafix Scarlet CA + 2 parts Lavafix Yellow CA).
6- Purple (1 part Lavafix Red CA + 1 part Lavafix Royal Blue E-FR).

A Werner Mathis AG Padder (horizontal/vertical padder) was used to apply all chemicals.

B. Dye Application and Finishing

1. Dyeing

A standard cold-pad-batch method (with soda ash) using Levafix CA Dyes was employed. Two depths of shade, one pale and one medium-heavy were dyed, as shown in Table 1.

Table 1. Dye concentration used.

Color	Pale shade	Medium - Heavy shade
1- Red	1 g/L	8 g/L
2- Orange	1 g/L	8 g/L
3- Yellow	1 g/L	6 g/L
4- Green	2 g/L	8 g/L
5- Blue	1 g/L	8 g/L
6- Purple	1 g/L	8 g/L

The following dyebath concentrations were used:

Dye	x g/L	
Sodium Carbonate	10 g/L	
Urea	100 g/L	
Wetting agent	3 g/L	(Clariant Pentrant EH)

The method was as follows:

1- The fabric (45 cm by 1 m) was padded with the dye solution to 100 % wet pick up.

2- Each dyed sample was then placed into nylon bags and batched for 24 hours at 20^{o}C.

3- The batched samples were rinsed with copious amounts of cold water three times.

4- The rinsed dyed samples were soaped off in a bath containing 0.5 g/L detergent agent (Apollo Scour SDRS) at 70 ^{o}C, for 10 min.

5- The soaped fabric was then rinsed in warm and cold water and tumble dried at 115^{o}F for 30 min.

2. Multiple Laundering

Each dyed fabric sample (45 cm by 1 m) was cut into 4 pieces of equal size and treated as follows:

1. One piece without washing (control).
2. One piece was washed and tumble dried once.
3. One piece was washed and tumble dried five times.
4. One piece was washed and tumble dried ten times.

The washing method used was AATCC Test Method 124-1996, except that no detergent was added. The basic procedure was as follows: Test specimens and enough ballast (100% cotton) to make 1.8 kg load. The washing temperature was set to 50 ^{o}C and washing was continued for 30 min. The washing machine contained about 18 gallons of treatment liquor and a 79-rpm agitator speed. The washing was continued for 15 min with 15 min for rinsing and spinning. Finally, the fabric was dried by tumble-drying at 150 ^{o}F for 15 min, followed by 10 min cold.

3. After-Treatment with Softening Agent

Three commercial softening agents were used to assess their effect on fabric hand and color difference. The goal was to achieve maximum softness with minimum change in color after the application of the softening agent. In order to determine which softener and concentration provided the desired properties, experiments were conducted to assess their performance on dyed samples (using two of the dyes selected above), but without any multiple-laundering experiments. Hiposoft LDS (Highpoint, NC, USA) (3% and 6% owb), SIL-FIN WHP (Highpoint) (0.5% and 2% owb) and SIL_FIN SBS (new) (Highpoint) (1% and 4% owb) were applied by cold-pad-batch method using 100% wet pick up and tumble dried at 150 ^{o}F for 15 min.

4. After Treatment with Stiffening Agent

Polyvinyl alcohol was padded onto dyed 100% cotton jersey fabric to 100% wet pick-up using concentrations of 10-50 g/L and dried in air. The initial treatments were assessed in terms of effect of stiffener on color change and hand.

C. Subjective Analysis

1. Color Vision Testing and General Training

All observers participating in this study were determined to exhibit color-normal vision using the Pseudoisochromatic Plates Test (Ishihara). In addition each observer was trained in the general method of assessing color differences of textile samples, as well as with the specific assessment protocol for the particular experiment. Experimental sessions were all limited to 25 min duration or less to avoid fatigue.

2. Hand Evaluation

Twenty-seven (27) human evaluators, all undergraduate and graduate students from NCSU College of Textiles within the age range of 18 to 30 years, were used for the hand evaluation of a series of fabric samples with either softener or stiffening agent applied. A ‘pillar box’ with two hand holes was constructed so that the observers could not see the fabric being handled, as shown in Figures 12 and 13. The responses from the human subjects were recorded individually. Each observer was asked to make magnitude estimations of softness/hardness. They were given one sample as standard (left-hand side), which was estimated to be of ‘neutral’ softness (i.e., in the middle of the respective sample set). The standards were assigned a ‘softness’ magnitude of 50. The task of the evaluators was to assign a number proportionally higher than 50 if the fabric was considered softer than the standard, lower than 50 if the fabric was considered to be less soft, and 50 if it was of equal softness. For each evaluation the number stated was recorded.

Figure 12. View of ‘pillar box’ constructed to ensure the observer did not observe fabric samples being evaluated for hand.

Figure 13. Back view of pillar box showing how fabric samples were assessed for hand without visual stimulation.

3. Visual Analysis Without Tactile Response

The same evaluators that performed the hand evaluation (section II.C.1) were asked to rate the samples for visual color difference only. In this case, the evaluators were not allowed to touch the samples. The evaluation was carried out under a standard light booth (GretagMacbeth Spectralite III) with a filtered tungsten daylight simulator calibrated to 6500K, according to the recommendations of Evaluation Procedure 9, AATCC Technical Manual 2002. The viewing geometry of the samples was 45/0 (45^o angle of incidence and 0^o angle of viewing), as shown in Figure 14. The evaluators were given one sample as standard (left-hand side), which was the untreated sample (not treated with either softener or stiffener). The task of the evaluator was to assign a number proportionally greater than 0 if any color difference between the samples was observed. The number chosen was whatever seemed appropriate to the evaluator.

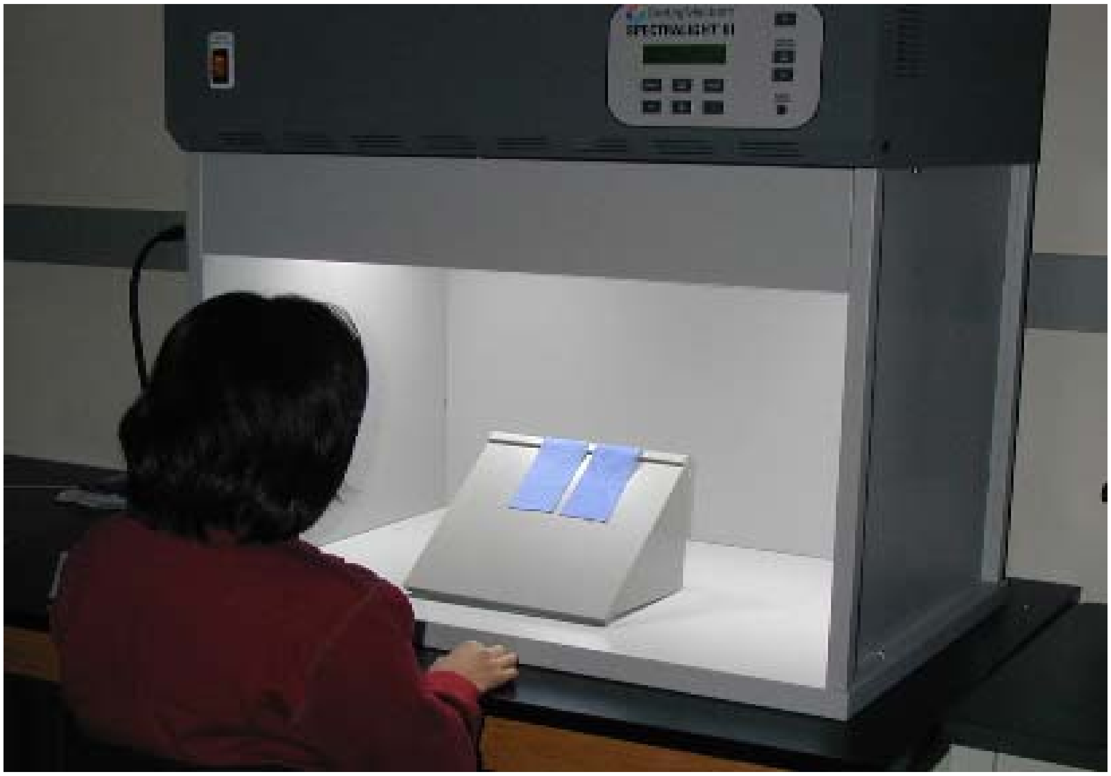


Figure 14. A photograph showing the viewing geometry for visual assessment of fabric samples.

4. Hand & Visual Evaluation Combined

The only difference between the visual evaluation method described above and hand & visual evaluation combined is that the evaluators were required to handle the samples in the latter case, as shown in Figure 15. The observers were asked to rate the softness/stiffeness first to force them to consider the hand as well as visual. Samples were presented to the observers in random order.

Figure 15. A photograph showing the combined viewing and tactile experience for visual assessment of fabric samples.

5. Visual and Odor Combined

A series of small bleached-cotton swatches (4inch square), with absorbency less than 3 sec were treated with 15 to 30μl of fragrance depending upon the strength of the fragrance. 20μl for lavender and 30μl was used for orange oil fragrance. Each treated swatch was placed in a plastic bag, sealed and stored over night. This swatch was removed from the bag and placed inside the light box behind the sample stand (observers did not see this swatch) approximately 3 min before the instructions were given to observers to assess the sample. Lavender-oil and orange-oil (Body Shop, NC, USA) were used.

After each session the observers were asked three questions:

1) Did you smell any fragrance?

2) Can you identify it?

3) Is it bearable?

Answers to above three questions were recorded and evaluated to ensure the correct level of fragrance was liberated during the experiment. Then same procedure was followed as the visual without tactile response assessment (section II.C.3).

D. Instrumental Analysis

1.Colorimetric analysis

All fabric samples were measured on a Datacolor International Spectraflash 300 with the following setup: Specular component included, UV included, 10^o supplemental standard observer, larger area view, and illuminant D_{65}. Samples were folded twice and three measurements were averaged following rotation of sample between each measurement. The spectrophotometer was connected to a personal computer and reflectance data were converted to colorimetric data DL*, Da*, Db*, DC*, $DE_{(cmc2:1)}$, using Sliform N/G software (SheLyn, Inc., Greensboro, NC, USA).

2. Kawabata Evaluation System (KES)

Physical testing of a series of dyed fabric samples treated with the selected softener and stiffening agent was performed using a KES system in a standard atmosphere laboratory (21 ± 2^0C, 63 to 67% RH). The KES quantified tensile, shear, bending, surface and compression properties of each fabric. All samples were equilibrated to standard conditions for 24 hours prior to the measurement. The tensile test measured the stress/strain parameters at the maximum load of 250 gf/cm. The shear test apparatus measured shear stiffness, or ease with which the yarns in a fabric slide against each other, which correlates with the perception of soft/pliable to stiff/rigid fabrics. The bending test apparatus measured the force required to bend the fabric approximately 150 degrees. Two surface properties were measured using two custom built probes made of steel piano wire, having the approximate touch sensitivity of human fingertip. The measure of surface friction (MIU) indicates the fabric resistance when the probe moves across the surface, while the surface roughness (SMD) is a measure of the contour of fabric surface. The compression determines the degree of compressional deformation and recovery of the test fabric at 0-50 gf/cm^2. Each sample was measured at three different places both in warp and weft direction and averaged for increased accuracy.

III. Results and Discussion

A. Dye Application and Finishing

1.Dyeing

Six hues were selected for this study to represent the major areas of color space. Also, two different dye concentrations were selected to produce pale and medium depths of shade. A cold pad-batch method was employed for ease of application of dyes and finish treatments. Dye concentrations were adjusted to provide approximately visual equal depth of shade for each hue. Hence, the possible effect of tactile response on color strength and hue could be investigated. Figure 16 shows the control samples for each hue and depth displayed on a CIE a*b* diagram.

2. Repeated Washing

Part of the goal of the project is to assess the influence of surface effects following mechanical action during laundering. Hence, each dyed sample was split into four sections and washed and tumble dried 0,1,5 or 10 times, the 0 wash sample being labeled as the control. A standard AATCC washing procedure (Test Method 124-1996) was used, except that detergent was omitted. The main goal of the washing treatment was to enable the study of surface abrasion following laundering, and hence 'cleaning' was not a requirement, and may have lead to inclusion of one or more additional and undesirable variables.

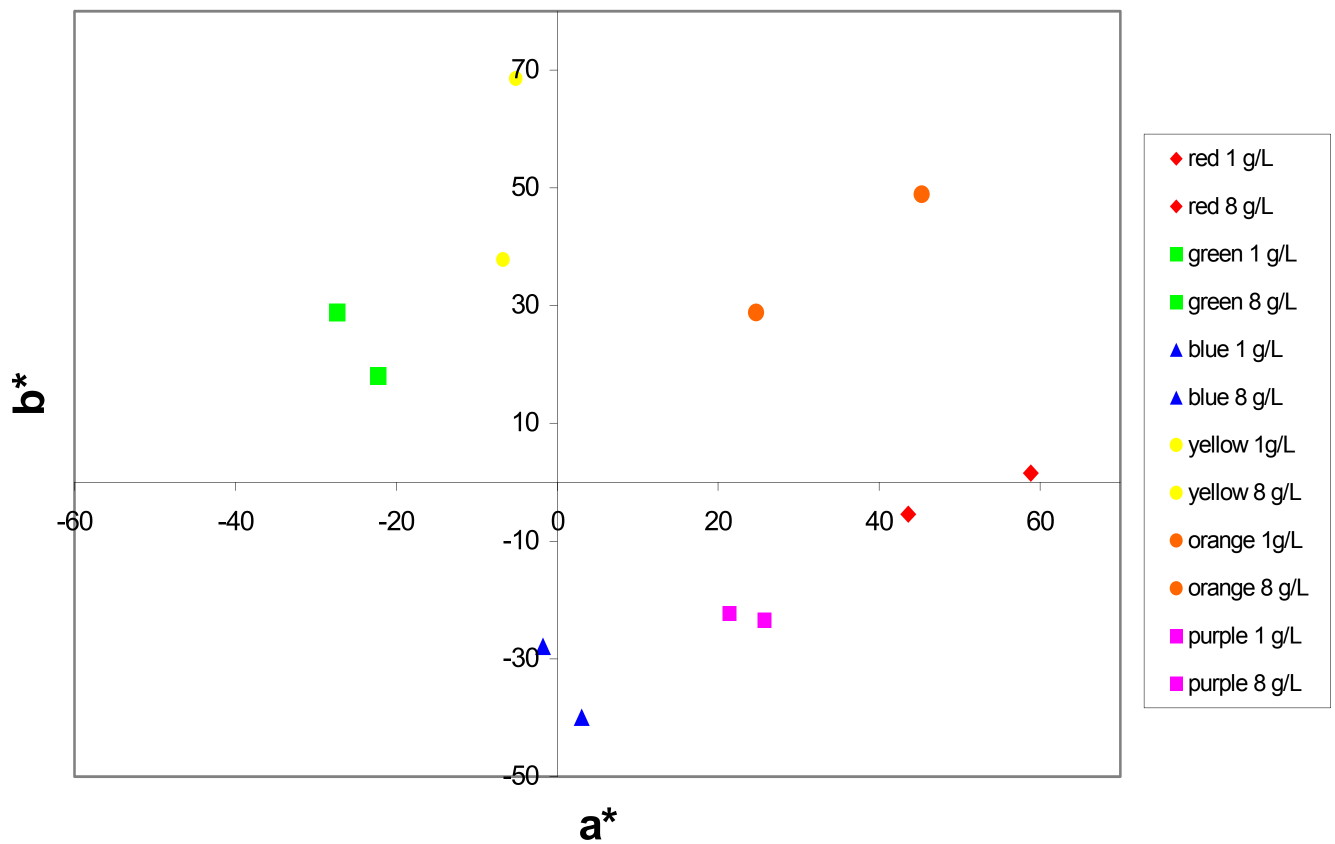


Figure 16. CIE a*b* diagram showing points in color space for each dyed control sample used in the study.

Table 2 shows colorimetric data for each sample washed and tumble dried 0,1,5, and 10 times. A surprisingly large color difference (DE_{CMC}) was observed in some cases with little difference between samples washed 5 and 10 times. This means that comparison of data for tactile-color perception responses between these washed samples may not be feasible. All the dyeings were level and all samples ironed to remove wrinkles or other blemishes.

3. Aftertreatments

Following the washing treatments, each control/washed sample was further cut into sections and treated with a softener and stiffening agent, in order to affect the hand of the fabric. One requirement was to produce significant changes in hand without significantly changing the color of the samples.

Hence, a preliminary set of experiments was conducted to select the appropriate softener and finish concentration to provide the desired effect. A red dyed fabric sample was chosen for the preliminary softener study. Three softeners were selected. Table 3 shows a summary of the colorimetric data following each softener treatment. An average difference of 0.31 with a standard deviation of 0.249 was obtained, showing that only very small color differences resulted from application of the softener finish. The softener, Hiposoft LDS, was selected since it displayed excellent softness characteristics with minimal color change. Hiposoft LDS is a quaternary ammonium cationic ester that is highly substantive towards cotton. It is resin stable, exhibits good napping properties and low yellowing. It is suitable for pad or exhaust application methods. A concentration of 2% and 4% owb was selected for hand evaluation studies.

Table 2. Summary of colorimetric data showing effect of washing on color.

Name	DEcmc (2.0:1)	L*	a*	b*	C*	Hº
Medium Red, without washing	0	49.62	58.84	1.57	58.86	1.53
Meduim Red, with 10 times washing	5.99	45.99	47.48	-5.71	47.82	353.15
Meduim Red, with 5 times washing	3.39	47.09	52.83	-2.74	52.9	357.03
Meduim Red, with 1 time washing	0.99	48.82	56.97	0.39	56.98	0.4
Pale Red, without washing	0	66.81	42.68	-5.49	43.03	352.67
Pale Red, with 10 times washing	5.35	65.77	36.73	-12.96	38.95	340.57
Pale Red, with 5 time washing	4.77	66.04	40.79	-13.41	42.94	341.8
Pale Red, with 1 time washing	2.82	66.92	42.92	-10.37	44.15	346.42
Pale Yellow, without washing	0	92.73	-6.76	37.82	38.42	100.14
Pale Yellow, with 10 times washing	5.69	90.12	-1.98	26.68	26.75	94.24
Pale Yellow, with 5 times washing	3.46	91.5	-4.23	30.64	30.93	97.86
Pale Yellow, with 1 time washing	1.71	92.65	-6.08	34	34.54	100.13
Medium Yellow, without washing	0	89.89	-5.15	68.57	68.77	94.29
Medium Yellow, with 10 times washing	5.33	84.74	-0.38	55.67	55.67	90.39
Medium Yellow, with 5 time washing	2.6	87.27	-2.59	62.48	62.54	92.38
Medium Yellow, with 1time washing	0.98	89.26	-4.48	65.92	66.07	93.89
Pale Green, without washing	0	73.58	-22.23	18.06	28.65	140.9
Pale Green, with 10 times washing	7.4	77.96	-11.09	20.24	23.08	118.71
Pale Green, with 5 times washing	6	76.83	-14.55	22.45	26.75	122.94
Pale Green, with 1 time washing	2.42	75.36	-19.37	20.08	27.9	133.98
Medium Green, without washing	0	63.81	-27.38	28.8	39.73	133.55
Medium Green, with 10 times washing	6.6	67.62	-16.33	31.76	35.72	117.21
Medium Green, with 5 times washing	4.65	66.68	-19.98	31.7	37.47	122.22
Medium Green, with 1 time washing	1.79	65.17	-24.73	30.18	39.02	129.33
Pale Orange, without washing	0	78.71	24.71	31.47	40.02	51.86
Pale Orange, with 10 times washing	3.56	79.49	19.54	25.13	31.83	52.14
Pale Orange, with 5 times washing	2.92	79.25	20.38	28.67	35.17	54.59
Pale Orange, with 1 time washing	1.18	79	22.86	29.94	37.67	52.65
Medium Orange, without washing	0	64.56	45.27	48.89	66.63	47.2

Table 2. Continued.

Name	DEcmc (2.0:1)	L*	a*	b*	C*	Hº
Medium Orange, with 10 times washing	4.74	63.46	35.52	43.08	55.84	50.49
Medium Orange, with 5 times washing	3.56	63.64	38.03	44.97	58.9	49.78
Medium Orange, with 1 time washing	1.1	63.96	43.13	47.95	64.5	48.03
Pale Purple, with 1 time washing	0	66.14	21.38	-22.27	30.87	313.83
Pale Purple, with 10 times washing	2.64	69.15	21.38	-18.55	28.31	319.05
Pale Purple, with 5 times washing	1.53	67.87	22.65	-20.93	30.83	317.26
Pale Purple, with 1 time washing	0.18	66.44	21.14	-22.16	30.63	313.65
Medium Purple, without washing	0	41.79	25.76	-23.38	34.79	317.77
Medium Purple, with 10 times washing	1.96	44.63	25.43	-21.07	33.02	320.36
Medium Purple, with 5 times washing	1.63	44.08	26.14	-21.64	33.93	320.38
Medium Purple, with 1 time washing	0.79	42.86	25.94	-22.5	34.34	319.07
Pale Blue, without washing	0	67.89	-1.8	-27.86	27.91	266.29
Pale Blue, with 10 times washing	4.36	71.32	-2.36	-20	20.14	263.28
Pale Blue, with 5 time washing	2.64	69.59	-1.77	-22.92	22.99	265.59
Pale Blue, with 1 time washing	0.46	68.36	-1.94	-27.07	27.14	265.91
Medium Blue, without washing	0	45.47	3.02	-39.91	40.03	274.33
Medium Blue, with 10 times washing	1.14	47.38	2.56	-38.52	38.6	273.8
Medium Blue, with 5 times washing	1.64	46.58	4.83	-42.07	42.34	276.55
Medium Blue, with 1 time washing	1.14	45.59	4.29	-41.63	41.85	275.89

Table 3. Summary of colorimetric data showing effect of softener on fabric color.

Name	**Decmc (2.0:1)**	**L***	**a***	**b***	**C***	**hº**
Pale Red, without softener	0	65.7	43.63	-5.45	43.97	352.88
Pale Red, + 0.5 % WHP softener	0.1	65.46	43.68	-5.5	44.02	352.83
Pale Red, +2 % WHP softener	0.25	65.91	43.07	-5.46	43.42	352.78
Pale Red, +3 % LDS softener	0.25	66.06	43.15	-5.46	43.49	352.79
Pale Red, +6 % LDS softener	0.11	65.71	43.86	-5.39	44.19	353
Pale Red, +1 % SBS softener	0.32	65.91	42.91	-5.5	43.26	352.7
Leva. Red, +4 % SBS softener	0.31	65.09	44	-5.3	44.32	353.13
Medium Red, without softener	0	48.82	58.31	1.53	58.33	1.5
Medium Red, + 0.5 % WHP softener	0.24	48.54	58.63	1.84	58.66	1.8
Medium Red, + 1% SBS softener	0.49	48.28	58.79	2.26	58.83	2.2
Medium Red, + 2 % WHP softener	0.44	48.4	59.16	1.99	59.2	1.92
Medium Red, + 3 % LDS softener	0.33	48.56	58.93	1.92	58.96	1.87
Leva. Red CA, + 4 % SBS softener	0.94	47.6	59.56	2.66	59.62	2.56
Medium Red, + 6 % LDS softener	0.58	48.49	59.44	2.25	59.49	2.16
Avge	0.31					
Standard deviation	0.249					

A stiffening agent was selected from preliminary studies using starch and PVA. The latter is easily prepared at high concentration and showed little color change at various concentrations of PVA applied. Table 4 shows a summary of colorimetric data following treatment of yellow and blue dyed fabrics with PVA. Hence, PVA was selected at 20 g/L and 40 g/L for hand-evaluation studies. These two concentrations were selected to provide two extremes in stiffeness without producing a significant Change in color.

Table 4. Summary of colorimetric data showing effect of stiffening agent on color.

Finish	DEcmc	L*	a*	b*	C*	hº
Medium Blue, +PVA 10gpl	0.31	41.01	5.3	-40.71	41.05	277.42
Medium Blue, +PVA 20gpl	0.71	42.48	4.76	-40.05	40.33	276.77
Pale Yellow, +PVA 40gpl	0.03	89.48	-6.3	34.29	34.86	100.41
Pale Yellow, +PVA 20gpl	0.24	88.97	-6.22	34.03	34.59	100.35
Medium Red, +PVA 5gpl	0.34	48.81	58.8	2.32	58.84	2.26

B. Effect of Tactile Response on Color Difference Perception

1. Subjective Analysis

Twenty Seven observers with normal color vision were selected and trained for color assessment and hand evaluation. Normal color vision was established using the Pseudo Isochromatic Plates Test and the Farnsworth-Munsell 100 Hue Test.

Initially, studies commenced on two hues of, a pale yellow and medium blue. This initial study was required to ensure that the designed experiment would provide appropriate data, and would allow refinement if necessary.

Colorimetric data for application of softener/stiffening agent are provided in Appendix A. Clearly, there is little color change between samples applied with different concentrations of softener/stiffness agent, except for the 2% softener applied on pale yellow. The latter sample was kept in the observer set to test the influence of a significant color difference. Hence, if observers did not perceive a significant difference between treated and control for this sample compared with other samples, then this would indicate the designed test would not provide appropriate data.

A three-stage evaluation of samples was commenced: Hand evaluation alone, visual evaluation alone and combined hand and visual evaluation.

1.1 Hand evaluation

1.1.1 Subjective Assessment

Each observer was asked to evaluate the hand of each fabric sample relative to a control sample that had no finish applied. The observers could not see the samples, as shown in Figures 12 and 13. A method using magnitude estimations of comparative softness/stiffness was used, the control being assigned an arbitrary value of 50, with stiffer samples to be described by lower values than the control and softer samples being described by higher values. Table 5 summarizes the averaged data for the 40gpl, 20gpl stiffener and 2% and 4% softener applications. The data clearly show that the observers could detect differences in hand for the four types of after-treatment. Moreover, the order of stiffness and softness in relation to the amount of finish applied was correct. Very few observers were unable to determine the 'correct' order of stiff to soft.

As anticipated, it appears that there is not a large perceived difference between 2% and 4% stiffener applications. This is not surprising since both of these concentrations are very high. It was intended that a 'maximum' softness and stiffness level would be used for the wider study.

Table 5. Averaged assigned values for stiffness/softness for both the yellow and blue treated fabric samples

--------------Stiffener--------		------------Softener--------	
40gpl	**20gpl**	**2%**	**4%**
27.61	34.574	55.558	59.104

1.1.2 Kawabata Analysis

It is assumed that hand can be associated with measurable fabric mechanical, surface and thermal properties of fabrics. Hence, a subset of the dyed and treated fabrics samples used for subjective hand analysis was used for KES assessments to determine if hand assessments of the current fabric samples could be correlated with mechanical measurement. Twelve samples were assessed with softener and stiffener applied at two concentrations to 1,5 and 10 wash samples. Key measurements from the Kawabata hand evaluation system are summarized in Table 5.

The Kawabata translation formulae for overall hand cannot be used to determine the hand in the present case, since the formulae were developed for a particular end use using a particular dataset [21,22]. However, a rank-average method can be used to indicate the overall hand properties. In Table 6 Shear stiffness (G), Bending Rigidity (B) and Surface roughness (SMD) are ranked in the order of stiff to soft. Figure 17 shows graphically the over-all rank ordering from stiff to soft using a rank average method that combines all three metrics shown in Table 6.

Table 6. Shear stiffness (G), Bending Rigidity (B) and Surface roughness (SMD) are Ranked from stiff to soft:

Rank	G	B	SMD
1	st4	st6	st4
2	st6	st1	st5
3	st2	st2	st2
4	st1	st3	st1
5	st3	st4	st6
6	st5	st5	s5
7	s6	s5	s4
8	s1	s2	st3
9	s3	s1	s2
10	s4	s6	s1
11	s5	s4	s3
12	s2	s3	s6

Table 7. Summary of key Kawabata output data for the 12 fabric samples analyzed.

Property	s1	s2	S3	s4	s5	s6		st1	st2	st3	st4	st5	st6
Compression													
RC(%)	32.202	32.427	31.691	32.667	31.679	32.126		31.184	31.035	31.021	32.547	31.197	32.29
EMC(%)	36.239	33.98	37.131	37.235	36.377	35.027		33.537	34.133	33.493	29.262	31.279	33.245
Surface													
MIU(-)	0.3229	0.3658	0.2819	0.323	0.3208	0.3463		0.2992	0.3163	0.3463	0.3118	0.3294	0.218
SMD (micron)	5.4571	5.5608	4.2246	5.8773	6.2158	3.5798		6.6598	6.842	5.7393	7.0385	6.9326	6.3332
Bending Regidity													
B(gf*cm2/cm)	0.0312	0.033	0.0288	0.0305	0.0355	0.031		0.0724	0.0721	0.0672	0.067	0.0593	0.1906
2 HB(0.5)	0.0177	0.0215	0.0209	0.0202	0.02	0.0196		0.0373	0.0354	0.0383	0.0323	0.0263	0.0405
Shear Stiffness													
G(gf/cm*Degree)	0.8624	0.7819	0.8511	0.8311	0.7906	0.9228		1.7852	1.9892	1.7251	2.5014	1.7065	2.0727
2HG	1.1799	1.1208	1.1687	1.2192	1.1435	0.9898		3.1112	3.175	2.9859	3.6913	2.8114	2.9482
Tensile													
EMT(%)	19.507	9.941	19.290	24.562	21.038	22.238		9.922	9.005	8.626	5.269	8.424	6.743
RT(%)	50.789	42.197	47.775	43.710	47.550	44.638		31.173	47.096	45.125	49.755	44.518	51.585

Note: s1= 2% Hiposoft LDS 1 wash, s4= 4% Hiposoft LDS 1 wash, st1= 20gpl PVA 1 wash, st4= 40gpl PVA 1 wash
s2= 2% Hiposoft LDS 5 wash, s5= 4% Hiposoft LDS 5 wash, st2= 20gpl PVA 5 wash, st5= 40gpl PVA 5 wash
s3= 2% Hiposoft LDS 10 wash, s6= 4% Hiposoft LDS 10 wash, st3= 20gpl PVA 10 wash, st6= 40gpl PVA 10 wash

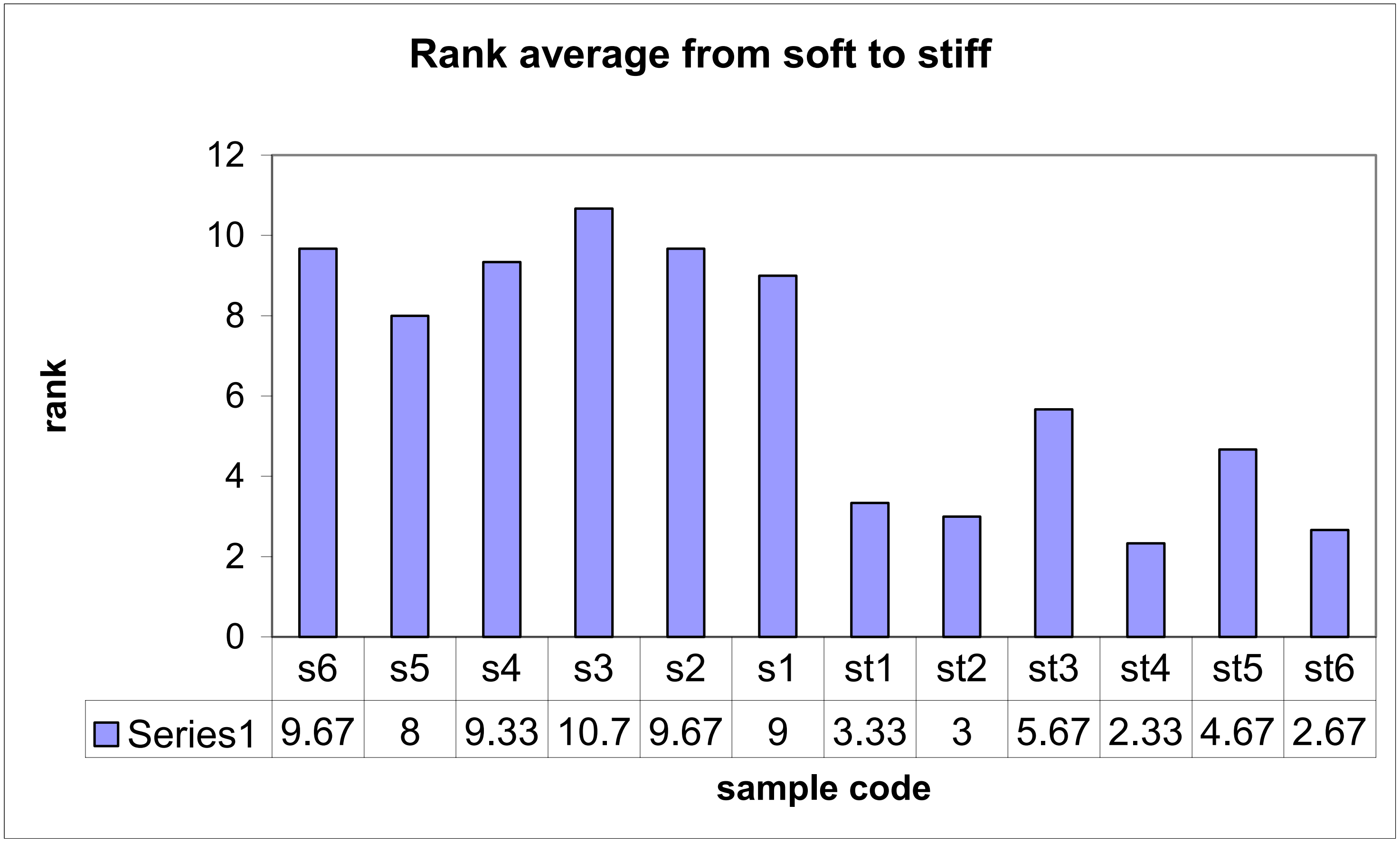


Figure 17. Final KES ranking (soft to stiff) for each of the 12 samples studied using an average rank order method that includes each variable listed in Table 6**.**

From the data in Tables 5 and 6 and Figure 17, there are some discrepancies between the KES data and the expected order of softness-stiffness. However, the general trend in softness to stiffness is in the correct direction. The variability within the softer samples and stiffer samples are probably due to the following:

A) KES measurements on knitted fabrics tend to be more variable and correlate with subjective hand evaluations less than woven fabric structures

B) Softer samples tend to stretch more evenly at minimum tension, which causes significant surface deformation, thus leading to higher MIU and SMD measurements than usual.

C) The softer samples tend to accommodate the friction sensor more when compared with stiffer samples leading to higher friction measurements.

Particular variability is often observed for surface roughness effects, as indicated in Table 6. If this effect is removed from the rank order, a slightly different ranking is observed. Figures 18 and 19 show the B and G values for each samples evaluated, respectively. The lower the value on the y axis, the lower is the stiffness or rigidity.

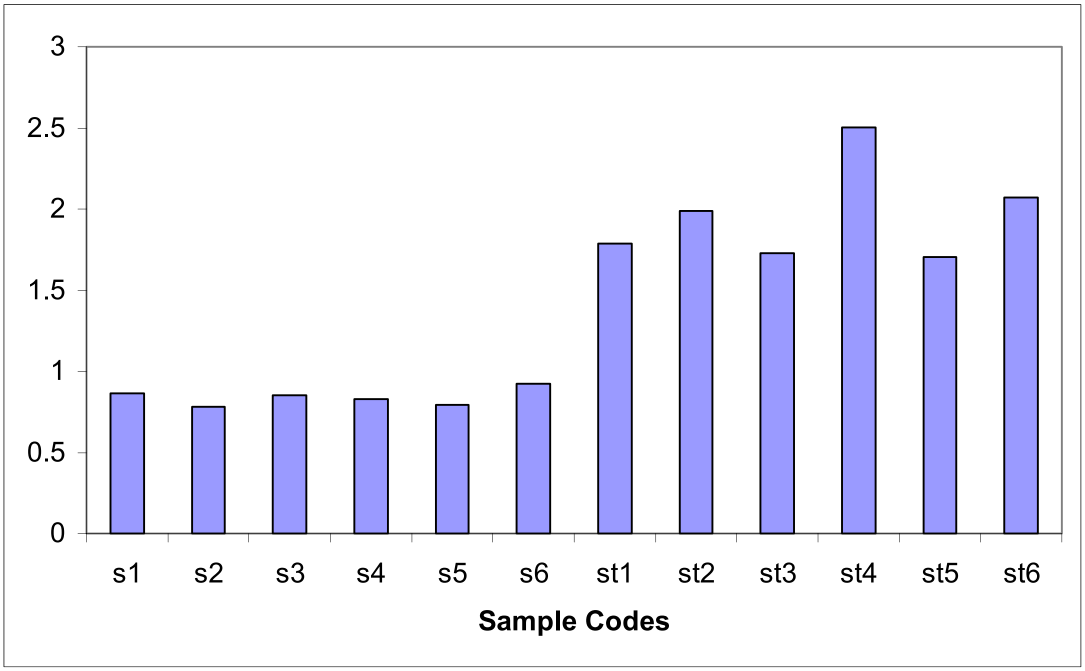


Figure 18. G value response for each sample.

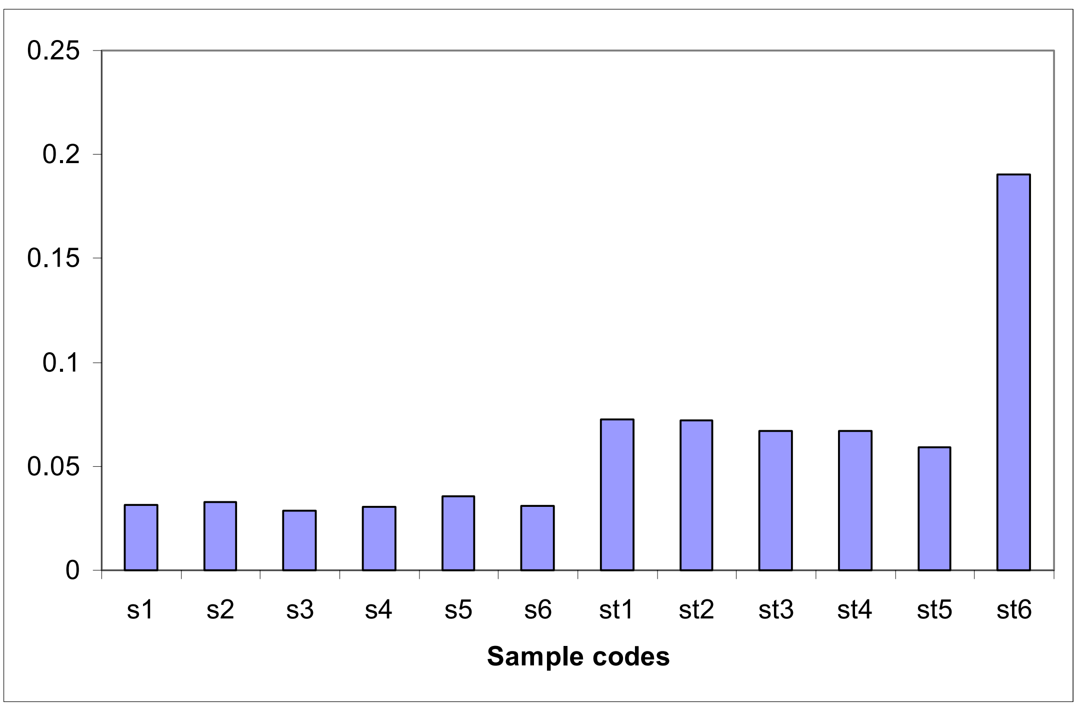


Figure 19. B value response for each sample.

Regression analysis

Regression analysis (Table 8) showed that the hand preference of the fabric is highly correlated with Bending (B), Bending hysteresis (2HB), Shear (G) and shear hysteresis (2HG), with a correlation coefficient of 0.96.

Table 8. Shows the observed and predicted hand using regression equation $Y=64.7 - 754.5(B) + 1049(2HB) + 14.63(G) - 15(2HG)$

Sample codes	Observed hand	Predicted hand
S1	55.888	54.718
S2	58.111	57.051
S3	59.777	59.888
S4	54.851	56.824
S5	55.037	53.379
S6	60.185	60.585
St1	32.740	28.857
St2	33.925	29.122
St3	30.444	34.821
St4	30.074	29.504
St5	26.185	30.526
St6	25.481	27.379

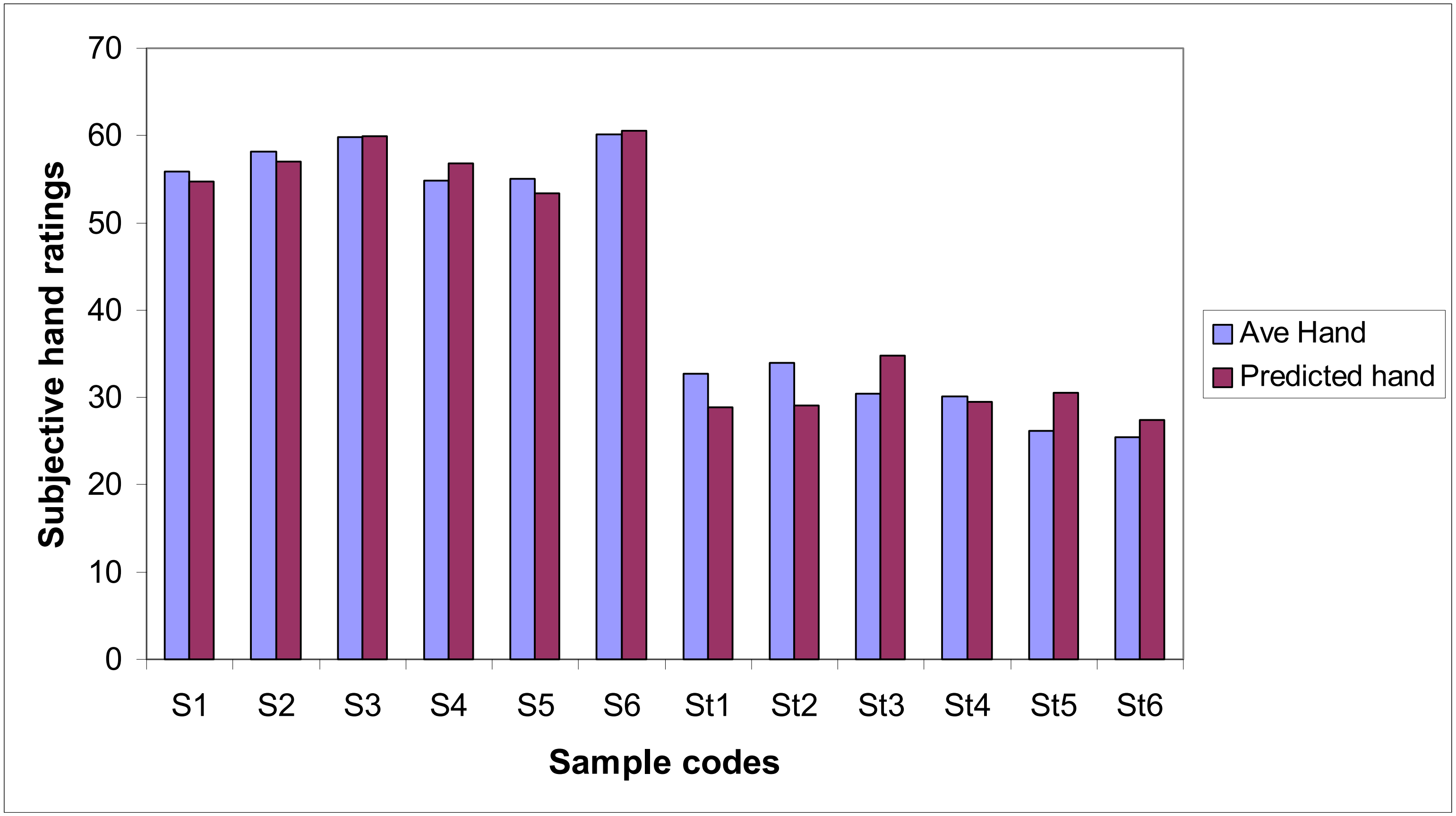


Figure 20. Represents observed and predicted hand values.

Hence, overall the KES data were able to show differences between samples with softener applied and samples with stiffener applied and correlated well with experimental observer data (Figure 20). In the present work, since we are ultimately testing the effect of extremes of softness and stiffness on color difference perception, the KES data were adequate to use as a softness/stiffness model to support the visual/tactile observer experiments

1.2 Visual Assessment Without Tactile Response

Each observer was required to compare color differences between a control and a treated (softened/ stiffened) fabric sample. The control was the equivalent fabric sample to the test sample except no softener or stiffening agent was applied. A set of 32 fabric samples was assessed in random order, which combined pale yellow and medium depth blue samples washed 1, 5 and 10 times, and each with softener or stiffening agent applied. Table 9 summarizes the coding of the samples. An arbitrary scale was used to assign perceived visual color difference (DV) and the data were normalized for the group of observers, in order to compare the data to colorimetric DE_{CMC} values. Observers were not allowed to touch the materials. Each time the samples were placed in the exact same location with the same gap between control and test (Figure 14). The visual data were compared with instrumental color difference (DE_{CMC}) data to assess the level of correlation. Figure 21 shows excellent agreement between normalized visual data for the 32 paired comparisons together with instrumental color difference data (DE_{CMC}). The three 'spikes' in the range 1.5-2.0 DE_{CMC} correspond to the yellow sample washed 1, 5 and 10 times with subsequent softner applied. Hence, the observers could easily detect these samples with larger color differences.

Table 9. Summary of 32 samples visually assessed, with coding which identifies the order in which the samples were presented.

	Washes	softner/stiffner conc	Sample order/code		Washes	softner/stiffner conc	Sample order/code
		Medium hue				Pale hue	
I	No wash						
		2%	11	V	No Wash	2%	5
		4%	15			4%	22
		20gpl	6			20gpl	1
		40gpl	26			40gpl	19
II	1 Wash			VI	1Wash		
		2%	32			2%	28
		4%	13			4%	8
		20gpl	21			20gpl	17
		40gpl	4			40gpl	20
III	5 Washes			VII	5 Washes		
		2%	9			2%	14
		4%	12			4%	25
		20gpl	16			20gpl	27
		40gpl	29			40gpl	30
IV	10 Washes			VIII	10 Washes		
		2%	10			2%	7
		4%	3			4%	24
		20gpl	18			20gpl	31
		40gpl	23			40gpl	2

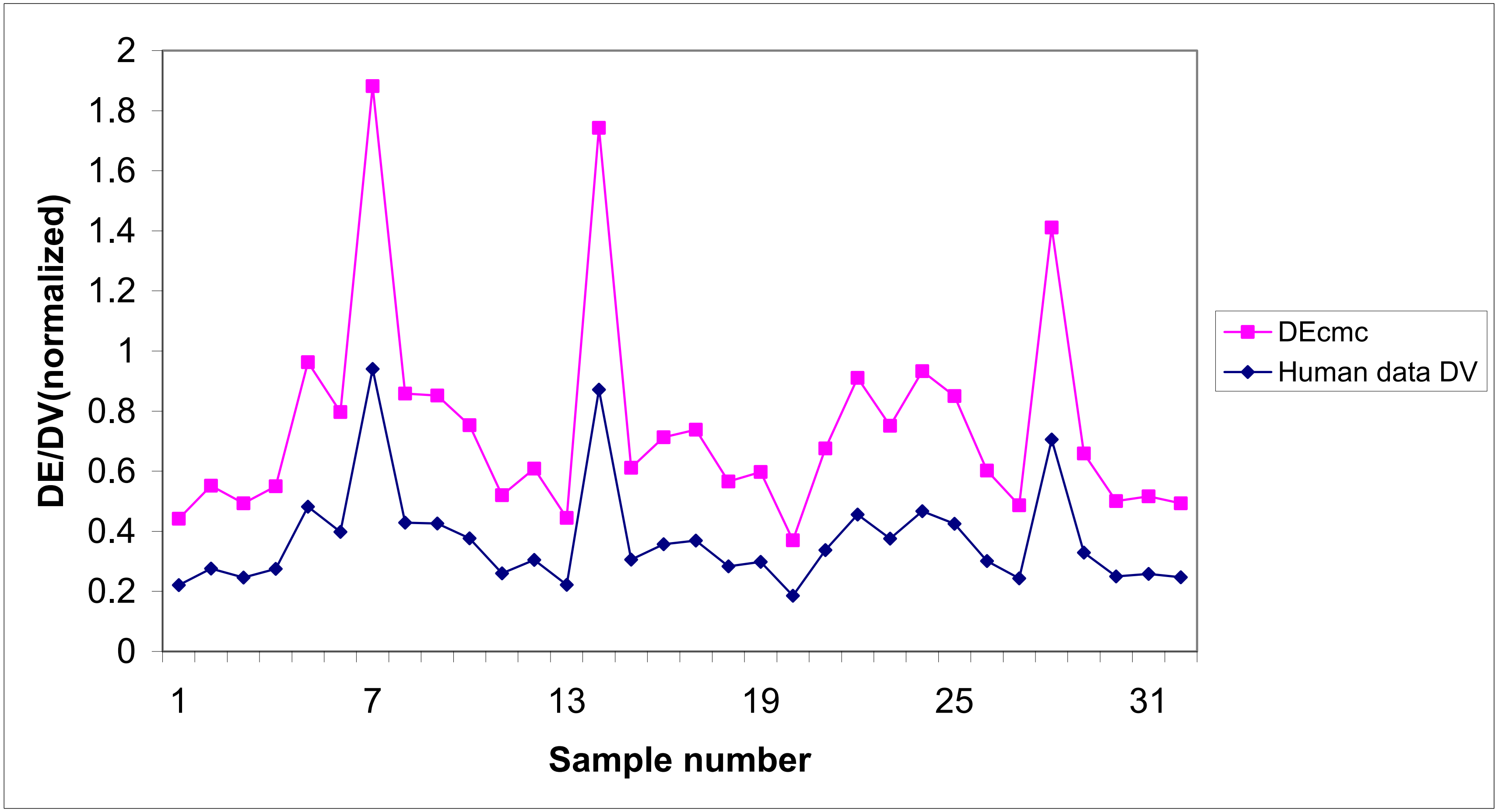


Figure 21. Comparison between human visual color difference and instrument measured color difference (DEcmc) (See Table 9 for description of sample Number).

1.3 Effect of Tactile Response on Visual Color Difference

1.3.1 Visual Evaluation of Small Color Differences (Within a Wash Set)

The experiment conducted above was repeated except that observers were required to visually compare each treated sample with a control (no finish applied) while touching the samples for the entire duration of the assessment. Color differences between control and test samples were at suprathreshold level since samples were assessed within a given wash set (either 1, 5 and 10 washes). For example a sample washed 5 times and treated with 2% softener was compared to a control that was washed 5 times but no softness applied. The observers were not told how to touch the samples, except to handle the samples well as shown in Figure 15. The observers were also asked to rate the hand of the fabric prior to providing a visual assessment, in order to force the processing of tactile responses. Hence, the color difference perception, if any, between visual alone and both visual and touch could be determined. Consequently, the effect of fabric hand on color difference perception could be assessed. Figure 22 shows a comparison of visual color-difference data (without tactile response) to visual color-difference data with tactile response. In general, the perceived color difference between samples was lower when a tactile response was included than when no touching of samples was allowed. Figure 23 shows a graph of the difference ($DV_{visual\ alone}$ - $DV_{visual\ +\ hand}$) between the two data sets. When the value on the y-axis is positive, the color difference of the sample pair was perceived to be less when a tactile response was included with the color difference perception. The opposite was the case if the value on the y-axis was negative. In general samples with softener applied showed positive values while samples with stiffener applied showed negative values in Figure 23. However, there is not agreement in all cases between the yellow samples and blue samples indicating that hue may influence the visual/hand data.

A statistical paired t-test method was used to determine if there was a significant difference between the visual alone and the hand and visual color difference data. The t statistic for these data was 3.03, and the significance, $P<0.0094$, showing that there is a significant difference between the mean values of the two data sets (see Appendix B.1).

When the mean visual assessment data samples are grouped into the four after-treatment groups (40 g/L and 20 g/L stiffener and 2% and 4% softener), it becomes clear that the color difference between the softer samples is significantly lower (by t-test analysis) when the samples were touched compared with when they were not, and vice versa for the control. However, no statistically significant difference between the two visual data sets was found for the stiffened samples.

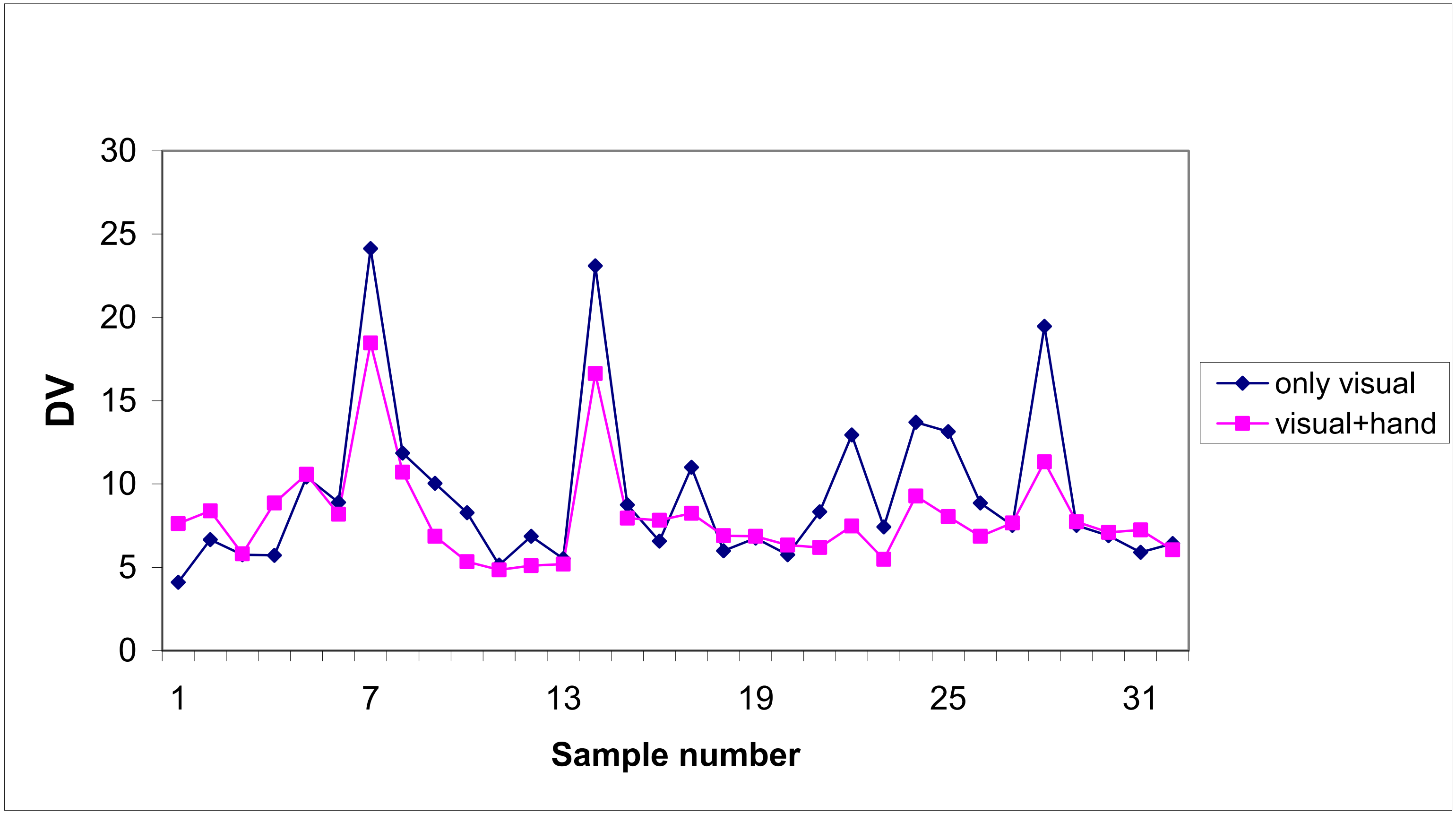


Figure 22. Comparison of unnormalized visual evaluation data for 32 color difference samples (yellow and blue) and visual & hand evaluation (See Table 9 for description of sample numbers).

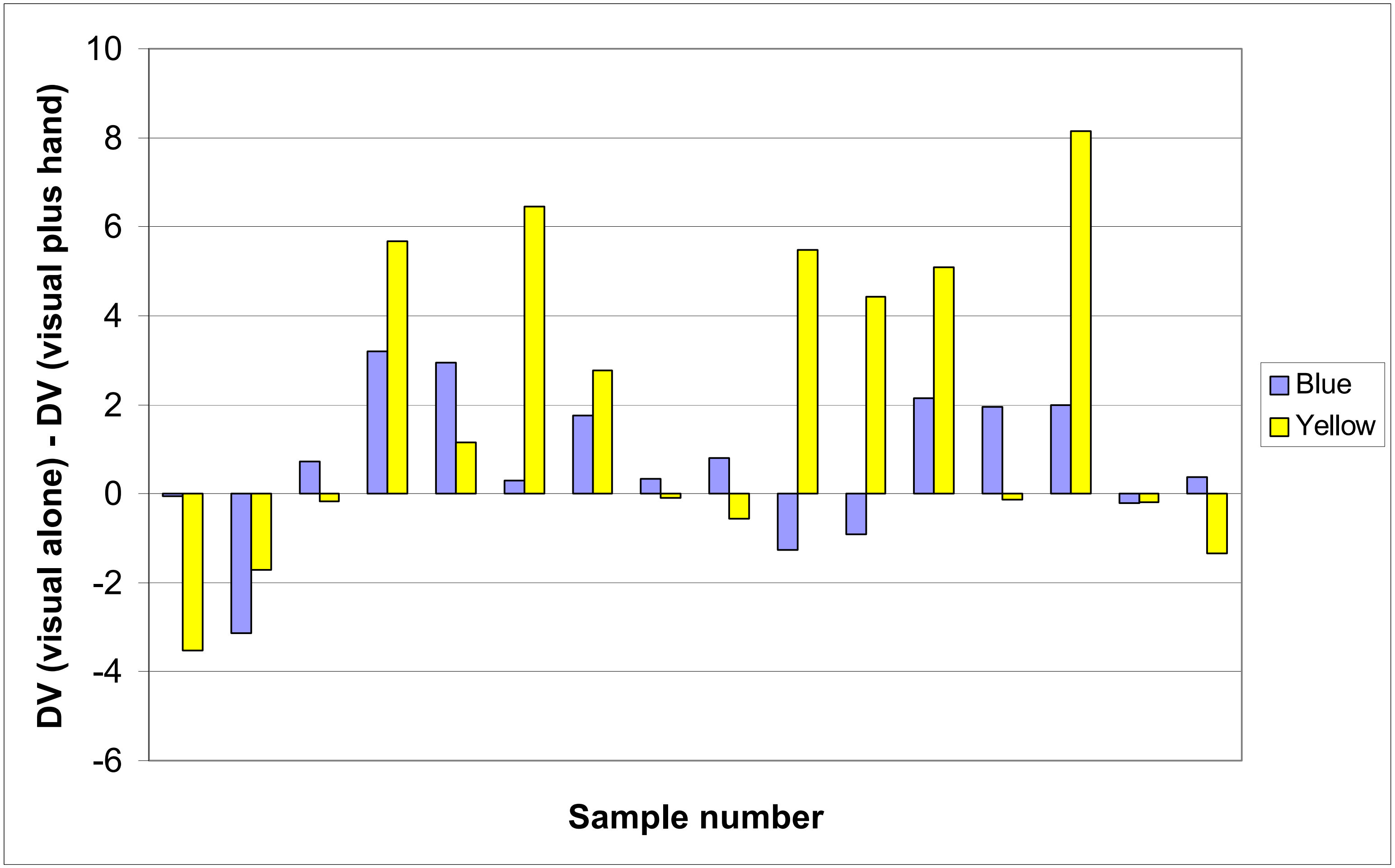


Figure 23. Difference plot (($DV_{visual\ alone}$ - $DV_{visual\ +\ hand}$)) between visual evaluation data for 32 color difference samples (yellow and blue) and visual & hand evaluation (see Table 9 for description of sample number).

The data supports the posit made by Rock and Victor (1964) [12] & Jones and O'Neil (1985) [11] that there exists cross-modal correspondence between sensory inputs. However cross-modal correspondence has not previously been demonstrated via tactile and color-difference magnitude perception on textured textile materials as is shown here. From this initial assessment of pale yellow and medium blue hue, a significant shift in the assessed color-difference was found when the fabric samples were touched compared to when they were not. This indicates that applying a softener may help reduce the perceived color differences of garments. The reason for this is unclear, and will likely be hard to demonstrate. However, it is possible that the more pleasing the feel, the more likely it is that an observer will be more lenient in color assessments.

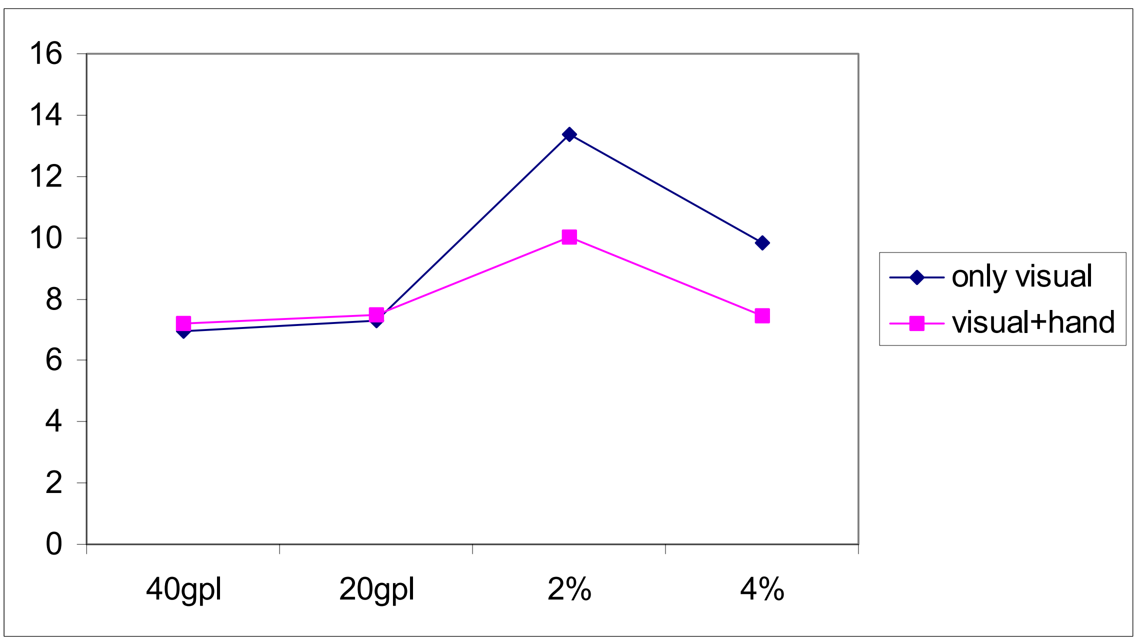


Figure 24. Comparison between mean visual evaluation and visual & hand evaluation for 40 g/L, 20 g/L stiffener and 2% and 4% softener application. (See Table 9 for description of samples assessed).

1.3.2. Visual evaluation of medium to large color differences (between wash set)

Most of the samples assessed in section 1.3.1 were at suprathreshold level of color difference, because the samples were selected within the same level of wash except for the three (pale yellow) samples, which were purposely added with large color difference. Interestingly, three samples with higher color differences were correctly observed by the observers and color differences of those samples showed a marked reduction when observers were allowed to handle the samples, particularly when softener had been applied. These data indicate the importance of assessing larger color differences following, between for instance zero wash and 5 or 10 washes and appropriate after treatment. However, prior to conducting this larger experiment, it was important to determine if there was any distortion of sample in handling, between observers. Hence initial subjective hand assessment was repeated with the same set of samples as used in the previous study.

1.2.3.1 Hand analysis verification

We used the same set of samples from the previous study and repeated the hand evaluation to verify if there was a degradation of the samples following the multiple handling during the experiments. Figure 25 shows the data for the two identical experiments before and after the study described in section 1.3.1.

Clearly there is a good correlation between the hand values of the previous study and the current study. The t test states at 95% confidence there is not a appreciable distortion of samples due to handling (Appendix A.1).

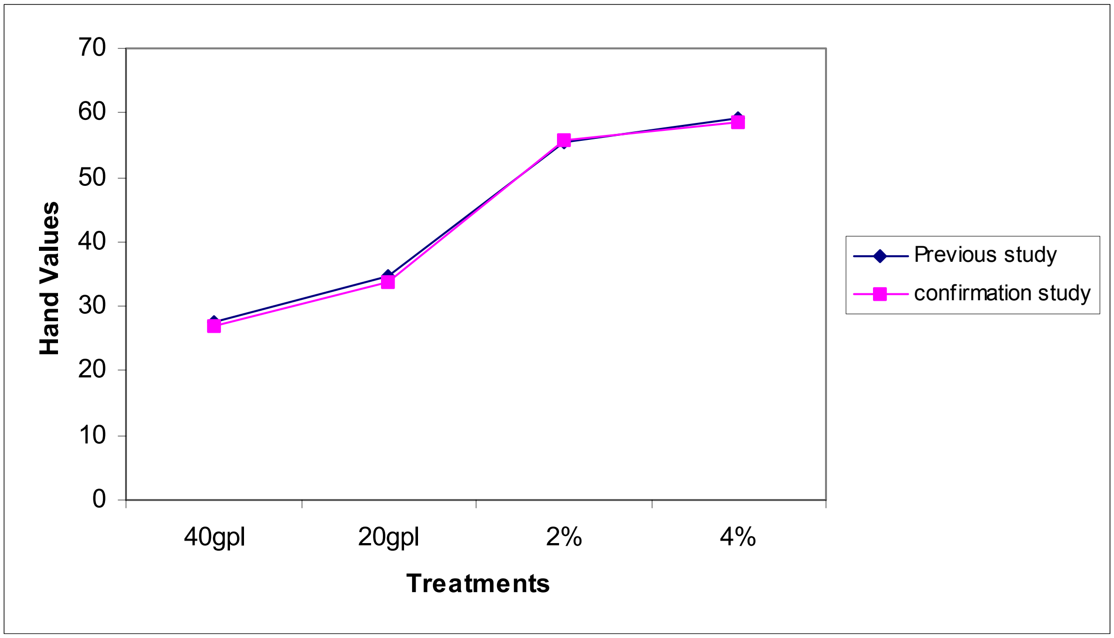


Figure 25. Shows the average hand data for 40gpl, 20gpl stiffener and 2% and 4% softener.

1.3.2.2 Visual Assessment of Yellow and Blue Hues Without Tactile Input

In the experiment, the same procedure of visual analysis as described in section 1.2, except the medium yellow and pale blue sample pairs compared were *between* washes and 26 observers were used. This means the observers were presented with a wide range of color difference pairs, rather than suprathreshold color differences. In addition, the effects of abrasion and aging following multiple laundering were now included in the color-difference perception.

Figure 26 shows clearly that the observer's color difference (visual alone) was in good agreement with measured values (DEcmc) after normalizing the DV values to the DEcmc scale. Figure 27 represents each wash level separately.

The medium yellow and pale blue samples were selected for larger color difference to test the methodology of the experiment, and once this had been validated was extended to samples with differing hue and chroma.

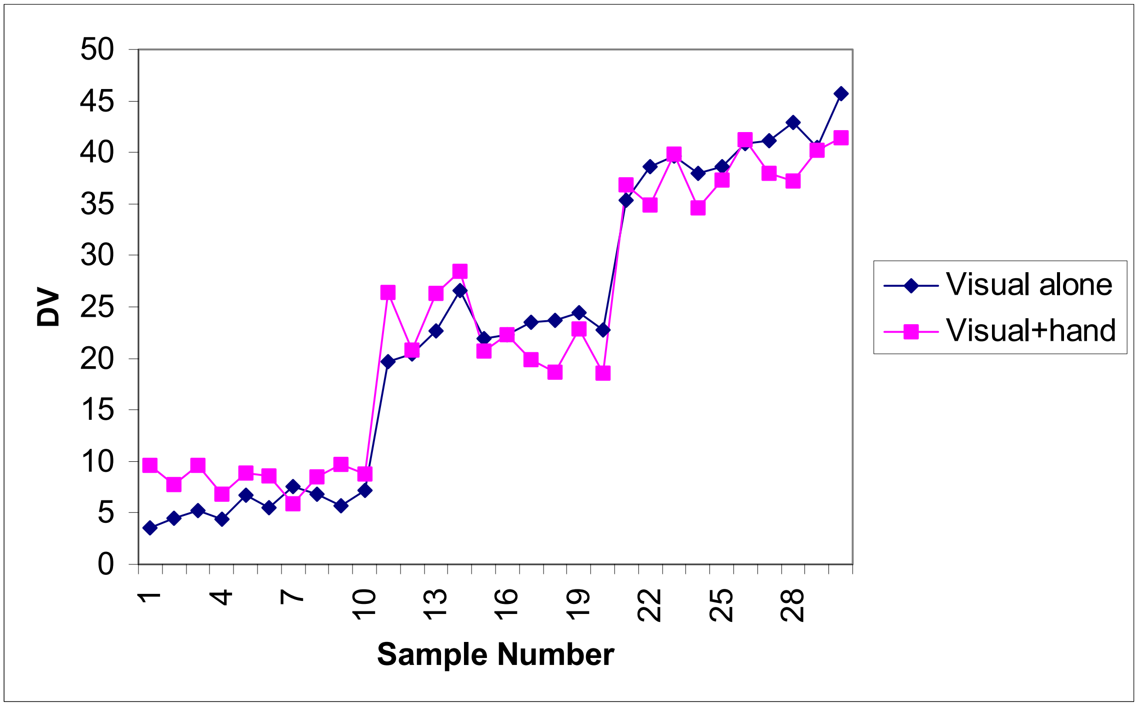


Figure 26. The measured color difference and the observed color difference (visual only) over the entire range of samples for medium yellow and pale blue. (See Table 9 for description of samples assessed)

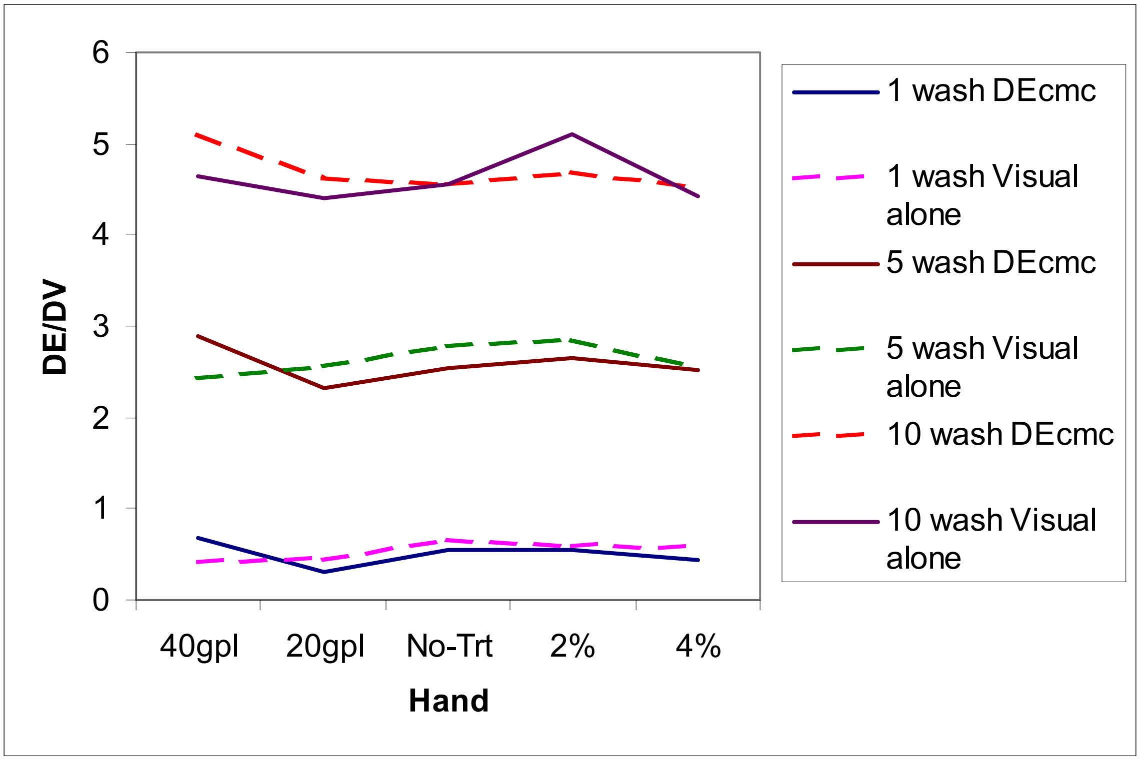


Figure 27. Shows the measured color difference and the observed color difference (visual only) over different washings 1,5 and 10 (yellow and blue combined).

1.3.2.3 Visual Assessment of Yellow and Blue Hues With Tactile Input

The 26 observers (from section 1.3.2.2) were required to visually assess the samples while at the same time assessing the hand of the fabric as described previously in section 1.3.1. Figure 28 shows a comparison of visual alone with visual & hand and a general trend is observed with relatively higher color difference for extreme stiff samples, but relatively smaller color difference for the softer samples where the tactile response is included. This general trend is more apparent as the number of washings increases. In other words, as the initial color difference is high, the observers tended to observe a higher color difference for stiffer samples and a lower color difference for the softer samples, between Visual alone and Visual and Hand observations. Figure 29 and 30 show data of medium yellow and pale blue separately and the same general trend as explained above, indicating that hue is not a significant factor in this experiment.

From the statistical analysis report attached in the appendix B.2 there is a significant difference between Visual and Visual and hand observations with all 40gpl, 20gpl stiffener and 2% softener at the 95% confidence level. The t-statistic values for 40 and 20gpl stiffer samples are in negative but positive for 2% and 4% softer samples, which signifies the direction of difference.

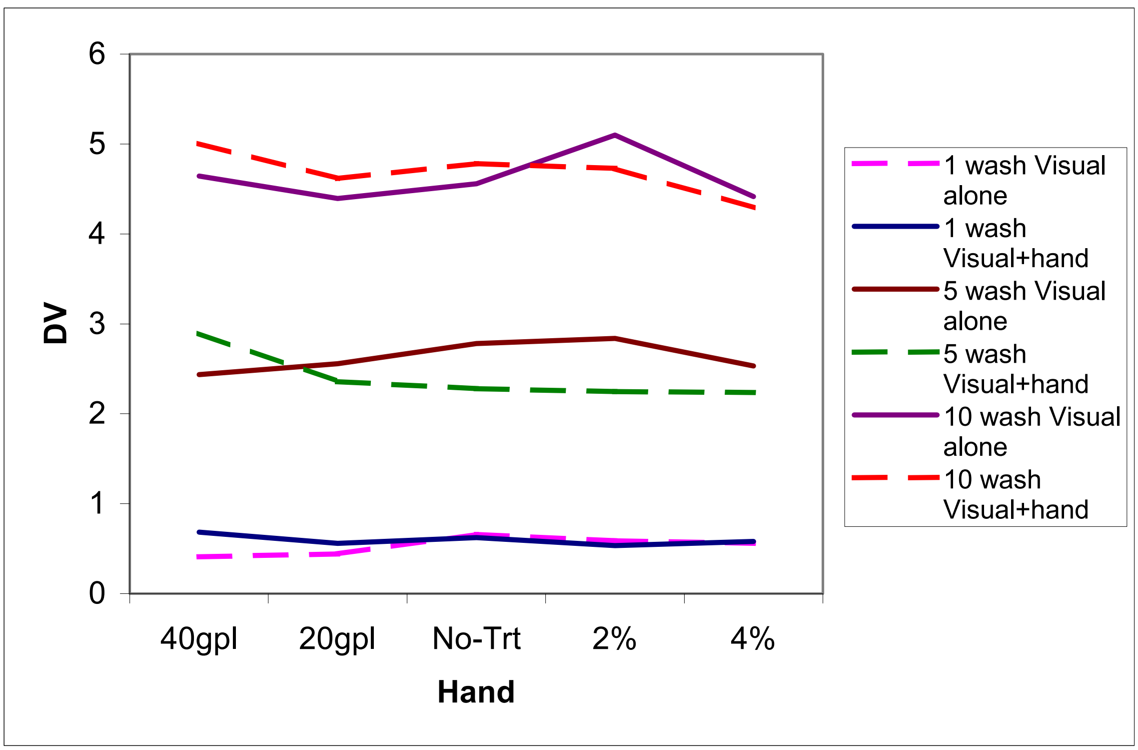


Figure 28. Comparison of DV without tactile input and DV with tactile input for samples of medium yellow and pale blue hue combined, washed 1, 5 and 10 times.

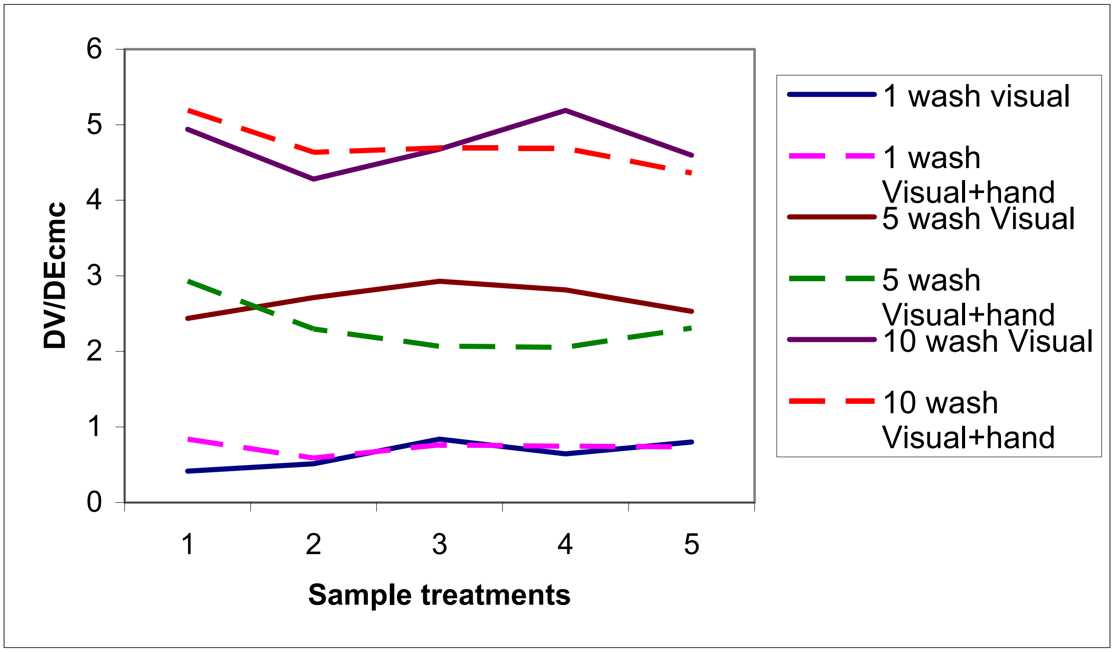


Figure 29. Comparison of DV without tactile input and DV with tactile input for samples of medium yellow hue washed 1, 5 and 10 times.

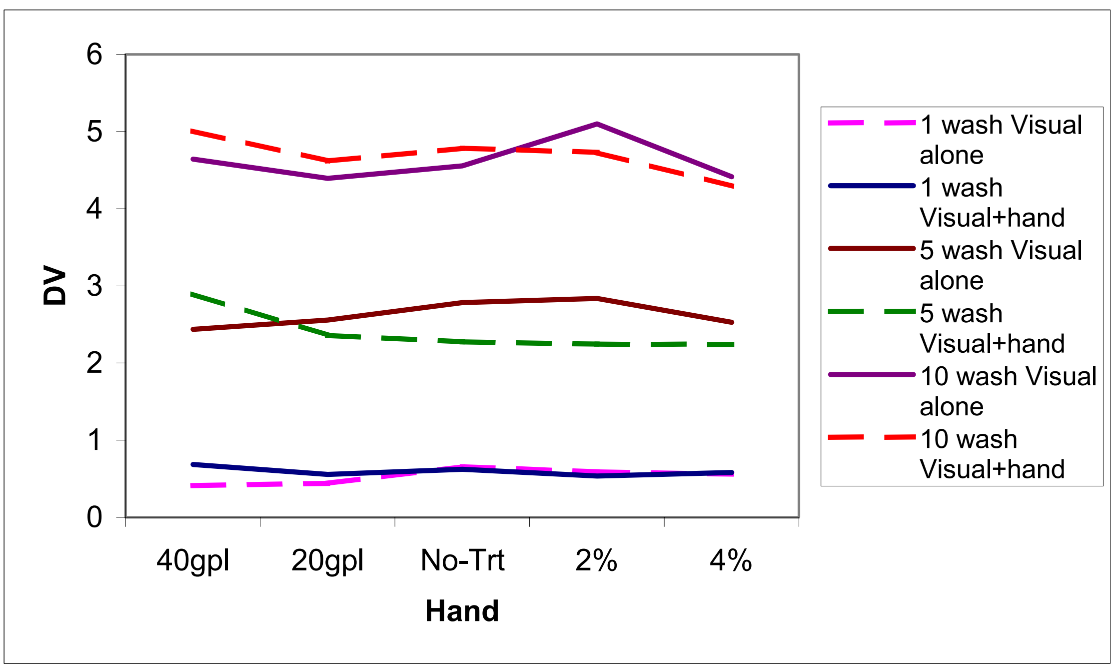


Figure 30. Comparison of DV without tactile input and DV with tactile input for samples of pale blue hue washed 1, 5 and 10 times.

1.3.2.4 Visual Assessment of green and Orange Hues Without Tactile Input

The data shown in previous section (1.3.2.2) indicate a statistically significant difference in perception of color difference when the samples were assessed visually without any tactile response compared to when tactile input was included for pale yellow and medium blue colors. This effect is more evident when the number of washes increases. In other words, if the color difference is high, then observers tend to judge color differences more harshly with stiffer samples and more leniently when samples feel soft. These findings prompted us to expand our experiment to a larger gamut of hues.

The procedure from section 1.2 was used for 26 trained observers judging pale and medium depth of shade of green and orange hues. Figures 31-34 compare the visual assessment (DV) without tactile input with measured color difference (DEcmc). The data are generally consistent with previous findings in that observers do correctly identify the magnitude of color difference.

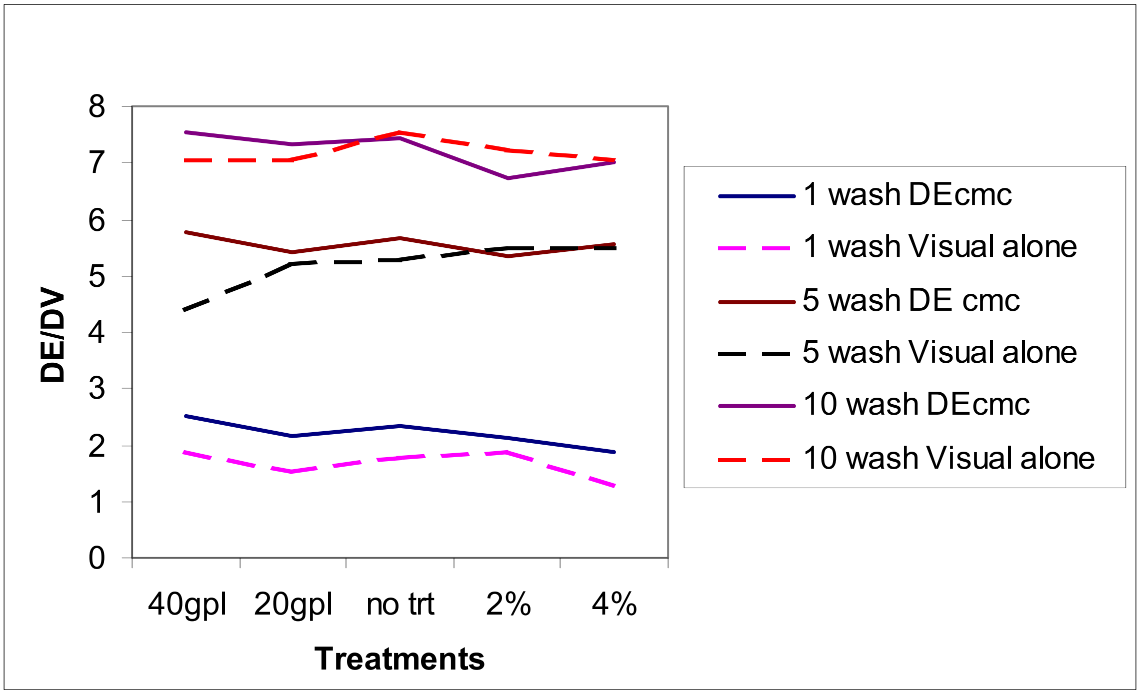


Figure 31. Comparison of measured (DEcmc) and the observed color difference (DV) for pale green samples washed 1,5 and 10 times.

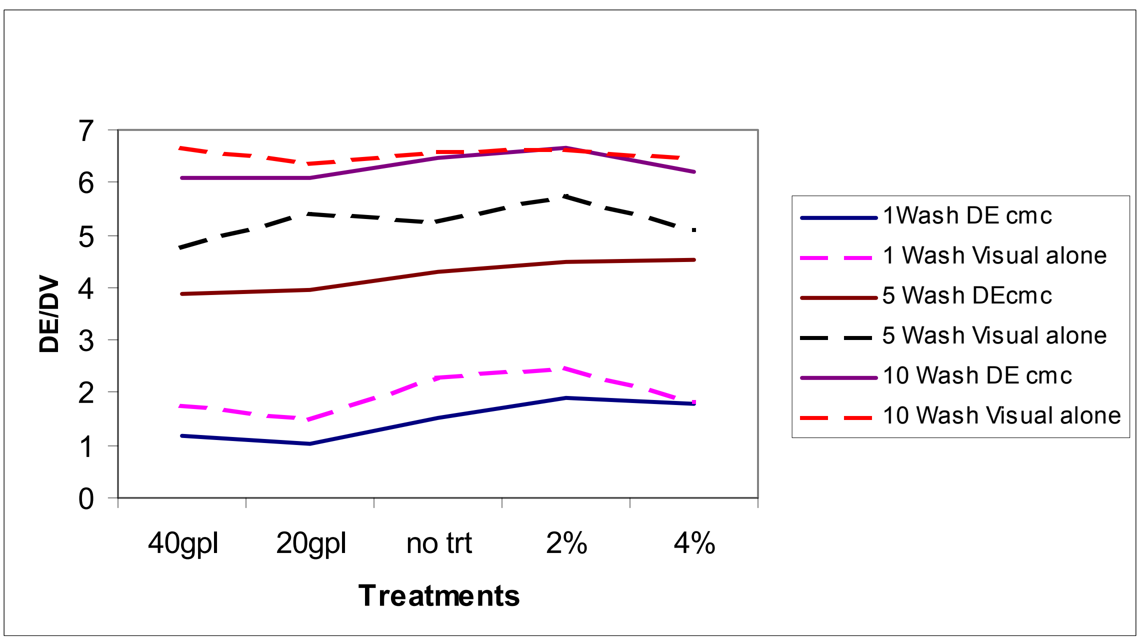


Figure 32. Comparison of measured (DEcmc) and the observed color difference (DV) for medium green samples washed 1,5 and 10 times.

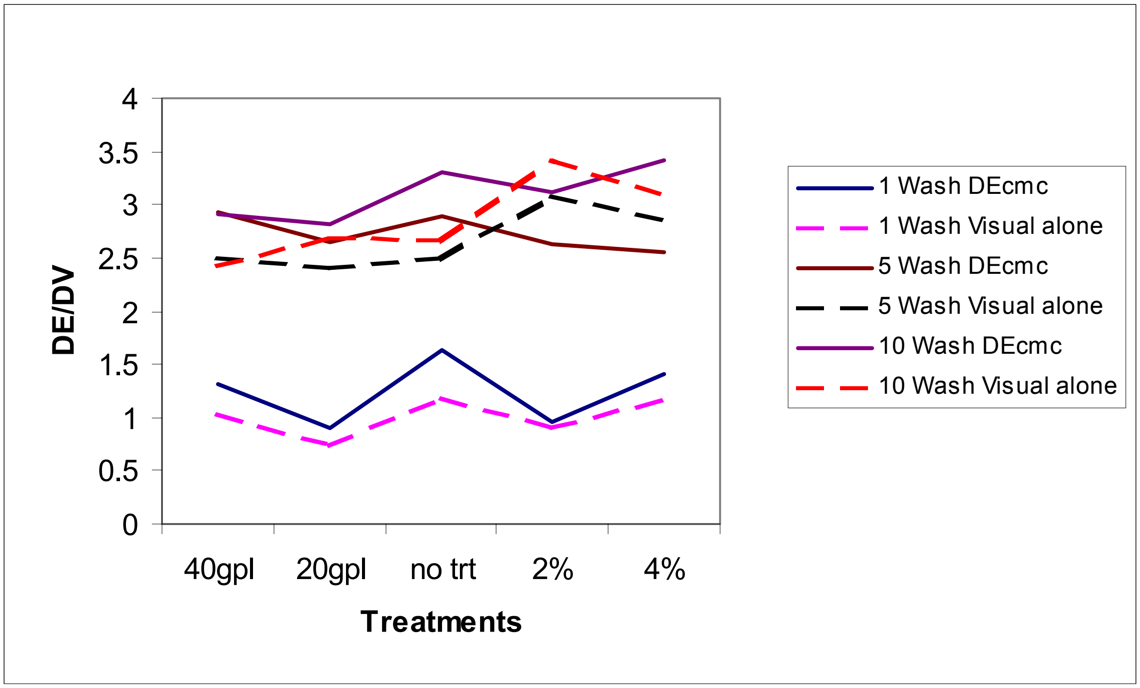


Figure 33. Comparison of measured (DEcmc) and the observed color difference (DV) for pale orange samples washed 1,5 and 10 times.

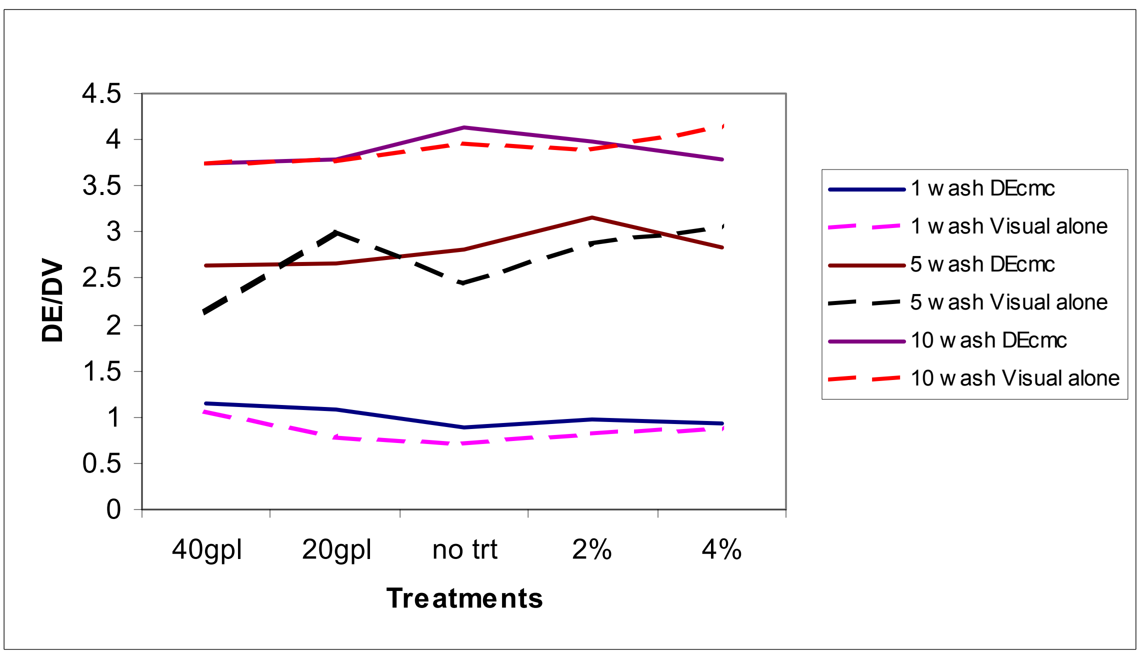


Figure 34. Comparison of measured (DEcmc) and the observed color difference (DV) for medium orange samples washed 1,5 and 10 times.

1.3.2.5 Visual Assessment of Green and Orange Hues with Tactile Input

Figures 35-38 show the same general trend for the effect of tactile response on the magnitude of color differences for orange and green hues and for yellow and blue (section 1.3.2.3). Hence, there does not appear to be a significant hue dependency of cross-modal correspondence for visual and tactile response. Again, the trend is more apparent as the number of washings increases. From the statistical analysis (appendix B.2.2), it was shown that there is a significant difference at 95% confidence interval for almost all of the paired t-test data, irrespective of hue or shade. Exceptions are pale orange with 20gpl stiffener and orange 40gpl stiffener for visual and tactile response. The anomalies are likely due to the initial lower color difference observed in each case compared to other sample set.

Interestingly, for some hues the effect of tactile response on the perceived magnitude of the color difference is significant in reducing the DV value. For instance, the pale and medium green samples that received 5 and 10 washes were assumed at far lower color difference when no tactile input was allowed. The magnitude of the difference gives strong evidence that softening agents in after-treatments will influence color-difference perception of observers in a positive direction.

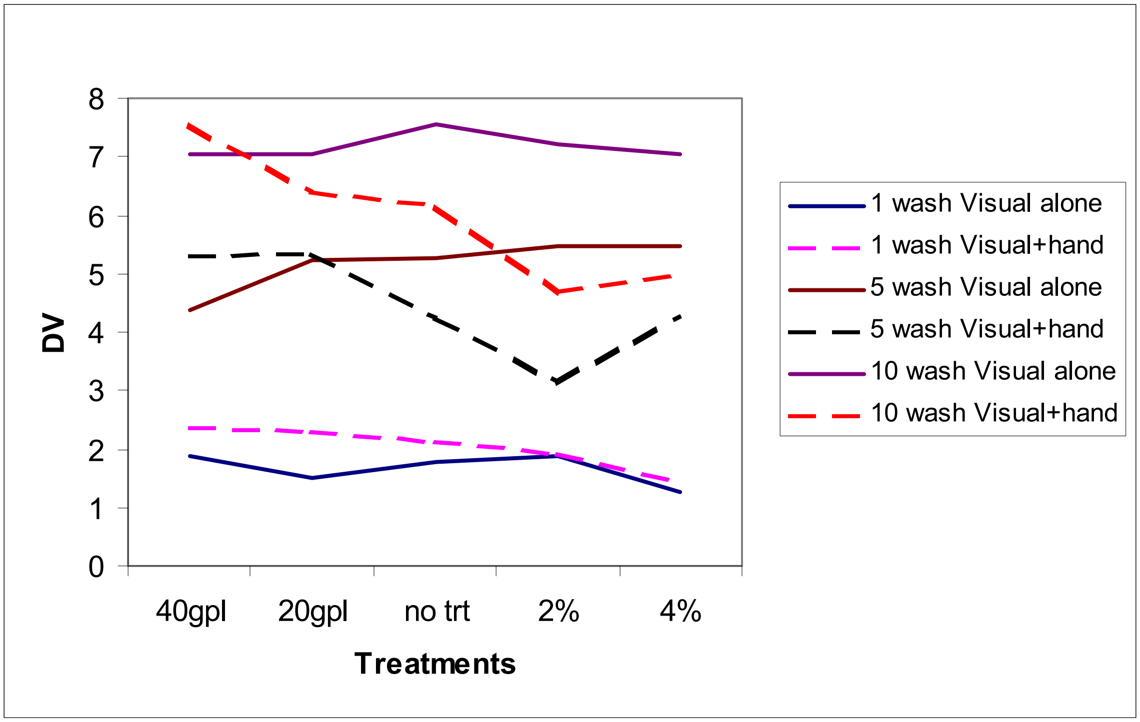


Figure 35. Comparison of DV without tactile input and DV with tactile input for samples of pale green hue washed 1, 5 and 10 times.

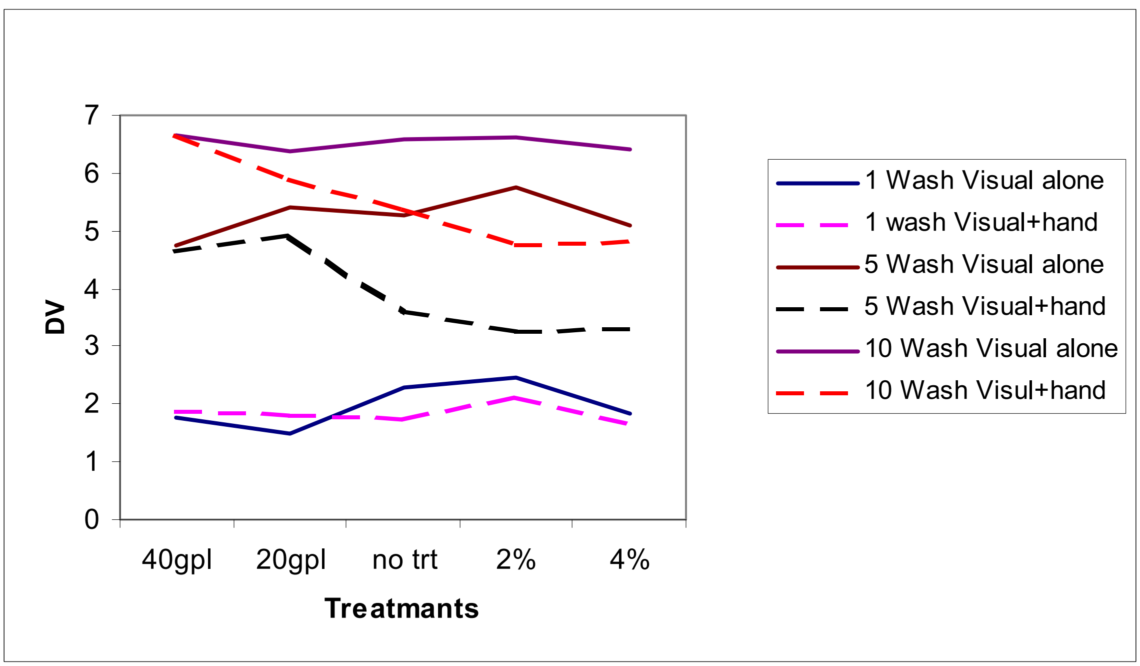


Figure 36. Comparison of DV without tactile input and DV with tactile input for samples of medium green hue washed 1, 5 and 10 times.

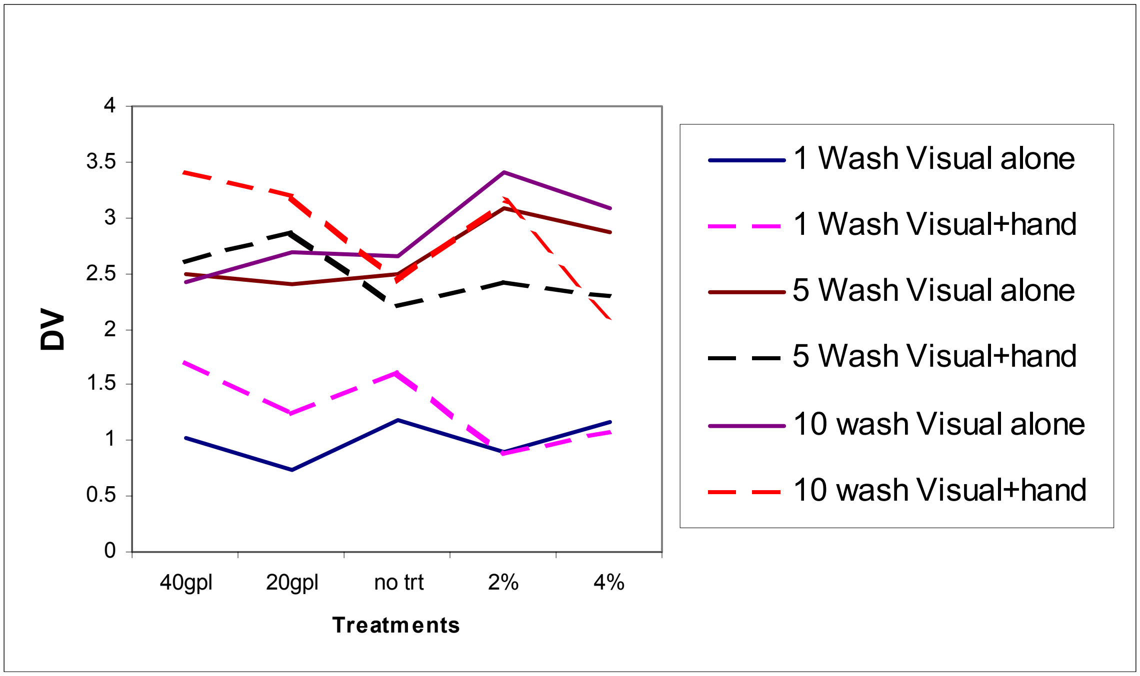


Figure 37. Comparison of DV without tactile input and DV with tactile input for samples of pale orange hue washed 1, 5 and 10 times.

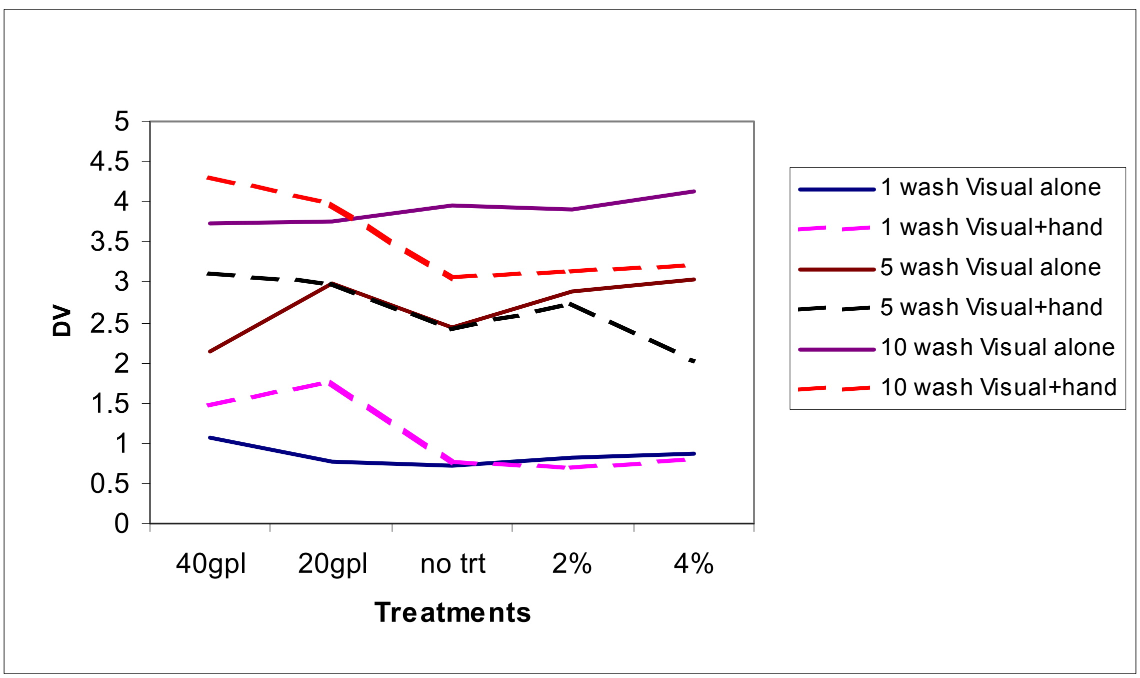


Figure 38. Comparison of DV without tactile input and DV with tactile input for samples of medium orange hue washed 1, 5 and 10 times.

C. Effect of Olfactory Response on Color Difference perception

1. Initial Assessment

In order to test the potential influence of fragrance on perceived magnitude of color difference, a feasible experiment was required to determine if it was possible to deliver consistent level of fragrance to each observer that would be clearly detected but at the same time would not be over powering, thereby causing a potentially negative (unpleasant) reaction. Also, in order to avoid having to produce hundreds of samples with same hue and wash characteristics, it was important to deliver the odor from a source that was not the sample itself. To achieve this end, 3" by 3" swatches of cotton fabric were prepared with a controlled amount of fragrance oil (20μl for lavender and 30μl orange-oil fragrance) delivered via micropipette. Each sample was immediately placed in a plastic bag and sealed. Three minutes prior to the start of an experiment a fragrance swatch was removed from the bag and placed behind the 45^o sample stand.

An initial experiment was conducted with 7 color-normal observers to determine the validity of the experimental approach. As in the case of experiments to determine the effect of tactile response on magnitude of perceived color differences (section B), it was necessary to determine the observers' perceived magnitude of color difference in the absence of any odor or other non-visual stimuli.

In the experiment, pale green and medium orange hues were used with lavender and orange-oil fragrance of particular interest was the potential influence of orange fragrance on orange hue in view of the obvious strong association. However, lavender fragrance, while may generally considered to be pleasant, has no obvious association with either green or orange hues. Also after each experiment the observers were asked three questions (see section II.C.5). Of the seven observers six observers positively reported detecting a fragrance, orange fragrance was more readily identified than lavender and all observers reported the fragrances to be bearable.

Figures 39 and 40 show a compression of the perceived magnitude of color differences in presence and absence of orange oil for pale green and medium orange hues. Figures 41 and 42 show the effect when lavender oil was used with the above setup. Interestingly, Figure 40 shows a marked reduction in color-difference values for orange hues in 5 and 10 washes. This was not observed in any of the other experiments (Figures 33, 35 and 36). This indicates that orange has a positive effect on perceived color differences of orange samples. However, since a small set of observers, statistical significance could not be established. Also, the effect could have been due to the specific ordering of samples. Hence, a more vigorous experiment was designed to establish statistical significance and to eliminate sample-ordering effects.

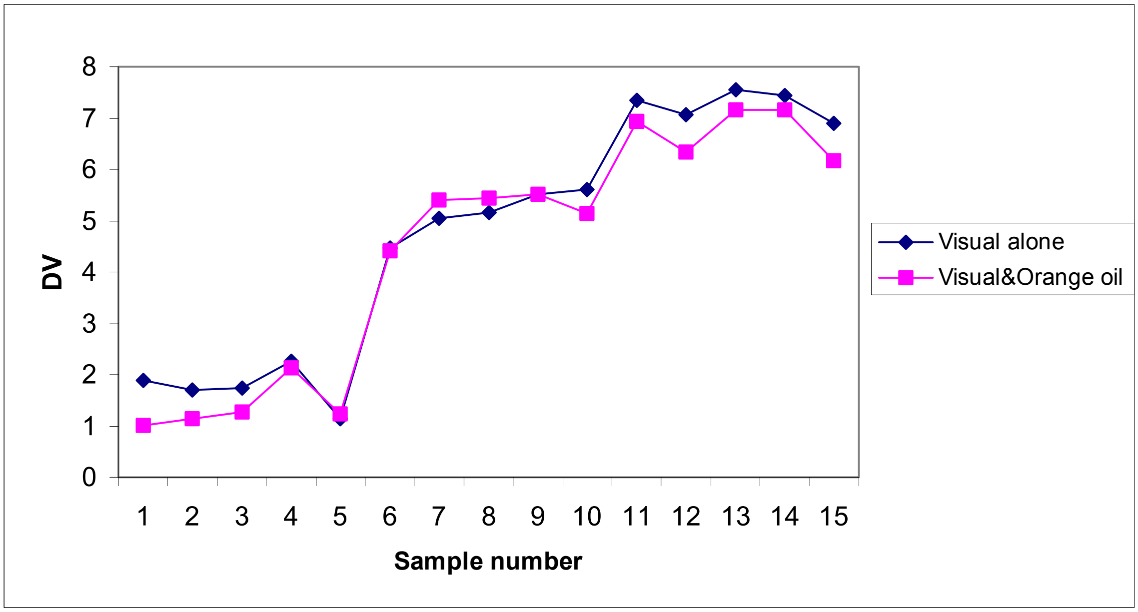


Figure 39. Comparison of the perceived magnitude of color difference (DV) for pale green hue after 1, 5, and 10 washes in the absence and presence of orange fragrance (See Table 9 for description of sample number).

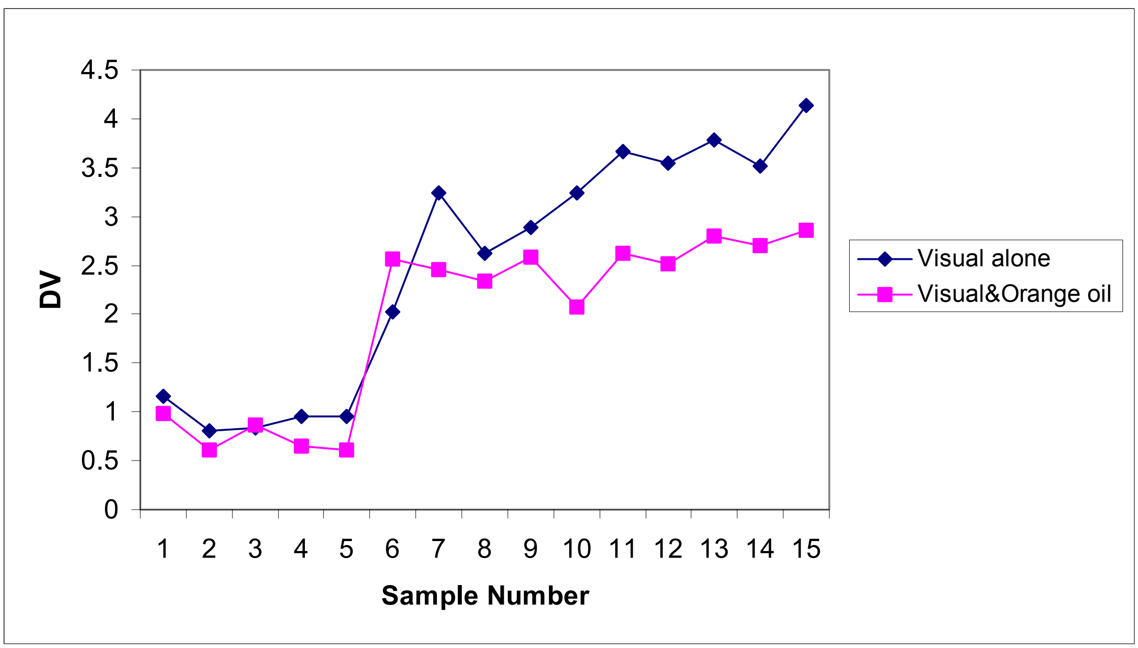


Figure 40. Comparison of the perceived magnitude of color difference (DV) for medium orange hue after 1, 5, and 10 washes in the absence and presence of orange fragrance (See Table 9 for description of sample number).

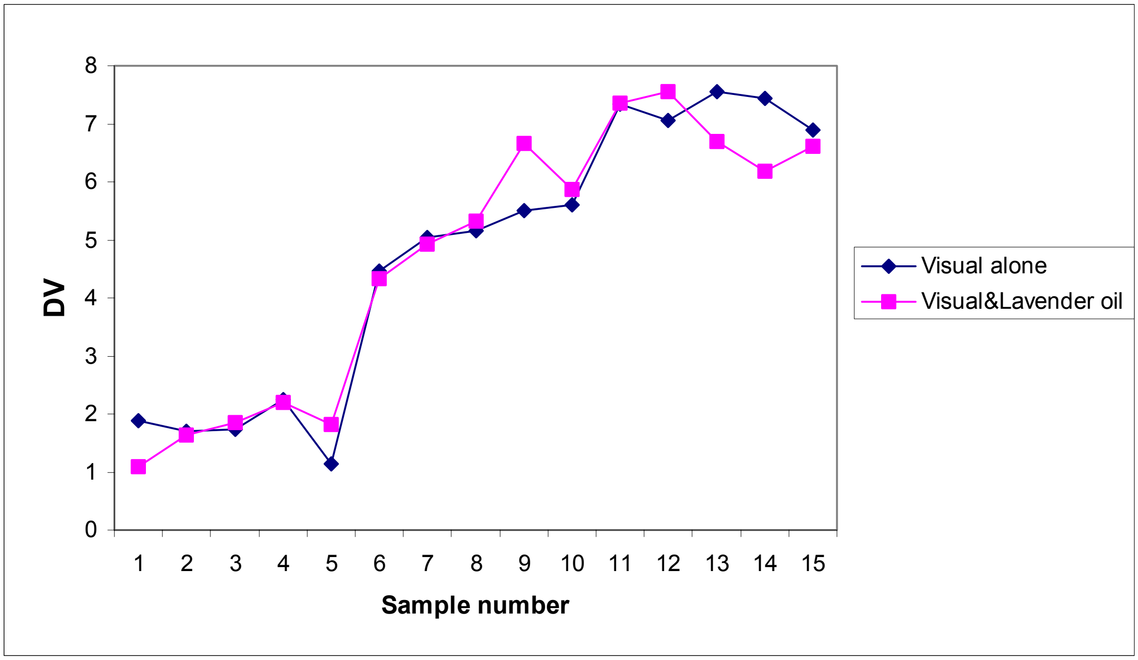


Figure 41. Comparison of the perceived magnitude of color difference (DV) for pale green hue after 1, 5, and 10 washes in the absence and presence of lavender fragrance (See Table 9 for description of sample number).

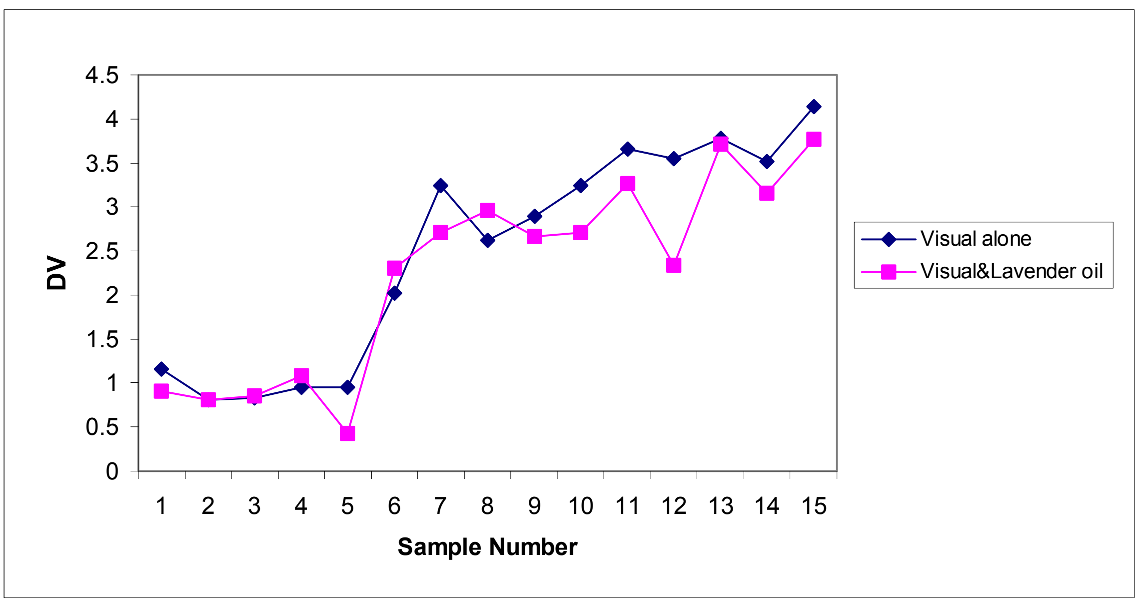


Figure 42. Comparison of the perceived magnitude of color difference (DV) for medium orange hue after 1, 5, and 10 washes in the absence and presence of lavender fragrance (See Table 9 for description of sample number).

2.Comprehensive Assessment on the Effect of Olfactory Response on Perceived Magnitude of Color Difference

The effect of odor on color-perception trial experiment shows some surprising results, especially the effect of orange-oil fragrance on the perception of color difference of fabric dyed with orange hue. The effect could have been due, however, to the small observer set (seven observers) or to the order in which the samples were presented. Hence, a comprehensive experiment was designed to eliminate or reduce these undesired variables.

Using three sets of 25 to 30 trained observers, all students at NC State University, each set of observers performed observations on 0 & 1 wash, 0 & 5 and 0 & 10 wash paired sets with samples randomized in each set. Each observer performed three observations without and with fragrance present, with orange-oil fragrance and with lavender-oil fragrance. In this way issues of number of observers or sample-ordering effects were eliminated or minimized.

2.1 Visual Assessment in Absence of Odor Stimulus

The same procedure for visual evaluation was used as described in section B.1.2. The hues used were pale green and medium orange. As also shown in section B.1.3.2.2, comparisons of DE_{cmc} and normalized DV value for 1, 5 and 10 wash for both pale green and medium orange were in agreement, as shown in Figure 43-48. In each case, sample pairs on the x-axis represent the ordering of sample pairs as shown in Tables 10-12.

Table 10. Table of sample pair numbering system associated with their after-treatment and sample order for 1 wash.

Green (2gpl)			
Sample pairs	**Softner/stiffener**	**Washes**	**Sample order**
I	40gpl		
		1	1
II	20gpl		
		1	4
III	no treatment		
		1	10
IV	2%		
		1	6
V	4%		
		1	8
Orange (8gpl)			
	Softner/stiffener	**Washes**	**Sampleoder/ codes**
VI	40gpl		
		1	9
VII	20gpl		
		1	3
VIII	no treatment		
		1	5
IX	2%		
		1	7
X	4%		
		1	2

Table 11. Table of sample pair numbering system associated with their after-treatment and sample order 5 washes.

Green (2gpl)			
Sample pairs	**Softner/stiffener**	**Washes**	**Sample order**
I	40gpl		
		5	11
II	20gpl		
		5	15
III	no treatment		
		5	18
IV	2%		
		5	20
V	4%		
		5	12
Orange (8gpl)			
	Softner/stiffener	**Washes**	**Sampleoder/ codes**
VI	40gpl		
		5	13
VII	20gpl		
		5	16
VIII	no treatment		
		5	19
IX	2%		
		5	14
X	4%		
		5	17

Table 12. Table of sample pair numbering system associated with their after-treatment and sample order 10 washes.

Green (2gpl)			
Sample pairs	**Softner/stiffener**	**Washes**	**Sample order**
I	40gpl		
		10	26
II	20gpl		
		10	21
III	no treatment		
		10	25
IV	2%		
		10	28
V	4%		
		10	24
Orange (8gpl)			
	Softner/stiffener	**Washes**	**Sampleoder/ codes**
VI	40gpl		
		10	23
VII	20gpl		
		10	27
VIII	no treatment		
		10	29
IX	2%		
		10	30
X	4%		
		10	22

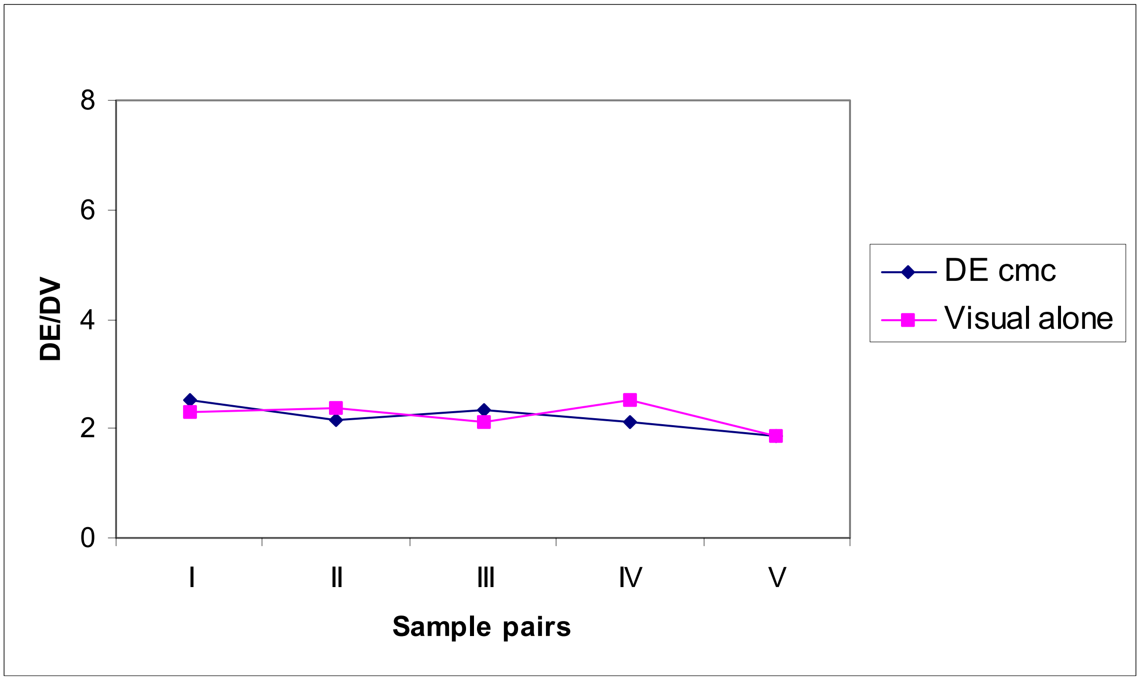


Figure 43. Comparison of measured (DE_{cmc}) and the observed color difference (DV) for Pale green samples washed 1 time (see Table 10 for description of sample pairs)

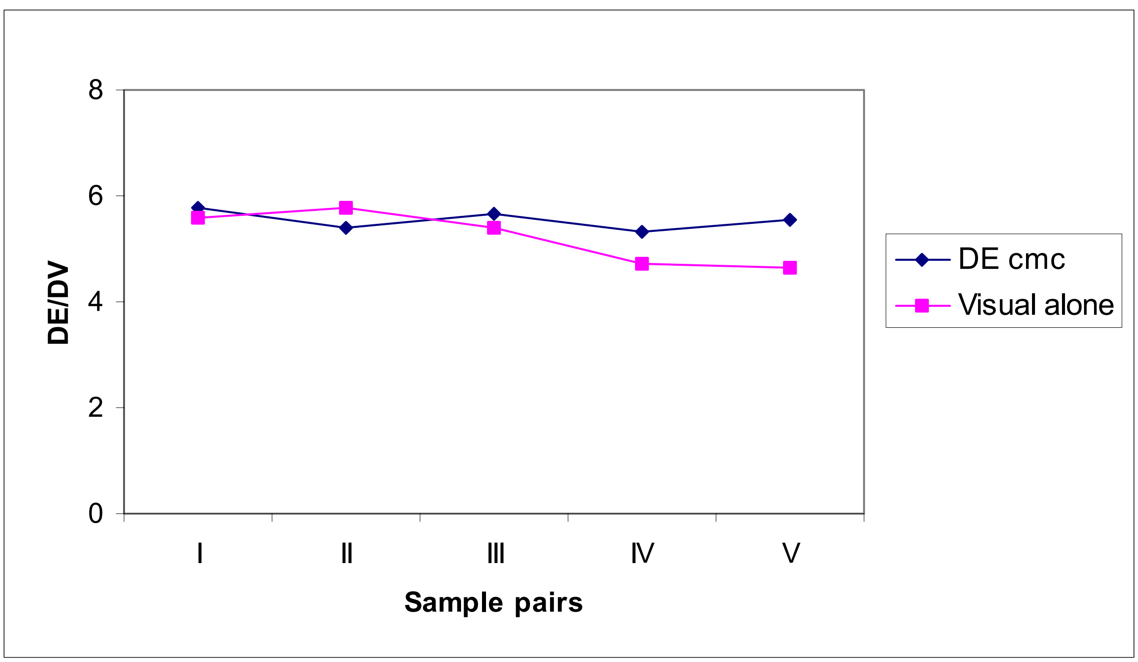


Figure 44. Comparison of measured (DE_{cmc}) and the observed color difference (DV) for Pale green samples washed 5 times (see Table 11 for description of sample pairs).

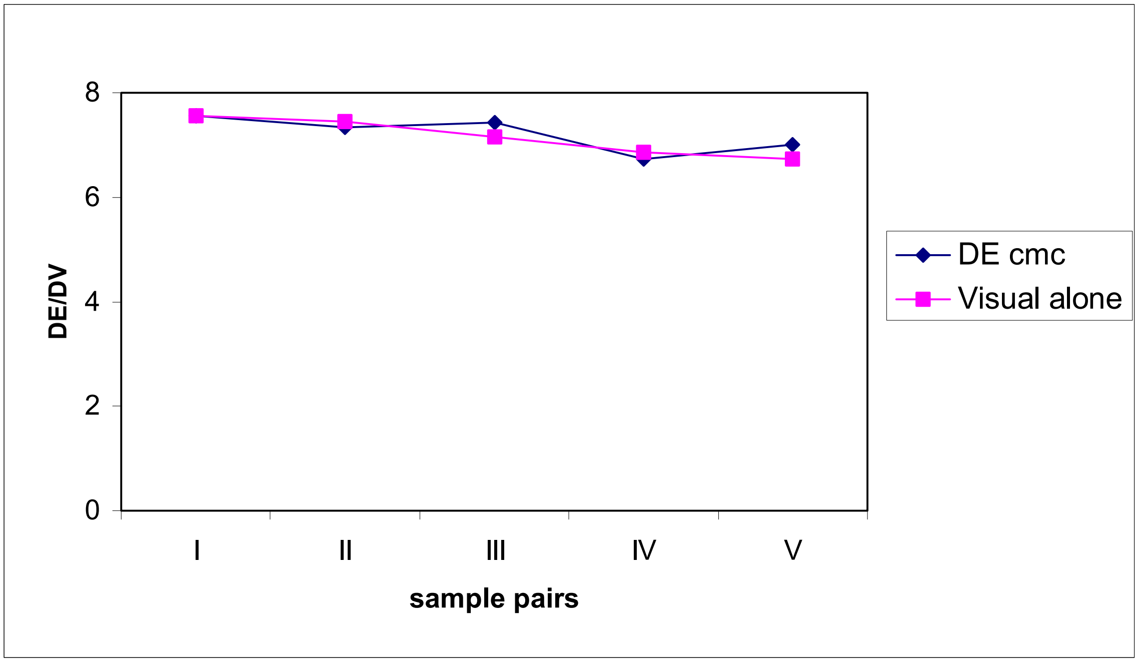


Figure 45. Comparison of measured (DE_{cmc}) and the observed color difference (DV) for Pale green samples washed 10 times (see Table 12 for description of sample pairs).

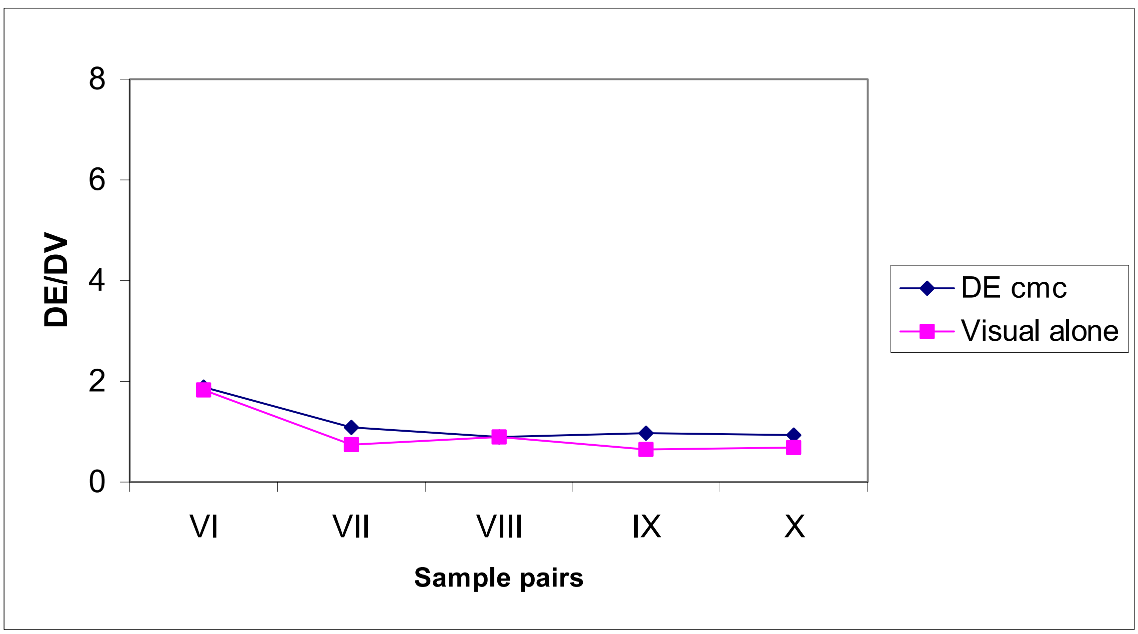


Figure 46. Comparison of measured (DE_{cmc}) and the observed color difference (DV) for medium orange samples washed 1 time (see Table 10 for description of sample pairs).

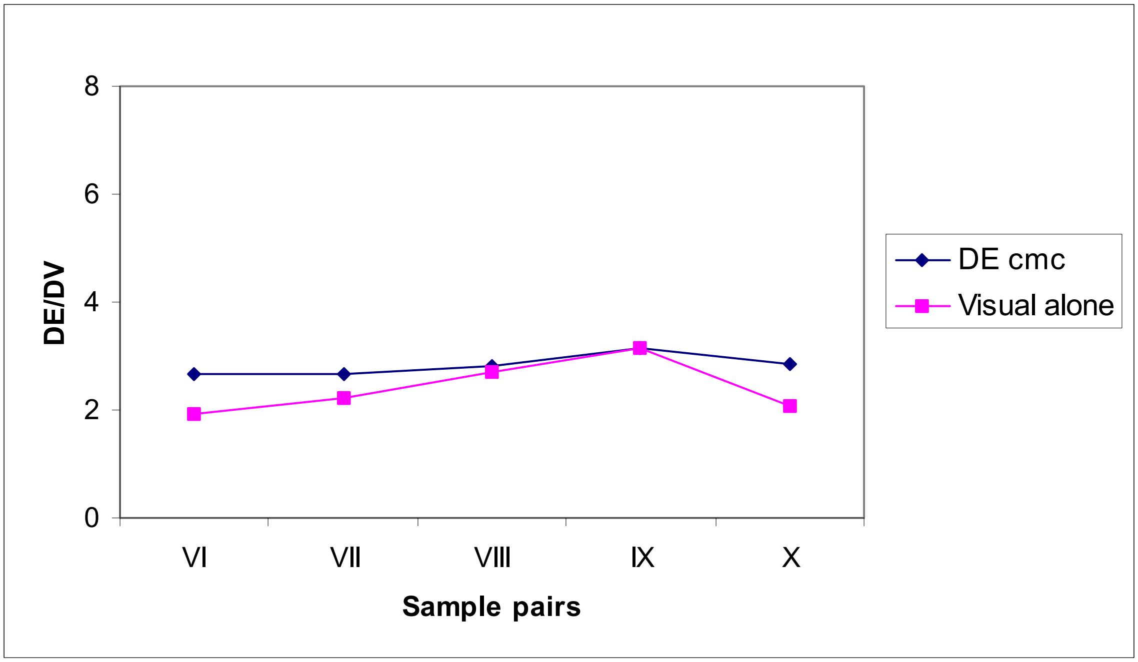


Figure 47. Comparison of measured (DE_{cmc}) and the observed color difference (DV) for medium orange samples washed 5 times (see Table 11 for description of sample pairs).

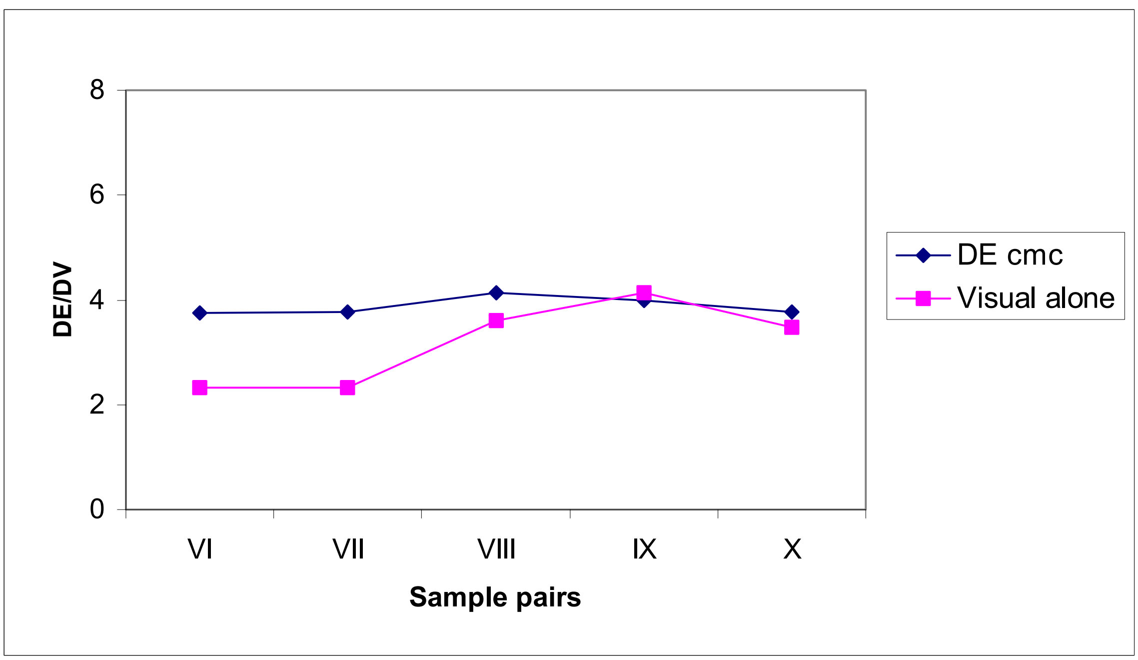


Figure 48. Comparison of measured (DE_{cmc}) and the observed color difference (DV) for medium orange samples washed 10 times (see Table 12 for description of sample pairs).

2.2 Visual Assessment in Presence of Odor Stimulus

The experimental setup remained the same as described in section C.1. Figures 49-51 show the effect of the lavender fragrance on perceived magnitude of color difference for pale green fabrics washed 1, 5, 10 times. Figures 52-54 show equivalent data for medium orange fabric. Statistical analysis of these two sets of data shows no significant difference. Figures 55-60 show the effect of orange oil was used with the above setup. It is curious to note from Figures 58-60 that there is a marked reduction in color difference. At the same time, Figures 55-57 show either no significant effect or a significant negative difference (Figure 57). The later indicates that when observers were asked to assess the visual difference of pale green sample pairs with orange-oil fragrance present, they tended to rate higher color differences higher than when no fragrance was present. Paired t-test analysis showed that, at a 95% confidence level, there is a significant difference between visual assessment of orange hues with and without the presence of orange-oil fragrance (see Appendix C.1, C.2). Hence, these results are consistent with the initial trail study on the effect of orange-oil fragrance discussed in section C.1 that used only seven observers.

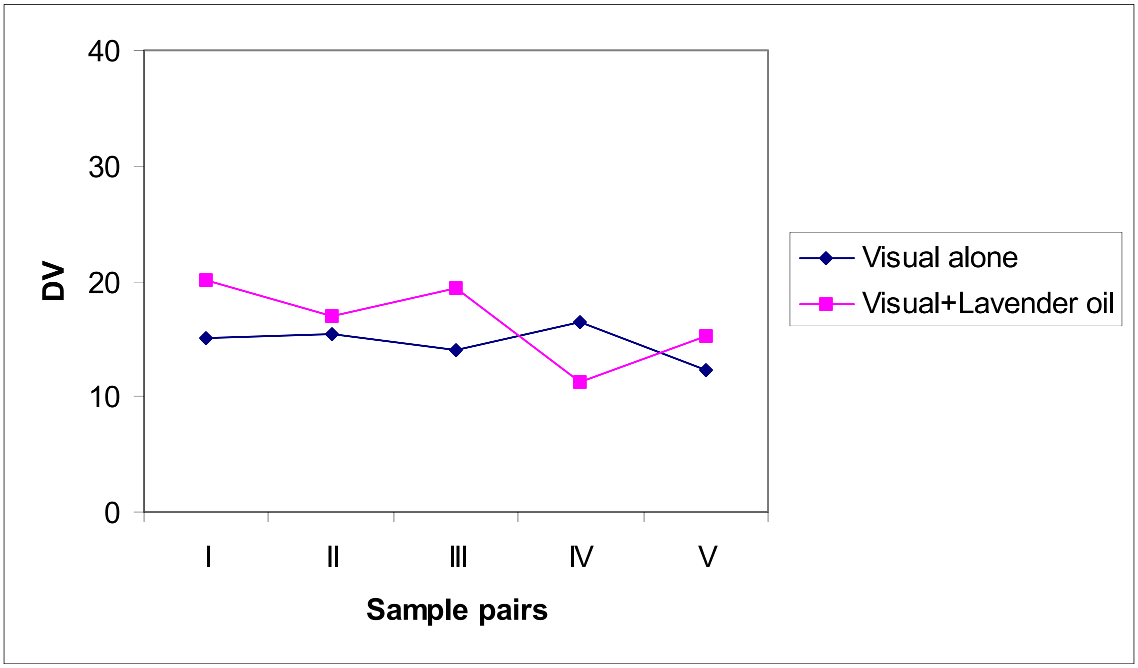


Figure 49. Comparison of the perceived magnitude of color difference (DV) for pale green hue washed 1 time, in the absence and presence of lavender fragrance (See Table 10 for description of sample pairs).

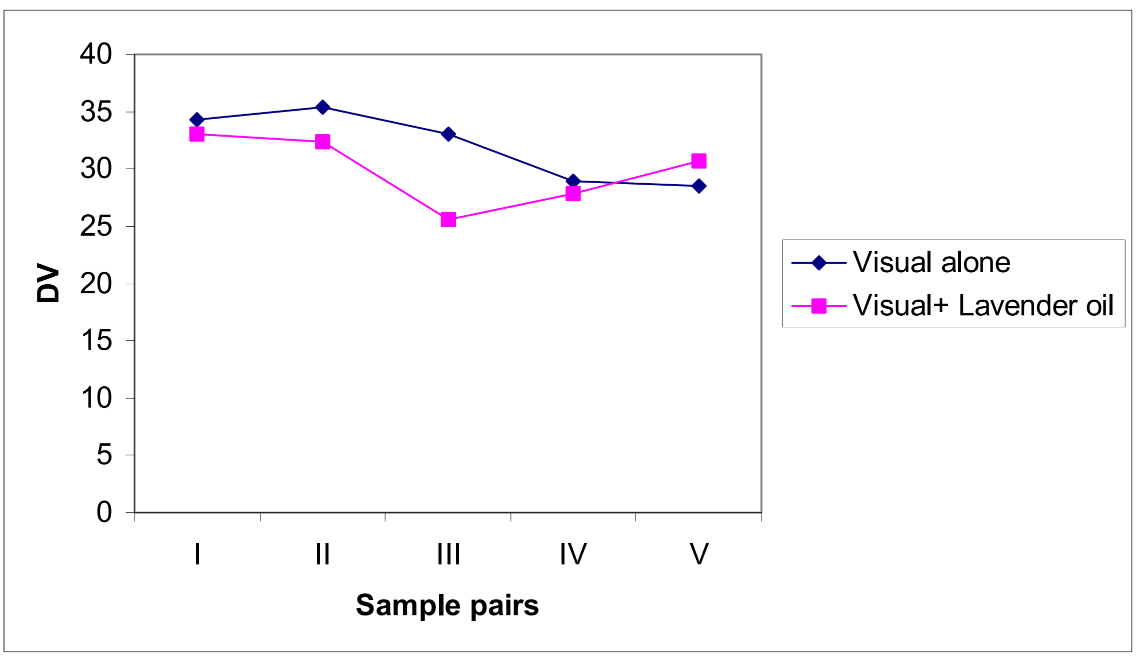


Figure 50. Comparison of the perceived magnitude of color difference (DV) for pale green hue washed 5 times, in the absence and presence of lavender fragrance (See Table 11 for description of sample pairs).

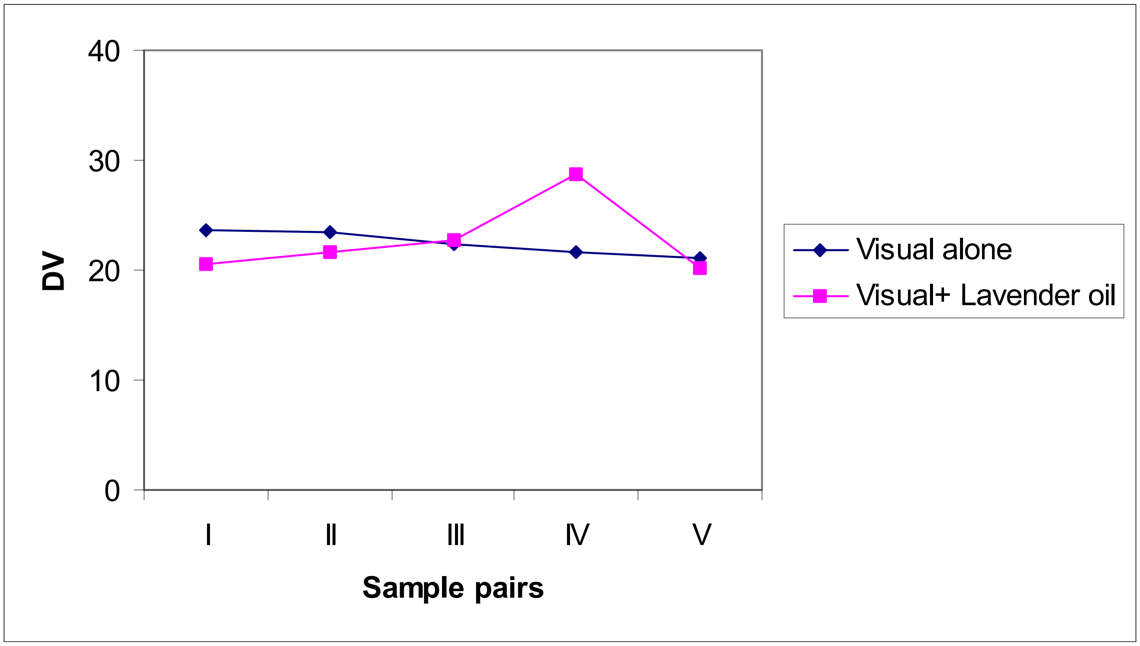


Figure 51. Comparison of the perceived magnitude of color difference (DV) for pale green hue washed 10 times, in the absence and presence of lavender fragrance (See Table 12 for description of sample pairs).

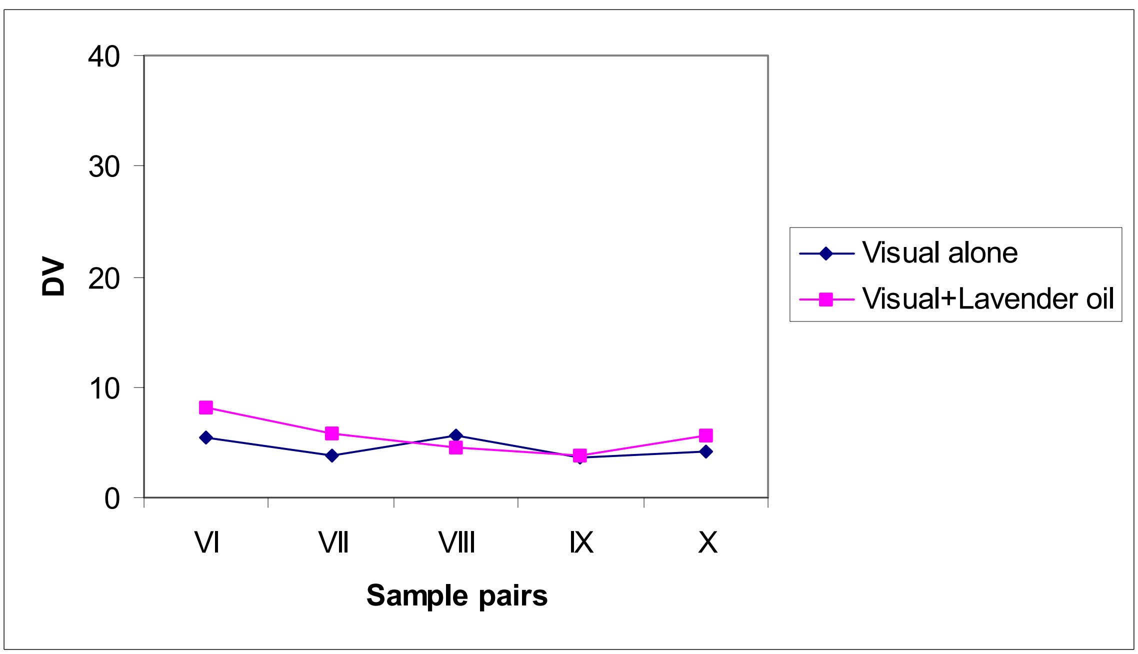


Figure 52. Comparison of the perceived magnitude of color difference (DV) for medium orange hue washed 1 time, in the absence and presence of lavender fragrance (See Table 10 for description of sample pairs).

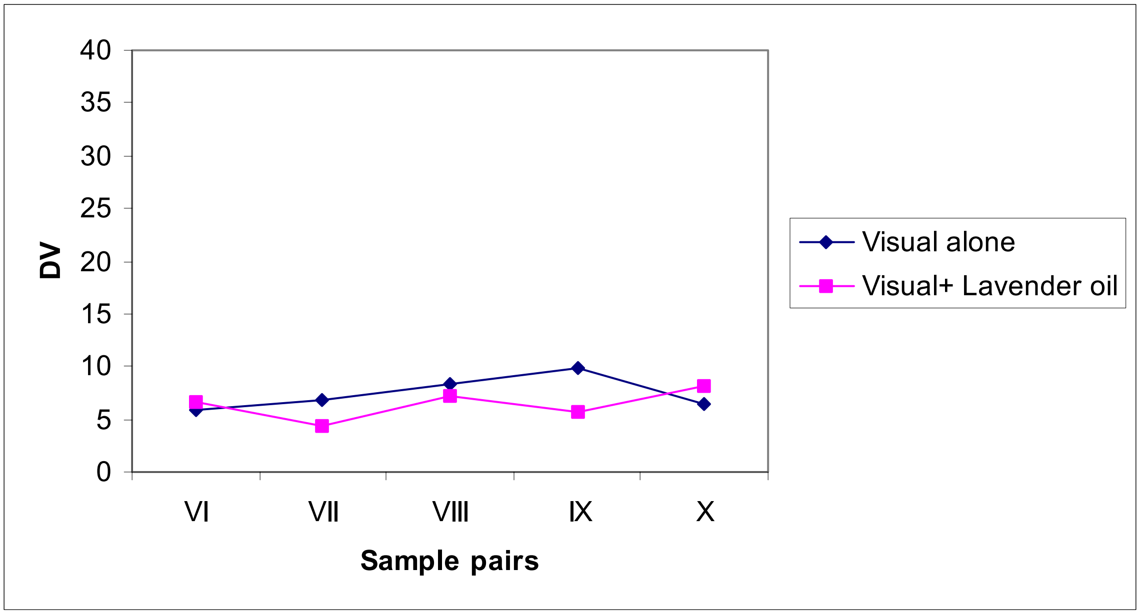


Figure 53. Comparison of the perceived magnitude of color difference (DV) for medium orange hue washed 5 times, in the absence and presence of lavender fragrance (See Table 11 for description of sample pairs).

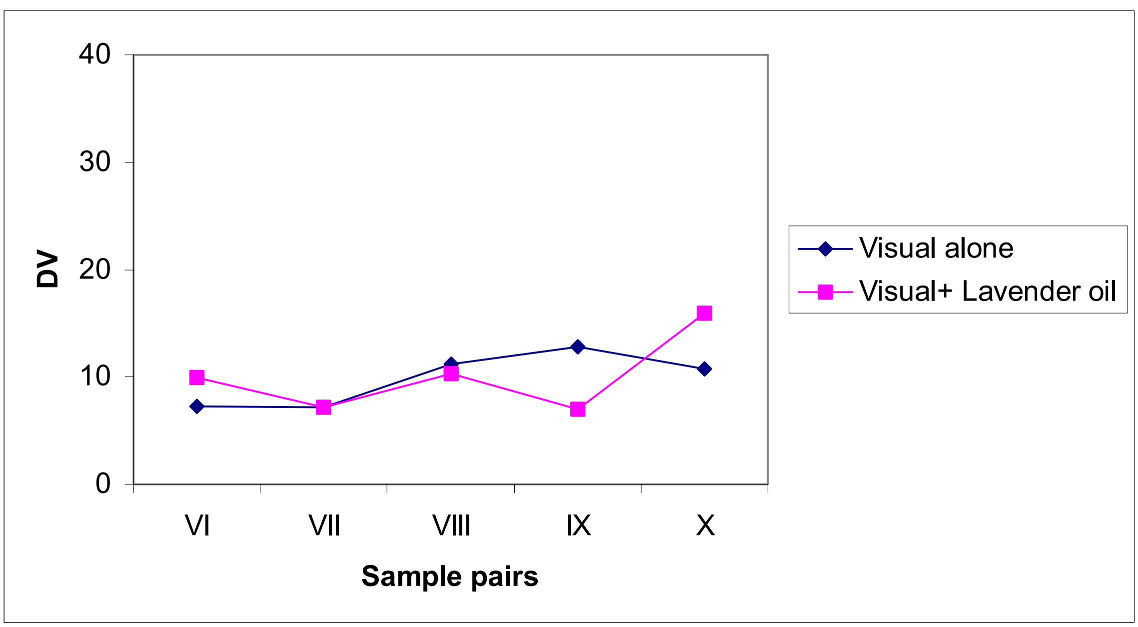


Figure 54. Comparison of the perceived magnitude of color difference (DV) for medium orange hue washed 10 times, in the absence/ presence of lavender fragrance (See Table 12 for description of sample pairs).

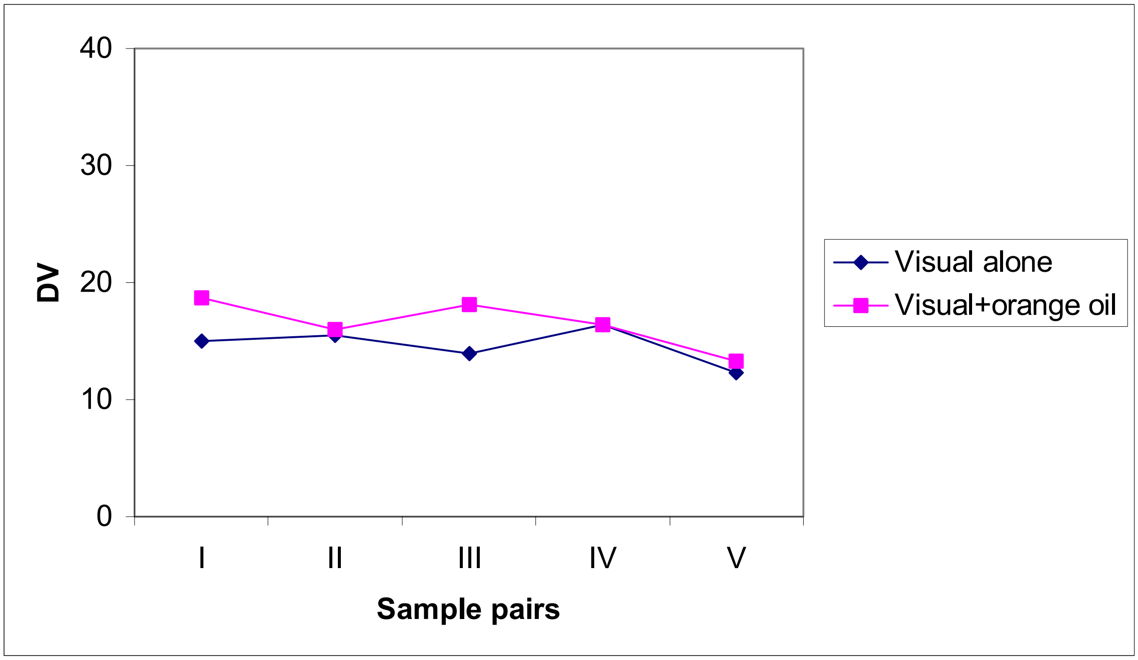


Figure 55. Comparison of the perceived magnitude of color difference (DV) for pale green hue washed 1 time, in the absence and presence of orange fragrance (See Table 10 for description of sample pairs).

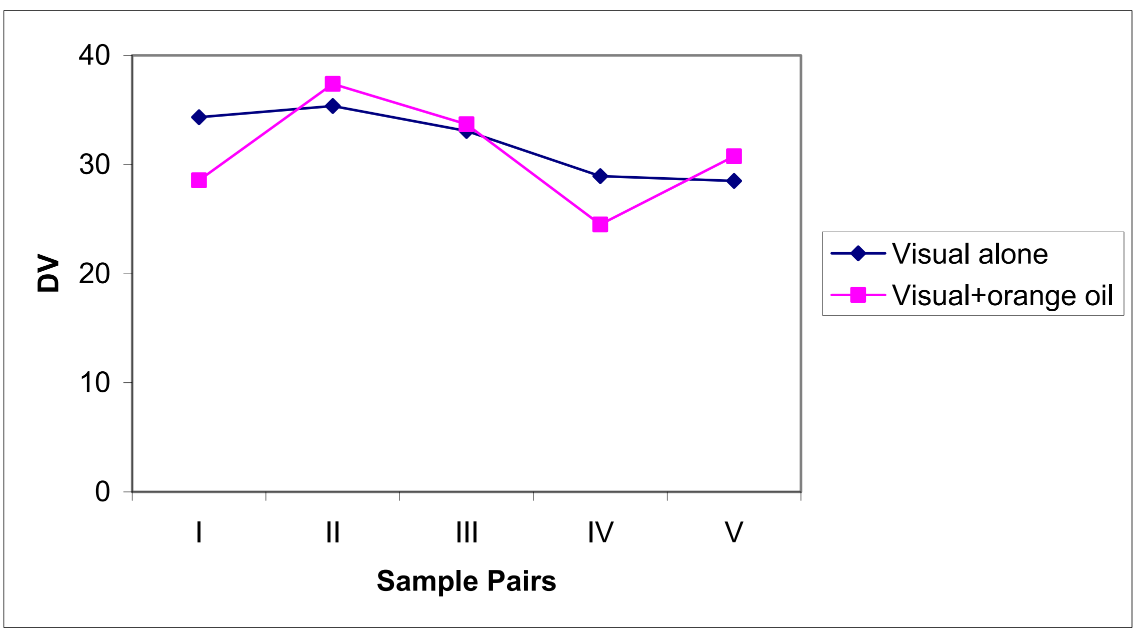


Figure 56. Comparison of the perceived magnitude of color difference (DV) for pale green hue washed 5 times, in the absence and presence of orange fragrance (See Table 11 for description of sample pairs).

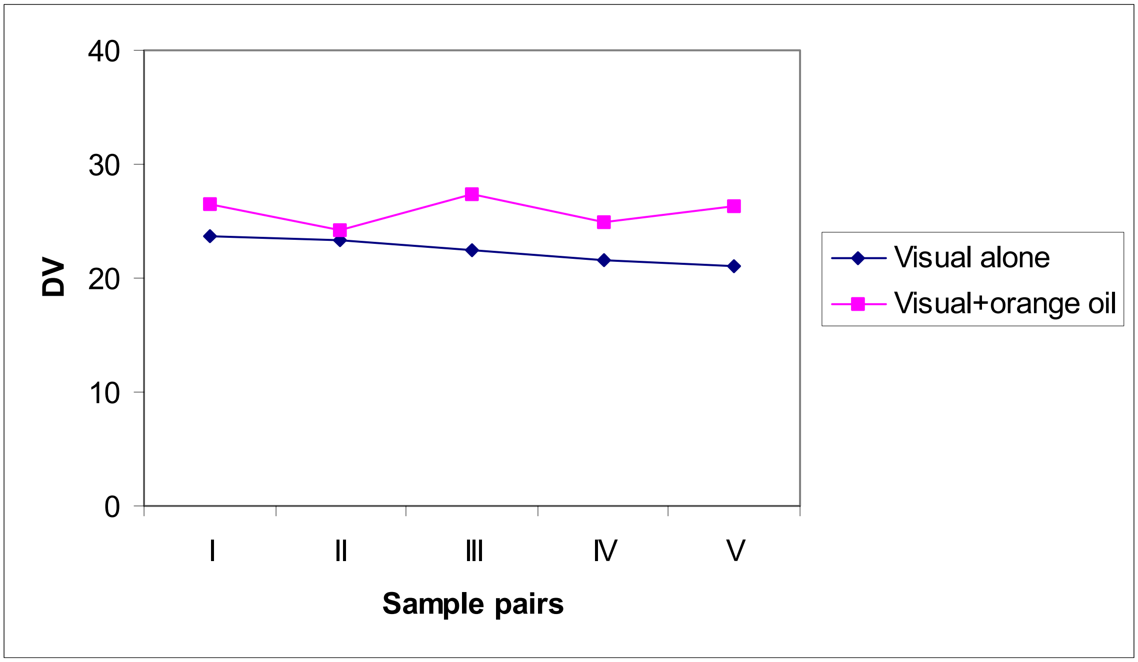


Figure 57. Comparison of the perceived magnitude of color difference (DV) for pale green hue washed 10 times, in the absence and presence of orange fragrance (See Table 12 for description of sample pairs).

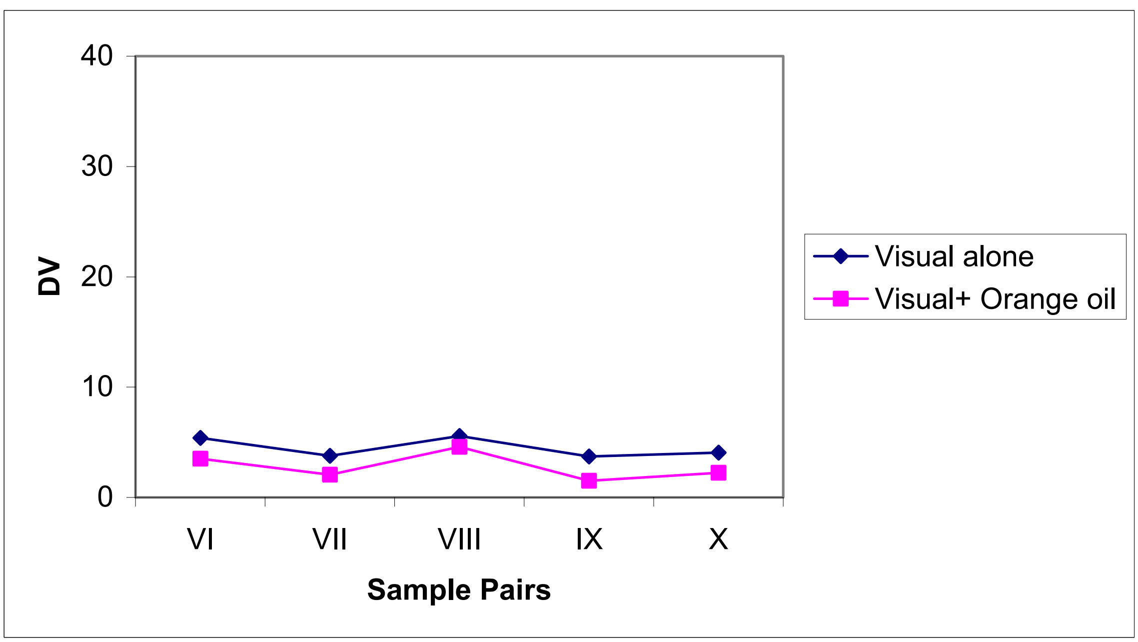


Figure 58. Comparison of the perceived magnitude of color difference (DV) for medium orange hue washed 1 time, in the absence and presence of orange fragrance (See Table 10 for description of sample pairs).

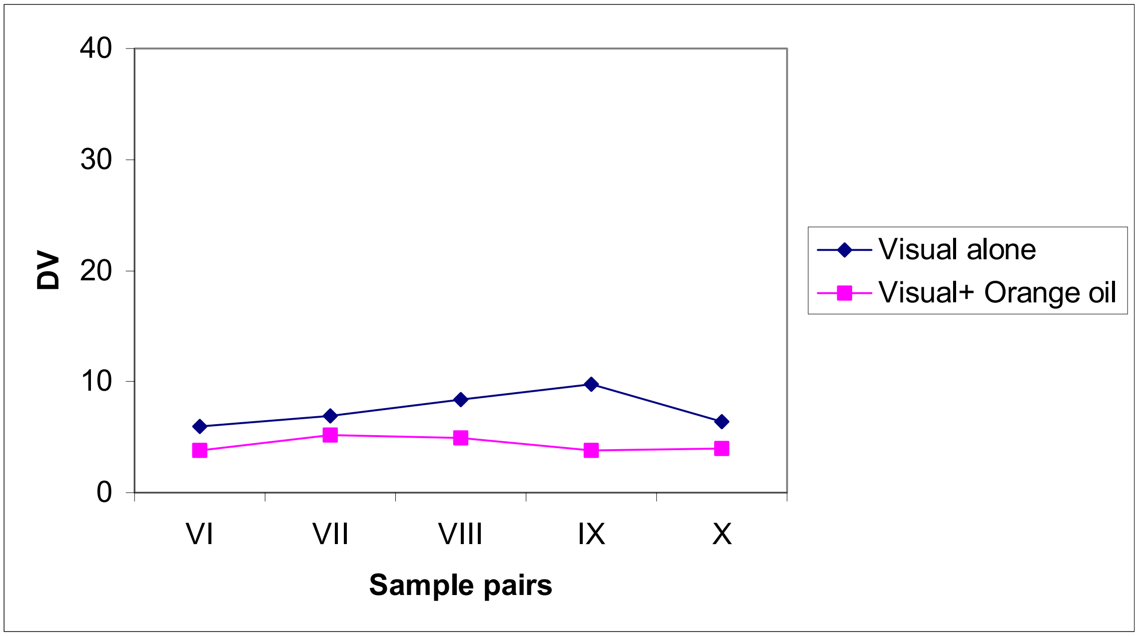


Figure 59. Comparison of the perceived magnitude of color difference (DV) for medium orange hue washed 5 times, in the absence and presence of orange fragrance (See Table 11 for description of sample pairs).

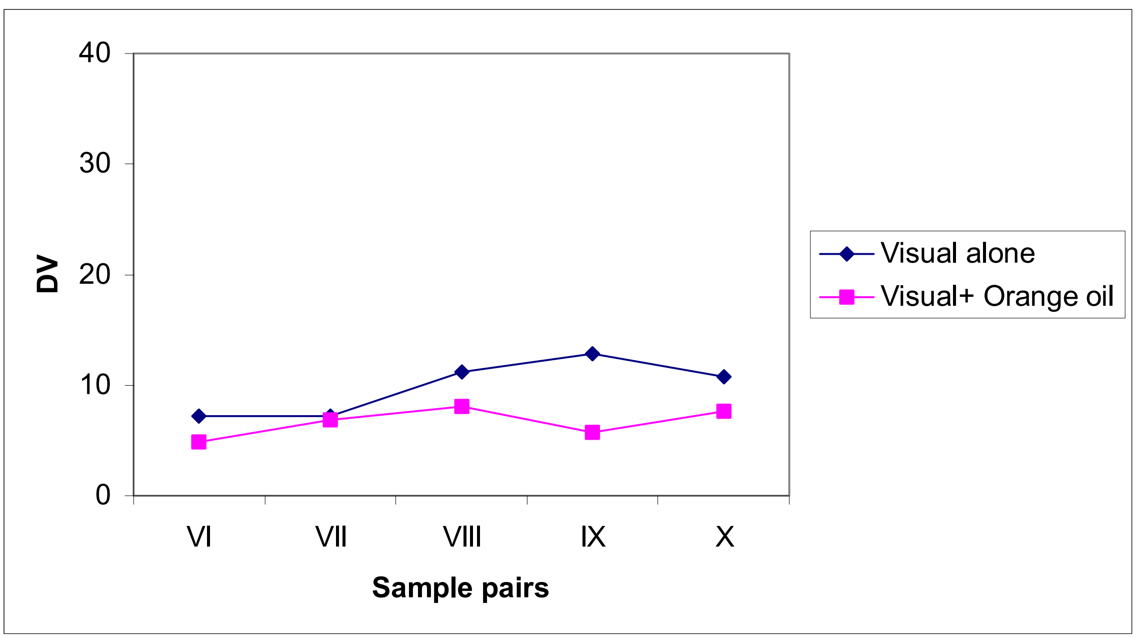


Figure 60. Comparison of the perceived magnitude of color difference (DV) for medium orange hue washed 10 times, in the absence and presence of orange fragrance (See Table 12 for description of sample pairs).

In summary, there is a significant influence of olfactory stimulation on the perceived magnitude of color difference in the case of orange-oil fragrance with orange hues. This was born out in two independent experiments, one consisting of seven color-normal observers, and other comprehensive study consisting of 3 independent sets of 25 to 30 color-normal observers. In the latter experiment, possible effects of sample ordering were eliminated, and the effect of odor release time was reduced by increasing the fragrance release time to 5 min from 3 minutes in our initial study. In addition, observers conducted visual assessments over 15 pairs and between the three-part experiment (visual assessment without odor input, with orange-oil fragrance and with lavender-oil fragrance). Observers had a minimum of three days to a week between observations, thereby eliminating any possible memory of previously assigned color-difference values. Perhaps the most significant source of error in this experiment is the adaptation of the observer to the odor stimulus during the visual assessment. However, overcoming this adaptation would require highly rigorous control of odor pulsing into the nasal passages of each observer; the experimental set up required for this approach may itself impact negatively on the visual assessment, since the observer would necessarily be connected to an odorometer that requires no head movement. The simple solution followed to overcome this problem was to use sufficient amount of fragrance in the room without being judged to be overpowering.

In contrast to the effect of orange odor on orange hue difference, orange fragrance had no effect on perceived magnitude of color difference for pale green samples. Furthermore, lavender fragrance did not affect color-difference perception for either orange or green hues. Taken together, these data indicate that visual responses of observers can be influenced positively by using fragrances that are associated with a specific hue. However, the utility of the pleasant fragrances in general may not appreciably affect the perceived magnitude of color differences.

IV. Summary and Conclusions

The purpose of this work was to systematically analyze the possible influence (positive or negative) that two key sensations, tactile response and odor, have of the perceived magnitude of color differences on textile materials.

The first experiment focused on the effect of tactile input on the color perception of sample pairs having a suprathreshold color difference (i.e., an initial color difference below 2 DE_{cmc}). The data showed that observers rated the magnitude of differences significantly lower in the case of samples receiving softener. Conversely, extreme stiffness leads to increases in perceived magnitude of color differences.

A second experiment was conducted to show the influence of larger color differences following repeated washing, and again results showed significantly lower color differences with soft samples and higher color differences for stiffer samples. The effect of tactile input was much larger in most of the cases for larger color differences (samples washed 5 and 10 times) and did not appear to be a function of hue and chroma.

A third experiment was conducted to demonstrate the effect, if any, of the influence of odor on the perceived magnitude of color difference. After establishing an appropriate concentration of two fragrances, orange-oil and lavender-oil, and a fragrance release mechanism, a significant effect was observed for orange fragrance on orange hue when seven observers were used.

In order to confirm the odor effect a large set of observers (three groups of 27 observers in each group) were used to assess the color difference of three different wash comparisons (0 & 1, 0 & 5 and 0 & 10) with and without orange fragrance present. The results of the experiment demonstrated a statistically significant reduction in color difference for orange hues when orange fragrance was present. Interestingly, the results of color difference assessment of the green samples showed, in some cases, a negative effect (increased color difference) in presence of orange fragrance. These results were consistent with all three groups and also consistent with previous findings that odor is associated with specific colors. No significant difference was observed for the effect of lavender fragrance on either orange or green hues.

V. Appendix

Appendix A. Subjective Hand Assessment:

Table A 1 Analysis of variance for subjective hand assessment.

Source of Variation	*SS*	*df*	*MS*	*F*	*F crit*
Between Groups	6472.339	3	2157.446	900.7466	2.901118
Within Groups	76.64562	32	2.395176		
Total	6548.984	35			

F-value is large indicating that there is a significant difference between treatment groups (40gpl, 20gpl, 2% and 4%).

1. Subjective Hand Assessment verification:

Table A 2 t-Test: paired two samples for means, between 1st and 2nd study for Hand assessment verification.

	1st study	*2nd study*
Mean	44.21164	43.81123
Variance	239.6773	247.6969
Observations	4	4
df	3	
T Stat	1.921447	
P(T<=t) two-tail	0.150424	
T Critical two-tail	3.182449	

From Table A.2, P-value is greater than 0.05. We conclude, at 95% level of significance that there is no difference between 1st and 2nd study for subjective assessment of hand. The conclusion indicates little deterioration, if any, of fabric hand between observers due to handling.

Appendix B. Effect of Tactile Response on Color Difference Perception

1. Visual Evaluation of Small Color Differences (Within a Wash Set)

1.1 Pale Yellow and Medium Blue hues

Table B. 1 t-Test: paired two sample for means, between visual alone and visual & hand for 40gpl stiffener concentration (pale yellow and medium blue hues combined).

	Visual&hand	*Visual alone*
Mean	6.958331	6.818452
Variance	1.019397	0.917385
Observations	8	8
df	7	
t Stat	0.315408	
P(T<=t) one-tail	0.380824	
t Critical one-tail	1.894578	

From Table B.1, P-value is greater than 0.05. We conclude, at 95% level of significance observers did not rate higher color difference for visual assessment in presence of tactile response when compared with visual assessment in absence of tactile response, 40gpl stiffener level (pale yellow and medium orange hues combined).

Table B. 2 t-Test: paired two sample for means, between visual alone and visual & hand for 40gpl stiffener concentration (pale yellow and medium blue hues combined).

	Visual&odor	*Visual alone*
Mean	7.261904	7.348214
Variance	4.64075	0.804493
Observations	8	8
df	7	
t Stat	-0.12103	
P(T<=t) one-tail	0.453535	
t Critical one-tail	1.894578	

From Table B.2, P-value is greater than 0.05. We conclude, at 95% level of significance observers did not rate higher color difference for visual assessment in presence of tactile response when compared with visual assessment in absence of tactile response, 20gpl stiffener level (pale yellow and medium orange hues combined)

Table B. 3 t-Test: paired two sample for means, between visual alone and visual & hand for 2% softener concentration (pale yellow and medium blue hues combined).

	Visual alone	*Visual&hand*
Mean	13.38096	10.01786
Variance	58.47558	27.40408
Observations	8	8
df	7	
t Stat	3.035991	
P(T<=t) one-tail	0.009477	
t Critical one-tail	1.894578	

From Table B.3, P-value is less than 0.05. We conclude, at 95% level of significance, that the observers rated higher color difference for visual assessment in absence of tactile response when compared with visual assessment in presence of tactile response for the 2% softener level (pale yellow and medium orange hues combined).

Table B. 4 t-Test: paired two sample for means, between visual alone and visual & hand for 4% softener concentration (pale yellow and medium blue hues combined).

	Visual alone	*Visual&hand*
Mean	9.821431	7.946429
Variance	12.14178	15.996724
Observations	8	8
df	7	
t Stat	1.578029	
P(T<=t) one-tail	0.090286	
t Critical one-tail	1.894578	

From Table B.4, P-value is greater than 0.05. We conclude, at 95% level of significance observers did not rate higher color difference for visual assessment in absence of tactile response when compared with visual assessment in presence of tactile response, 4% softener level (pale yellow and medium orange hues combined).

2. Visual evaluation of medium to large color differences (between wash set

2.1 Medium Yellow and Pale Green Hues

Table B. 5 t-Test: paired two sample for means, between visual alone and visual & hand for 40gpl stiffener concentration (medium yellow and pale blue hues combined).

	Visual&hand	*Visual alone*
Mean	2.862541	2.496522
Variance	3.621916	3.76105
Observations	6	6
df	5	
t Stat	6.17336	
P(T<=t) one-tail	0.000812	
t Critical one-tail	2.015049	

From Table B.5, P-value is less than 0.05. We conclude, at 95% level of significance, that the observers rated higher color difference for visual assessment in presence of tactile response when compared with visual assessment in absence of tactile response for the 40gpl stiffener level (medium yellow and pale blue hues combined).

Table B. 6 t-Test: paired two sample for means, between visual alone and visual & hand for 20gpl stiffener concentration (medium yellow and pale blue hues combined).

	Visual&hand	*Visual alone*
Mean	2.911063	2.464021
Variance	3.148903	3.308856
Observations	6	6
df	5	
t Stat	7.45203	
P(T<=t) one-tail	0.00009	
t Critical one-tail	2.015049	

From Table B.6, P-value is less than 0.05. We conclude, at 95% level of significance, that the observers rated higher color difference for visual assessment in presence of tactile response when compared with visual assessment in absence of tactile response for the 20gpl stiffener level (medium yellow and pale blue hues combined).

Table B. 7 t-Test: paired two samples for means, between visual alone and visual & hand for no finish treatment (medium yellow and pale blue hues combined).

	Visual alone	*Visual&hand*
Mean	2.66492867	2.561005
Variance	3.07599622	3.535022
Observations	6	6
Df	5	
t Stat	0.60177733	
P(T<=t) one-tail	0.2867828	
t Critical one-tail	2.01504918	

From Table B.7, P-value is greater than 0.05. We conclude, at 95% level of significance observers did not rate higher color difference for visual assessment in absence of tactile response when compared with visual assessment in presence of tactile response, for no after treatment level (medium yellow and pale blue hues combined).

Table B. 8 t-Test: paired two samples for means, between visual alone and visual & hand for 2% softener concentration (medium yellow and pale blue hues combined).

	Visual alone	*Visual&hand*
Mean	2.841539	2.504008
Variance	4.076736	3.591899
Observations	6	6
df	5	
t Stat	2.826289	
P(T<=t) one-tail	0.018418	
t Critical one-tail	2.015049	

From Table B.8, P-value is less than 0.05. We conclude, at 95% level of significance, that the observers rated higher color difference for visual assessment in absence of tactile response when compared with visual assessment in presence of tactile response for the 2% softener level (medium yellow and pale blue hues combined).

Table B. 9 t-Test: paired two samples for means, between visual alone and visual & hand for 4% softener concentration (medium yellow and pale blue hues combined).

	Visual alone	*Visual&hand*
Mean	2.601286	2.369046
Variance	3.011665	2.773815
Observations	6	6
df	5	
t Stat	2.855554	
P(T<=t) one-tail	0.031335	
t Critical one-tail	2.015049	

From Table B.9, P-value is less than 0.05. We conclude, at 95% level of significance, that the observers rated higher color difference for visual assessment in absence of tactile response when compared with visual assessment in presence of tactile response for the 4% softener level (medium yellow and pale blue hues combined).

2.2 Medium Green Pale Orange Hues

2.2.1 Pale Orange Hue

Table B. 10 t-Test: paired two samples for means, between visual alone and visual & hand for 40gpl stiffener concentration (pale orange hue).

	Visual&hand	*Visual alone*
Mean	2.572431	1.978422
Variance	0.734373	0.680167
Observations	3	3
df	2	
t Stat	2.933646	
P(T<=t) one-tail	0.042392	
t Critical one-tail	2.919987	

From Table B.10, P-value is less than 0.05. We conclude, at 95% level of significance, that the observers rated higher color difference for visual assessment in presence of tactile response when compared with visual assessment in absence of tactile response for the 40gpl stiffener level (pale orange hue).

Table B. 11 t-Test: paired two samples for means, between visual alone and visual & hand for 20gpl stiffener concentration (pale orange hue).

	Visual&hand	*Visual alone*
Mean	2.430551	1.941373
Variance	1.096638	1.11627
Observations	3	3
df	2	
t Stat	43.04555	
P(T<=t) one-tail	0.00027	
t Critical one-tail	2.919987	

From Table B.11, P-value is less than 0.05. We conclude, at 95% level of significance, that the observers rated higher color difference for visual assessment in presence of tactile response when compared with visual assessment in absence of tactile response for the 20gpl stiffener level (pale orange hue).

Table B. 12 t-Test: paired two samples for means, between visual alone and visual & hand for no finish treatment (pale orange hue).

	Visual alone	*Visual&hand*
Mean	2.111799	2.084294
Variance	0.655064	0.180178
Observations	3	3
df	2	
t Stat	0.120332	
P(T<=t) one-tail	0.45761	
t Critical one-tail	2.919987	

From Table B.12 P-value is greater than 0.05. We conclude, at 95% level of significance observers did not rate higher color difference for visual assessment in absence of tactile response when compared with visual assessment in presence of tactile response, for no after treatment level (pale orange hue).

Table B. 13 t-Test: paired two samples for means, between visual alone and visual & hand for 2% softener concentration (pale orange hue).

	Visual alone	*Visual&hand*
Mean	2.465989	2.149527
Variance	1.859668	1.336838
Observations	3	3
df	2	
t Stat	1.710321	
P(T<=t) one-tail	0.114667	
t Critical one-tail	2.919987	

From Table B.13 P-value is greater than 0.05. We conclude, at 95% level of significance observers did not rate higher color difference for visual assessment in absence of tactile response when compared with visual assessment in presence of tactile response, 2% softener level (pale orange hue).

Table B. 14 t-Test: paired two samples for means, between visual alone and visual & hand for 2% softener concentration (pale orange hue).

	Visual alone	*Visual&hand*
Mean	2.568179	1.817924
Variance	1.105952	0.415055
Observations	3	3
df	2	
t Stat	2.953639	
P(T<=t) one-tail	0.038198	
t Critical one-tail	2.919987	

From Table B.14, P-value is less than 0.05. We conclude, at 95% level of significance, that the observers rated higher color difference for visual assessment in absence of tactile response when compared with visual assessment in presence of tactile response for the 4% softener level (pale orange hue).

2.2.2 Medium Green Hue

Table B. 15 t-Test: paired two samples for means, between visual alone and visual & hand for 40gpl stiffener concentration (medium green hue).

	Visual&hand	*Visual alone*
Mean	5.397164	4.391051
Variance	5.754999	6.107248
Observations	3	3
df	2	
t Stat	4.091673	
P(T<=t) one-tail	0.035657	
t Critical one-tail	2.919987	

From Table B.15, P-value is less than 0.05. We conclude, at 95% level of significance, that the observers rated higher color difference for visual assessment in presence of tactile response when compared with visual assessment in absence of tactile response for the 40gpl stiffener level (medium green hue).

Table B. 16 t-Test: paired two samples for means, between visual alone and visual & hand for 20gpl stiffener concentration (medium green hue).

	Visual&hand	*Visual alone*
Mean	5.197975	4.418405
Variance	4.535878	6.703322
Observations	3	3
df	2	
t Stat	3.812412	
P(T<=t) one-tail	0.037093	
t Critical one-tail	2.919987	

From Table B.16, P-value is less than 0.05. We conclude, at 95% level of significance, that the observers rated higher color difference for visual assessment in presence of tactile response when compared with visual assessment in absence of tactile response for the 20gpl stiffener level (medium green hue).

Table B. 17 t-Test: paired two samples for means, between visual alone and visual & hand for no finish treatment (medium green hue).

	Visual alone	*Visual&hand*
Mean	4.7049027	3.561829
Variance	4.8579675	3.29167
Observations	3	3
df	2	
t Stat	3.5269614	
P(T<=t) one-tail	0.0359174	
t Critical one-tail	2.9199873	

From Table B.17, P-value is less than 0.05. We conclude, at 95% level of significance, that the observers rated higher color difference for visual assessment in absence of tactile response when compared with visual assessment in presence of tactile response for the no finish treatment level (medium green hue).

Table B. 18 t-Test: paired two samples for means, between visual alone and visual & hand for 2% softener concentration (medium green hue).

	Visual alone	*Visual&hand*
Mean	4.9438911	3.368776
Variance	4.7861296	2.748479
Observations	3	3
df	2	
t Stat	3.526346	
P(T<=t) one-tail	0.0437072	
t Critical one-tail	2.9199873	

From Table B.18, P-value is less than 0.05. We conclude, at 95% level of significance, that the observers rated higher color difference for visual assessment in absence of tactile response when compared with visual assessment in presence of tactile response for the 2% softener level (medium green hue).

Table B. 19 t-Test: paired two samples for means, between visual alone and visual & hand for 4% softener concentration (medium green hue).

	Visual alone	*Visual&hand*
Mean	4.4529572	3.259216
Variance	5.6227329	3.504789
Observations	3	3
df	2	
t Stat	3.301952	
P(T<=t) one-tail	0.043975	
t Critical one-tail	2.9199873	

From Table B.19, P-value is less than 0.05. We conclude, at 95% level of significance, that the observers rated higher color difference for visual assessment in absence of tactile response when compared with visual assessment in presence of tactile response for the 4% softener level (medium green hue).

2.3. Pale Green and Medium Orange Hues

2.3.1 Pale Green Hue

Table B. 20 t-Test: paired two samples for means, between visual alone and visual & hand for 40gpl stiffener concentration (pale green hue).

	Visual&hand	*Visual alone*
Mean	5.060624	4.432259
Variance	6.814556	6.690946
Observations	3	3
df	2	
t Stat	4.717178	
P(T<=t) one-tail	0.021061	
t Critical one-tail	2.919987	

From Table B.20, P-value is less than 0.05. We conclude, at 95% level of significance, that the observers rated higher color difference for visual assessment in presence of tactile response when compared with visual assessment in absence of tactile response for the 40gpl stiffener level (pale green hue).

Table B. 21 t-Test: paired two samples for means, between visual alone and visual & hand for 20gpl stiffener concentration (pale green hue).

	Visual&hand	*Visual alone*
Mean	5.673128	4.588487
Variance	4.477762	5.889468
Observations	3	3
df	2	
t Stat	4.20376	
P(T<=t) one-tail	0.038696	
t Critical one-tail	2.919987	

From Table B.21, P-value is less than 0.05. We conclude, at 95% level of significance, that the observers rated higher color difference for visual assessment in presence of tactile response when compared with visual assessment in absence of tactile response for the 20gpl stiffener level (pale green hue).

Table B. 22 t-Test: paired two samples for means, between visual alone and visual & hand for no finish treatment (pale green hue).

	Visual alone	*Visual&hand*
Mean	4.86912	4.163092
Variance	8.453146	4.070806
Observations	3	3
df	2	
t Stat	1.329512	
P(T<=t) one-tail	0.157524	
t Critical one-tail	2.919987	

From Table B.22, P-value is greater than 0.05. We conclude, at 95% level of significance observers did not rate higher color difference for visual assessment in absence of tactile response when compared with visual assessment in presence of tactile response, for no after treatment level (pale green hue).

Table B. 23 t-Test: paired two samples for means, between visual alone and visual & hand for 2% softener concentration (pale green hue).

	Visual alone	*Visual&hand*
Mean	4.860441	3.249
Variance	7.40785	1.930069
Observations	3	3
df	2	
t Stat	1.953907	
P(T<=t) one-tail	0.094962	
t Critical one-tail	2.919987	

From Table B.23, P-value is greater than 0.05. We conclude, at 95% level of significance observers did not rate higher color difference for visual assessment in absence of tactile response when compared with visual assessment in presence of tactile response, 2% softener level (pale green hue)

Table B. 24 t-Test: paired two samples for means, between visual alone and visual & hand for 4% softener concentration (pale green hue).

	Visual alone	*Visual&hand*
Mean	4.594274	3.576881
Variance	8.962486	6.518667
Observations	3	3
df	2	
t Stat	5.557441	
P(T<=t) one-tail	0.029836	
t Critical one-tail	2.919987	

From Table B.24, P-value is less than 0.05. We conclude, at 95% level of significance, that the observers rated higher color difference for visual assessment in absence of tactile response when compared with visual assessment in presence of tactile response for the 4% softener level (pale green hue).

2.3.2 Medium orange

Table B. 25 t-Test: paired two samples for means, between visual alone and visual & hand for 40gpl stiffener concentration (medium orange hue).

	Visual&hand	*Visual alone*
Mean	2.955597	2.312967
Variance	2.031729	1.822617
Observations	3	3
df	2	
t Stat	3.791972	
P(T<=t) one-tail	0.03152	
t Critical one-tail	2.919987	

From Table B.25, P-value is less than 0.05. We conclude, at 95% level of significance, that the observers rated higher color difference for visual assessment in presence of tactile response when compared with visual assessment in absence of tactile response for the 40gpl stiffener level (medium orange hue).

Table B. 26 t-Test: paired two samples for means, between visual alone and visual & hand for 20gpl stiffener concentration (medium orange hue).

	Visual&hand	*Visual alone*
Mean	2.911578	2.507334
Variance	1.25407	2.408199
Observations	3	3
df	2	
t Stat	1.354002	
P(T<=t) one-tail	0.154219	
t Critical one-tail	2.919987	

From Table B.26, P-value is greater than 0.05. We conclude, at 95% level of significance observers did not rate higher color difference for visual assessment in presence of tactile response when compared with visual assessment in absence of tactile response, 20gpl stiffener level (medium orange hue).

Table B. 27 t-Test: paired two samples for means, between visual alone and visual & hand for no finish treatment (medium orange hue).

	Visual alone	*Visual&hand*
Mean	2.371277	2.090928
Variance	2.612112	1.386023
Observations	3	3
df	2	
t Stat	0.920853	
P(T<=t) one-tail	0.22717	
t Critical one-tail	2.919987	

From Table B.27, P-value is greater than 0.05. We conclude, at 95% level of significance observers did not rate higher color difference for visual assessment in absence of tactile response when compared with visual assessment in presence of tactile response, for no after treatment level (medium orange hue).

Table B. 28. t-Test: paired two samples for means, between visual alone and visual & hand for 2% softener concentration (medium orange hue).

	Visual alone	*Visual&hand*
Mean	2.530658	2.197833
Variance	2.461512	1.705154
Observations	3	3
df	2	
t Stat	1.579383	
P(T<=t) one-tail	0.127506	
t Critical one-tail	2.919987	

From Table B.28, P-value is greater than 0.05. We conclude, at 95% level of significance observers did not rate higher color difference for visual assessment in absence of tactile response when compared with visual assessment in presence of tactile response, 2% softener level (medium orange hue).

Table B. 29 t-Test: paired two samples for means, between visual alone and visual & hand for 4% softener concentration (medium orange hue).

	Visual alone	*Visual&hand*
Mean	3.682264	2.006033
Variance	2.78275	2.469217
Observations	3	3
df	2	
t Stat	12.220847	
P(T<=t) one-tail	0.018251	
t Critical one-tail	2.919987	

From Table B.29, P-value is less than 0.05. We conclude, at 95% level of significance, that the observers rated higher color difference for visual assessment in absence of tactile response when compared with visual assessment in presence of tactile response for the 4% softener level (medium orange hue).

Appendix C. Statistical Analysis for Effect of Olfactory Response on Perceived Magnitude of Color Difference

1. Lavender Fragrance.

1.1 Pale Green Hue

Table C. 1 t-Test: paired two sample for means, between visual alone and visual & lavender fragrance for pale green washed 1 time.

	Visual	*Visual+odor*
Mean	14.62963	16.55652
Variance	2.478052	2.74707
Observations	5	5
df	4	
T Stat	-1.00121	
P(T<=t) one-tail	0.186691	
T Critical one-tail	2.131846	

From Table C.1 P-value is greater than 0.05. We conclude, at 95% level of significance observers did not rate higher color difference for visual assessment in absence of fragrance when compared with visual assessment in presence of lavender fragrance for pale green hue washed 1 time.

Table C. 2 t-Test: paired two sample for means, between visual alone and visual & lavender fragrance for pale green washed 5 times.

	Visual	*Visual+odor*
Mean	32.03704	29.90435
Variance	9.945126	9.744234
Observations	5	5
df	4	
t Stat	1.354022	
P(T<=t) one-tail	0.123587	
t Critical one-tail	2.131846	

From Table C.2 P-value is greater than 0.05. We conclude, at 95% level of significance observers did not rate higher color difference for visual assessment in absence of fragrance when compared with visual assessment in presence of lavender fragrance for pale green hue washed 5 times.

Table C. 3 t-Test: paired two sample for means, between visual alone and visual & lavender fragrance for pale green washed 10 times.

	Visual	*Visual+odor*
Mean	22.43704	22.77143
Variance	1.252671	2.40295
Observations	5	5
df	4	
t Stat	-0.18366	
P(T<=t) one-tail	0.431608	
t Critical one-tail	2.131846	

From Table C.3 P-value is greater than 0.05. We conclude, at 95% level of significance observers did not rate higher color difference for visual assessment in absence of fragrance when compared with visual assessment in presence of lavender fragrance for pale green hue washed 10 times.

1.2 Medium Orange Hue

Table C. 4 t-Test: paired two sample for means, between visual alone and visual & lavender fragrance for medium orange washed 1 time.

	Visual	*Visual+odor*
Mean	4.503704	5.556522
Variance	0.818656	2.704537
Observations	5	5
df	4	
t Stat	-1.54807	
P(T<=t) one-tail	0.09826	
t Critical one-tail	2.131846	

From Table C.4 P-value is greater than 0.05. We conclude, at 95% level of significance observers did not rate higher color difference for visual assessment in absence of fragrance when compared with visual assessment in presence of lavender fragrance for medium orange hue washed 1 time.

Table C. 5 t-Test: paired two sample for means, between visual alone and visual & lavender fragrance for medium orange washed 5 times.

	Visual	*Visual+odor*
Mean	7.474074	6.347826
Variance	2.533882	2.086011
Observations	5	5
df	4	
t Stat	1.06553	
P(T<=t) one-tail	0.17334	
t Critical one-tail	2.131846	

From Table C.5 P-value is greater than 0.05. We conclude, at 95% level of significance observers did not rate higher color difference for visual assessment in absence of fragrance when compared with visual assessment in presence of lavender fragrance for medium orange hue washed 5 times.

Table C. 6 t-Test: paired two sample for means, between visual alone and visual & lavender fragrance for medium orange washed 10 times.

	Visual	*Visual+odor*
Mean	9.829629	10.05714
Variance	6.342657	5.03333
Observations	5	5
df	4	
t Stat	-0.12326	
P(T<=t) one-tail	0.453925	
t Critical one-tail	2.131846	

From Table C.6 P-value is greater than 0.05. We conclude, at 95% level of significance observers did not rate higher color difference for visual assessment in absence of fragrance when compared with visual assessment in presence of lavender fragrance for medium orange hue washed 10 times.

2. Orange Fragrance

2.1 Pale Green Hue

Table C. 7 t-Test: paired two sample for means, between visual alone and visual & orange fragrance for pale green hue washed 1 time.

	Visual	*Visual+odor*
Mean	14.62963	16.5
Variance	2.478052	4.589876
Observations	5	5
df	4	
t Stat	-2.16003	
P(T<=t) one-tail	0.048443	
t Critical one-tail	2.131846	

From Table C.7 P-vale is less than 0.05. We conclude, at 95% level of significance there is a difference between visual assessment in absence of fragrance and visual assessment in presence of orange fragrance, for pale green hue washed 1 time. Note: t-stat value is negative indicating a negative difference i.e., observers perceived higher color difference in presence of fragrance when compared to with absence of fragrance.

Table C. 8 t-Test: paired two sample for means, between visual alone and visual & orange fragrance for pale green hue washed 5 times.

	Visual	*Visual+odor*
Mean	32.03704	30.98
Variance	9.945126	8.14075
Observations	5	5
df	4	
t Stat	0.62555	
P(T<=t) one-tail	0.282764	
t Critical one-tail	2.131846	

From Table C.8 P-value is greater than 0.05. We conclude, at 95% level of significance observers did not rate higher color difference for visual assessment in absence of fragrance when compared with visual assessment in presence of orange fragrance for pale green hue washed 5 times.

Table C. 9 t-Test: paired two sample for means, between visual alone and visual & orange fragrance for pale green hue washed 10 times.

	Visual	*Visual+odor*
Mean	22.43704	25.84211
Variance	1.252671	1.548476
Observations	5	5
df	4	
t Stat	-4.3174	
P(T<=t) one-tail	0.006236	
t Critical one-tail	2.131846	

From Table C.9 P-vale is less than 0.05. We conclude, at 95% level of significance there is a difference between visual assessment in absence of fragrance and visual assessment in presence of orange fragrance, for pale green hue washed 10 times. Note: t-stat value is negative indicating a negative difference i.e., observers perceived higher color difference in presence of fragrance when compared with absence of fragrance.

2.2 Medium Orange Hue

Table C. 10 t-Test: paired two sample for means, between visual alone and visual & orange fragrance for medium orange hue washed 1 time.

	Visual	*Visual+odor*
Mean	4.503704	2.772727
Variance	0.818656	1.570248
Observations	5	5
df	4	
t Stat	8.370522	
P(T<=t) one-tail	0.000557	
t Critical one-tail	2.131846	

From Table C.10 P-vale is less than 0.05. We conclude, at 95% level of significance, that the observers rated higher color difference for visual assessment in absence of fragrance when compared with visual assessment in presence of orange fragrance for medium orange hue washed 1 time.

Table C. 11 t-Test: paired two sample for means, between visual alone and visual & orange fragrance for medium orange hue washed 5 times.

	Visual	*Visual+odor*
Mean	7.474074	4.32
Variance	2.533882	0.42575
Observations	5	5
df	4	
t Stat	4.124417	
P(T<=t) one-tail	0.00728	
t Critical one-tail	2.131846	

From Table C.11 P-vale is less than 0.05. We conclude, at 95% level of significance, that the observers rated higher color difference for visual assessment in absence of fragrance when compared with visual assessment in presence of orange fragrance for medium orange hue washed 5 times.

Table C. 12 t-Test: paired two sample for means, between visual alone and visual & orange fragrance for medium orange hue washed 10 times.

	Visual	*Visual+odor*
Mean	9.829629	6.642105
Variance	6.342657	1.810803
Observations	5	5
df	4	
t Stat	2.897855	
P(T<=t) one-tail	0.022106	
t Critical one-tail	2.131846	

From Table C.12 P-vale is less than 0.05. We conclude, at 95% level of significance, that the observers rated higher color difference for visual assessment in absence of fragrance when compared with visual assessment in presence of orange fragrance for medium orange hue washed 10 times.

Appendix D. Statistical Analysis for Effect of Tactile and Olfactory Response on Perceived Magnitude of Color Difference Using SAS

A comprehensive statistical analysis was performed using SAS (Version 8) software to show the effect of tactile response on color difference perception and odor response on color difference perception. The results are consistent with the simple paired comparison tests performed with each experimental set, as explained below.

Tactile

A split-split plot method (for both simple average and square root model) was used to perform the analysis. oth models show there is a significant effect between visual assessment in absence of tactile response and visual assessment in presence of tactile response. As shown on pages 123 and 124 the p-value for the effect of stimulus (stim) is 0.0064 and 0.0013 for square root and simple average models respectively. Also, the analysis show there is no significant difference between stiffness levels, but there is a significant difference when compared between stiffness level and stimulus (page 123 124). This signifies a significant interaction between stimulus and stiffness levels. Figures D1 shows a plot of Least Mean Square values (simple average model) for each stiffness levels for visual alone and Visual & hand. Figure D2 shows the plot of square root model. In both cases we can observe visual & hand values start below visual alone at stiffness level one and goes past visual alone at stiffness level 5.

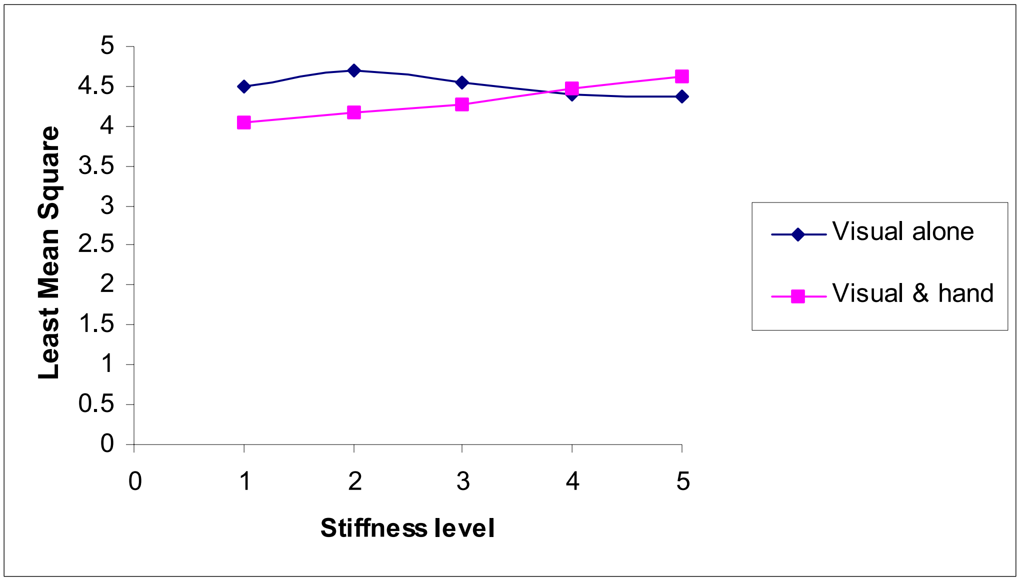


Figure D. 1. Comparison of Least Mean Square values with and without tactile input for samples over all hue, chroma and washes. For simple average model.

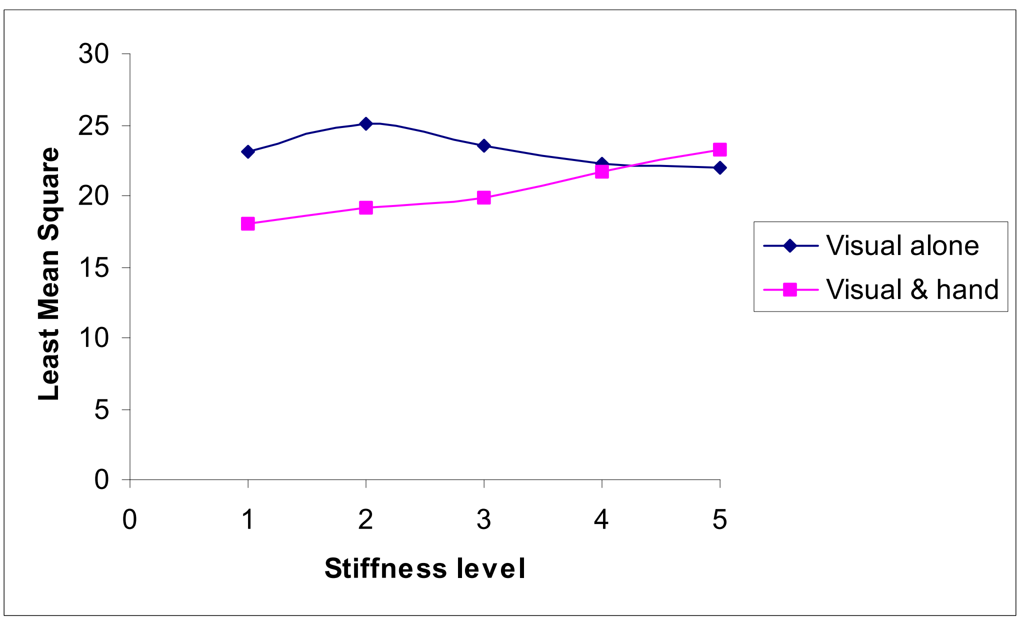


Figure D. 2. Comparison of Least Mean Square values with and without tactile input for samples over all hue, chroma and washes. For square root model.

Effect on Tactile Response on Color Perceptiom

The GLM Procedure

Class Level Information

Class	Levels	Values
expset	3	1 2 3
Hue	4	blue green orange yellow
Shade	2	medium pale
washes	3	1 5 10
stiff	5	1 2 3 4 5
Stim	2	No yes

Number of observations 180

Dependent Variable: sqavr

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	65	395.1699815	6.0795382	28.87	<.0001
Error	114	24.0053843	0.2105735		
Corrected Total	179	419.1753658			

R-Square	Coeff Var	Root MSE	sqavr Mean
0.942732	10.40236	0.458883	4.411334

Source	DF	Type I SS	Mean Square	F Value	Pr > F
expset	2	59.6439310	29.8219655	141.62	<.0001
Stim	1	1.6221662	1.6221662	7.70	0.0064
expset*Stim	2	0.2343439	0.1171720	0.56	0.5748
washes	2	241.122121	120.561060	572.54	<.0001
washes*Stim	2	4.7193335	2.3596667	11.21	<.0001
Shade	1	1.6403599	1.6403599	7.79	0.0062
stiff	4	1.0382929	0.2595732	1.23	0.3010
Shade*stiff	4	0.1320343	0.0330086	0.16	0.9596
Shade*Stim	1	0.3027522	0.3027522	1.44	0.2330
stiff*Stim	4	4.1734410	1.0433602	4.95	0.0010
Shade*stiff*Stim	4	0.0683238	0.0170810	0.08	0.9880
Shade*washes	2	0.6787302	0.3393651	1.61	0.2041
washes*stiff	8	0.6094275	0.0761784	0.36	0.9385
Shade*washes*stiff	8	0.3222426	0.0402803	0.19	0.9917
Shade*washes*Stim	2	0.2137812	0.1068906	0.51	0.6033
washes*stiff*Stim	8	0.1913984	0.0239248	0.11	0.9987
Shad*wash*stiff*Stim	8	0.3431215	0.0428902	0.20	0.9897
expset*Shade	2	78.1141793	39.0570897	185.48	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
expset	2	59.6439310	29.8219655	141.62	<.0001
Stim	1	1.6221662	1.6221662	7.70	0.0064
expset*Stim	2	0.2343439	0.1171720	0.56	0.5748
washes	2	241.122121	120.5610609	572.54	<.0001
washes*Stim	2	4.7193335	2.3596667	11.21	<.0001
Shade	1	1.6403599	1.6403599	7.79	0.0062

Dependent Variable: sqavr

Source	DF	Type III SS	Mean Square	F Value	Pr > F
stiff	4	1.0382929	0.2595732	1.23	0.3010
Shade*stiff	4	0.1320343	0.0330086	0.16	0.9596
Shade*Stim	1	0.3027522	0.3027522	1.44	0.2330
stiff*Stim	4	4.1734410	1.0433602	4.95	0.0010
Shade*stiff*Stim	4	0.0683238	0.0170810	0.08	0.9880
Shade*washes	2	0.6787302	0.3393651	1.61	0.2041
washes*stiff	8	0.6094275	0.0761784	0.36	0.9385
Shade*washes*stiff	8	0.3222426	0.0402803	0.19	0.9917
Shade*washes*Stim	2	0.2137812	0.1068906	0.51	0.6033
washes*stiff*Stim	8	0.1913984	0.0239248	0.11	0.9987
Shad*wash*stiff*Stim	8	0.3431215	0.0428902	0.20	0.9897
expset*Shade	2	78.1141793	39.0570897	185.48	<.0001

Dependent Variable: Average

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	65	33143.71029	509.90324	16.50	<.0001
Error	114	3523.21110	30.90536		
Corrected Total	179	36666.92139			

R-Square	Coeff Var	Root MSE	Average Mean
0.903913	25.51451	5.559259	21.78862

Source	DF	Type I SS	Mean Square	F Value	Pr > F
expset	2	5422.95790	2711.4789	87.73	<.0001
Stim	1	336.35683	336.35683	10.88	0.0013
expset*Stim	2	25.03364	12.51682	0.41	0.6679
washes	2	17941.124	8970.562	290.26	<.0001
washes*Stim	2	378.81409	189.4070	6.13	0.0030
Shade	1	531.80034	531.80034	17.21	<.0001
stiff	4	92.37156	23.09289	0.75	0.5618
Shade*stiff	4	7.42905	1.85726	0.06	0.9932
Shade*Stim	1	9.97085	9.97085	0.32	0.5712
stiff*Stim	4	332.88492	83.22123	2.69	0.0345
Shade*stiff*Stim	4	3.13230	0.78308	0.03	0.9987
Shade*washes	2	157.82065	78.91033	2.55	0.0823
washes*stiff	8	68.69808	8.58726	0.28	0.9720
Shade*washes*stiff	8	20.21260	2.52657	0.08	0.9996
Shade*washes*Stim	2	16.46162	8.23081	0.27	0.7667
washes*stiff*Stim	8	41.79661	5.22458	0.17	0.9945
Shad*wash*stiff*Stim	8	14.56552	1.82069	0.06	0.9999
expset*Shade	2	7742.2793	3871.139	125.26	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
expset	2	5422.95790	2711.4789	87.73	<.0001
Stim	1	336.35683	336.35683	10.88	0.0013
expset*Stim	2	25.03364	12.51682	0.41	0.6679
washes	2	17941.12438	8970.56219	290.26	<.0001
washes*Stim	2	378.81409	189.40704	6.13	0.0030
Shade	1	531.80034	531.80034	17.21	<.0001

Dependent Variable: Average

Source	DF	Type III SS	Mean Square	F Value	Pr > F
stiff	4	92.37156	23.09289	0.75	0.5618
Shade*stiff	4	7.42905	1.85726	0.06	0.9932
Shade*Stim	1	9.97085	9.97085	0.32	0.5712
stiff*Stim	4	332.88492	83.22123	2.69	0.0345
Shade*stiff*Stim	4	3.13230	0.78308	0.03	0.9987
Shade*washes	2	157.82065	78.91033	2.55	0.0823
washes*stiff	8	68.69808	8.58726	0.28	0.9720
Shade*washes*stiff	8	20.21260	2.52657	0.08	0.9996
Shade*washes*Stim	2	16.46162	8.23081	0.27	0.7667
washes*stiff*Stim	8	41.79661	5.22458	0.17	0.9945
Shad*wash*stiff*Stim	8	14.56552	1.82069	0.06	0.9999
expset*Shade	2	7742.27934	3871.13967	125.26	<.0001

Level	Level of		------------sqavr-----------		-----------Average----------	
Of stiff	Stim	N	Mean	Std Dev	Mean	Std Dev
1	No	18	4.50372716	1.70911619	23.0423543	15.7342464
1	yes	18	4.03948042	1.32124973	17.9661195	11.5037386
2	No	18	4.70491577	1.76118366	25.0656799	16.8684801
2	yes	18	4.17653868	1.36878602	19.2129630	11.7086242
3	No	18	4.55554389	1.69189870	23.4564724	15.9943442
3	yes	18	4.26831601	1.33882993	19.9114057	12.4001919
4	No	18	4.38763261	1.76195247	22.1833255	16.1685752
4	yes	18	4.47504533	1.34511578	21.7348485	12.9293471
5	No	18	4.37950847	1.73716564	22.0301864	16.1003824
5	yes	18	4.62263010	1.42362710	23.2828279	14.5993142

Level of	Level of		------------sqavr-----------		----------Average----------	
washes	Stim	N	Mean	Std Dev	Mean	Std Dev
1	No	30	2.72587369	0.85962935	8.1447179	5.3301823
1	yes	30	2.99398412	0.74904907	9.5063129	4.8289807
5	No	30	4.94579727	1.13553996	25.7073800	11.856628
5	yes	30	4.52448765	0.83326316	21.1421717	8.1659505
10	No	30	5.84712578	1.21449580	35.6147133	14.191289
10	yes	30	5.43073456	1.07809041	30.6164141	12.675609

Source	DF	Type III SS	Mean Square	F Value	Pr > F
expset*Stim	2	0.234344	0.117172	0.56	0.5748
*washes	2	241.122122	120.561061	572.54	<.0001
*washes*Stim	2	4.719333	2.359667	11.21	<.0001
*stiff	4	1.038293	0.259573	1.23	0.3010
*Shade*stiff	4	0.132034	0.033009	0.16	0.9596
*Shade*Stim	1	0.302752	0.302752	1.44	0.2330
*stiff*Stim	4	4.173441	1.043360	4.95	0.0010
*Shade*stiff*Stim	4	0.068324	0.017081	0.08	0.9880
*Shade*washes	2	0.678730	0.339365	1.61	0.2041
*washes*stiff	8	0.609427	0.076178	0.36	0.9385
*Shade*washes*stiff	8	0.322243	0.040280	0.19	0.9917
*Shade*washes*Stim	2	0.213781	0.106891	0.51	0.6033
*washes*stiff*Stim	8	0.191398	0.023925	0.11	0.9987
Shad*wash*stiff*Stim	8	0.343122	0.042890	0.20	0.9897
expset*Shade	2	78.114179	39.057090	185.48	<.0001
Error: MS(Error)	114	24.005384	0.210574		

* This test assumes one or more other fixed effects are zero.

Least Squares Means

stiff	Stim	sqavr LSMEAN	Average LSMEAN
1	No	4.50372716	23.0423543
1	yes	4.03948042	17.9661195
2	No	4.70491577	25.0656799
2	yes	4.17653868	19.2129630
3	No	4.55554389	23.4564724
3	yes	4.26831601	19.9114057
4	No	4.38763261	22.1833255
4	yes	4.47504533	21.7348485
5	No	4.37950847	22.0301864
5	yes	4.62263010	23.2828279

Least Squares Means

stiff*Stim Effect Sliced by stiff for sqavr

stiff	1DF	Squares	Sum of Mean Square	F Value	Pr > F
1	1	1.939725	1.939725	9.21	0.0030
2	1	2.512641	2.512641	11.93	0.0008
3	1	0.742499	0.742499	3.53	0.0630
4	1	0.068769	0.068769	0.33	0.5688
5	1	0.531973	0.531973	2.53	0.1147

Least Squares Means

stiff*Stim Effect Sliced by stiff for Average

stiff	DF	Squares	Sum of Mean Square	F Value	Pr > F
1	1	231.913437	231.913437	7.50	0.0071
2	1	308.288655	308.288655	9.98	0.0020
3	1	113.107482	113.107482	3.66	0.0582
4	1	1.810185	1.810185	0.06	0.8092
5	1	14.121997	14.121997	0.46	0.5004

Least Squares Means

Expset	Shade	sqavr LSMEAN	Average LSMEAN
1	medium	4.24411428	20.2096737
1	pale	4.18868672	19.6230769
2	medium	6.12731210	39.6172777
2	pale	4.25927908	18.8801667
3	medium	3.14896299	10.6954545
3	pale	4.49964789	21.7060605

Odor

The same procedure as tactile response was used to analyze the odor data. However in the case of odor analysis there are no stiffness levels and there are three levels of stimulus (no stimulus, lavender and orange fragrance). The possible interaction of color difference perception and fragrance was assessed by statistical analysis of each fragrance on each hue independently. The results in the following pages clearly indicate there is no statistical significance for the following:

a) Lavender fragrance on green hue p-value 0.9674.

b) Lavender fragrance on orange hue p-value 0.9488.

c) Orange fragrance on green hue p-value 0.1677.

However in the case of orange fragrance on orange hue the p-value is less than 0.001, demonstrating indicating a significant difference in the data.

Lavender fragrance on Green hue

The GLM Procedure

Class Level Information

Class	Levels	Values
Expset	3	1 2 3
Hue	1	green
Stim	2	No lavender
washes	3	1 5 10

Number of observations 30

Dependent Variable: Average

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	1206.34957	241.269914	29.80	<.0001
Error	24	194.280365	8.095015		
Corrected Total	29	1400.629935			

R-Square	Coeff Var	Root MSE	Average Mean
0.861291	12.34028	2.845174	23.05600

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Expset	2	1185.41683	592.708419	73.22	<.0001
Stim	1	0.013781	0.013781	0.013	0.9674
Expset*Stim	2	20.918950	10.459475	1.29	0.2931

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Expset	2	1185.41683	592.708419	73.22	<.0001
Stim	1	0.013781	0.013781	0.013	0.9674
Expset*Stim	2	20.918950	10.459475	1.29	0.2931

Source	Type III Expected Mean Square
Expset	Var(Error) + 5 Var(Expset*Stim) + Q(Expset)
Stim	Var(Error) + 5 Var(Expset*Stim) + Q(Stim)
Expset*Stim	Var(Error) + 5 Var(Expset*Stim)

Tests of Hypotheses for Mixed Model Analysis of Variance

Dependent Variable: Average

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Expset	2	1185.41683	592.708419	56.67	0.0173
Stim	1	0.013781	0.013781	0.013	0.9743
Error	2	20.918950	10.459475		

Error: MS(Expset*Stim)

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Expset*Stim	2	20.918950	10.459475	1.29	0.2931
Error	24	194.280365	8.095015		

Least Squares Means

Expset	Average LSMEAN
1	15.5930759
2	30.9706923
3	22.6042331

Lavender fragrance on Orange hue

The GLM Procedure

Class Level Information

Class	Levels	Values
Expset	3	1 2 3
Hue	1	orange
Stim	2	No lavender
washes	3	1 5 10

Number of observations 30

Dependent Variable: Average

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	128.9831413	25.7966283	5.62	0.0014
Error	24	110.0763228	4.5865134		
Corrected Total	29	239.0594641			

R-Square	Coeff Var	Root MSE	Average Mean
0.539544	29.35803	2.141615	7.294816

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Expset	2	122.911583	61.455791	13.40	0.0001
Stim	1	0.0197847	0.0197847	0.019	0.9482
Expset*Stim	2	6.0517730	3.0258865	0.66	0.5261

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Expset	2	122.911583	61.4557918	13.40	0.0001
Stim	1	0.0197847	0.0197847	0.019	0.9482
Expset*Stim	2	6.0517730	3.0258865	0.66	0.5261

Source	Type III Expected Mean Square
Expset	Var(Error) + 5 Var(Expset*Stim) + Q(Expset)
Stim	Var(Error) + 5 Var(Expset*Stim) + Q(Stim)
Expset*Stim	Var(Error) + 5 Var(Expset*Stim)

Tests of Hypotheses for Mixed Model Analysis of Variance

Dependent Variable: Average

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Expset	2	122.911584	61.455792	20.31	0.0469
Stim	1	0.019785	0.019785	0.01	0.9429
Error	2	6.051773	3.025887		

Error: MS(Expset*Stim)

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Expset*Stim	2	6.051773	3.025887	0.66	0.5261
Error: MS(Error)	24	110.07632	4.586513		

Least Squares Means

Expset	Average LSMEAN
1	5.03011270
2	6.91095005
3	9.94338623

Orange fragrance on Green hue

The GLM Procedure

Class Level Information

Class	Levels	Values
Expset	3	1 2 3
Hue	1	green
Stim	2	No orange
washes	3	1 5 10

Number of observations 30

Dependent Variable: Average

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	1313.956941	262.791388	35.87	<.0001
Error	24	175.819815	7.325826		
Corrected Total	29	1489.776755			

R-Square	Coeff Var	Root MSE	Average Mean
0.881982	11.40226	2.706626	23.73763

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Expset	2	1273.43167	636.715838	86.91	<.0001
Stim	1	14.829103	14.829103	2.02	0.1677
Expset*Stim	2	25.696162	12.848081	1.75	0.1946

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Expset	2	1273.43167	636.715838	86.91	<.0001
Stim	1	14.829103	14.829103	2.02	0.1677
Expset*Stim	2	25.696162	12.848081	1.75	0.1946

Source	Type III Expected Mean Square
Expset	Var(Error) + 5 Var(Expset*Stim) + Q(Expset)
Stim	Var(Error) + 5 Var(Expset*Stim) + Q(Stim)
Expset*Stim	Var(Error) + 5 Var(Expset*Stim)

Tests of Hypotheses for Mixed Model Analysis of Variance

Dependent Variable: Average

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Expset	2	1273.43167	636.715838	49.56	0.0198
Stim	1	14.829103	14.829103	1.15	0.3951
Error	2	25.696162	12.848081		

Error: MS(Expset*Stim)

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Expset*Stim	2	25.696162	12.848081	1.75	0.1946
Error: MS(Error)	24	175.819815	7.325826		

Least Squares Means

Expset	Average LSMEAN
1	15.5648148
2	31.5085182
3	24.1395708

Orange fragrance on Orange hue

The GLM Procedure

Class Level Information

Class	Levels	Values
Expset	3	1 2 3
Hue	1	orange
Stim	2	No orange
washes	3	1 5 10

Number of observations 30

Dependent Variable: Average

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	163.464622	32.6929244	14.53	<.0001
Error	24	54.0080008	2.2503334		
Corrected Total	29	217.4726228			

R-Square	Coeff Var	Root MSE	Average Mean
0.751656	25.32386	1.500111	5.923707

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Expset	2	105.702687	52.8513437	23.49	<.0001
Stim	1	54.3053861	54.3053861	24.13	<.0001
Expset*Stim	2	3.4565484	1.7282742	0.77	0.4750

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Expset	2	105.70268	52.8513437	23.49	<.0001
Stim	1	54.305386	54.3053861	24.13	<.0001
Expset*Stim	2	3.456548	1.7282742	0.77	0.4750

Source	Type III Expected Mean Square
Expset	Var(Error) + 5 Var(Expset*Stim) + Q(Expset)
Stim	Var(Error) + 5 Var(Expset*Stim) + Q(Stim)
Expset*Stim	Var(Error) + 5 Var(Expset*Stim)

Tests of Hypotheses for Mixed Model Analysis of Variance

Dependent Variable: Average

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Expset	2	105.702687	52.851344	30.58	0.0317
Stim	1	54.305386	54.305386	31.42	0.0304
Error	2	3.456548	1.728274		
Error: MS(Expset*Stim)					

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Expset*Stim	2	3.456548	1.728274	0.77	0.4750
Error: MS(Error)	24	54.008001	2.250333		

Least Squares Means

Expset	Average LSMEAN
1	3.63821545
2	5.89703704
3	8.23586742

Appendix E. Respondent Data

Study 1

Sex:

Male 54.54%

Female 45.46%

Age: 19~31

Education:

Textile background 100%

Non-textile background 0%

Occupation:

Students 100%

Non students 0%

Study 2

Sex:

Male 33.33%

Female 66.67%

Age: 19~26

Education:

Textile background 100%

Non-textile background 0%

Occupation:

Students 100%

Non students 0%

Study 3

Sex:

Male 34%

Female 64%

Age: 19~24

Education:

Textile background 100%

Non-textile background 0%

Occupation:

Students 100%

Non students 0%

Study 4

Sex:

Male 33.33%

Female 66.67%

Age: 19~24

Education:

Textile background 100%

Non-textile background 0%

Occupation:

Students 100%

Non students 0%

Study 5

Sex:

Male 36.84%

Female 63.16%

Age: 17~34

Education:

Textile background 13.16%

Non-textile background 86.84%

Occupation:

Students 100%

Non students 0%

List of References

1. Meilgaard, M., Civille, G.V. and Carr, B.T., Sensory Evaluation Techniques, 3rd edition, CRC press, 1999.
2. Stone, H. and Sidel, J.L., Sensory Evaluation Practices, 2nd edition, San Diego Academic Press, 1993.
3. Coren, S., Ward, L.M., Enns, J.T., Sensation and Perception, 5th edition, John Wiley & Sons, 1999.
4. Kolb, H., "How the Retina Works," American Scientist, Vol. 91, 2003, p 28.
5. Fuller, T., Foote, C.S., The chemistry of vision, Vol. 1, 2000.
6. Casiday, R., Frey, R., " 'I Have Seen the Light!' Vision and Light-Induced Molecular changes", http://wunmr.wustl.edu/EduDev/LabTutorials/Vision/ Vision.html.
7. Upton, C., "Rhodopsin", http://www.chemsoc.org/exemplarchem/entries/ 2002/upton /rhodopsin.htm.
8. Ophardt, C.E., "Chemistry of Vision", http://www.elmhurst.edu/~chm/ vchembook/ 531vision.html.
9. Morrot, G., Brochet, F., and Dubourdieu D., "The Color of Odors", Brain and Language, No. 79, 2001, p 309.
10. Gilbert, N.A., Martin, R., and Kemp, E.S., "Cross-Modal Correspondence Between Vision and Olfaction: the Color of Smells", American Journal of Psychology, Vol. 109, No. 3, fall 1996, p 335.
11. Jones, B., and O'Neil, S., "Combining Vision and Touch in Texture Perception", Perception & Psychophysics, Vol. 1, No. 37, 1985, p 66.

12. Rock, I., and Victor. J., "Vision and Touch: An Experimentally Created Conflict Between the Two Senses", Science, No. 143, 1964, p 594.

13. Wright, W.D., "A Re-Determination of the Trichromatic Coefficients of the Spectral Colors", Transaction of the Optical Society, Vol. 30, No. 4, 1928-1929, p 141.

14. Wright, W.D., "A Re-Determination of the Mixture Curves of the Spectrum", Transaction of the Optical Society, Vol. 31, 1929-1930, p 201.

15. Berns, R.S., Principals of Color Technology, 3rd edition, John Wiley & Sons, 2000.

16. Wyszecki, G., Stiles, W.S., Color Science, 2nd edition, John Wiley & Sons, 1982.

17. McDonald, R., Color Physics for Industry, 2nd edition, Society of Dyers and Colourists, 1997.

18. Perice, F.T., "The 'Handles' of Cloth as a Measurable Quality," Shirley Institute Memoirs, Vol. 8, No. 9, 1930, p 83.

19. Kim, C.J. and Vaughn, E.A., "Prediction of Fabrics Hand from Mechanical Properties of Woven Fabrics," Journal of Textile Machinery Society of Japan, Vol. T47, No. 6, 1979, p 32.

20. Peak, S.L., "Response Profiles of Flame Retardant fabric Hand," Textile Research Journal, Vol. 48, 1978, p 487.

21. Kawabata, S., The Standardization and Analysis of Hand Evaluation, 2nd edition, The Hand Evaluation and Standardization committee, The Textile Machinery Society of Japan, Osaka, 1980.

22. Kawabata, S., "Recent developments in the Objective Measurement of Apparel Fabric Handle, Quality and Physical Properties," Objective Evaluation of Apparel Fabrics, The textile Machinary Society of Japan, Osaka, 1983, p 15.

23. Kawabata, S., and Niwa, M., "A Propasal of the Standardized Measuring Condition for Mechanical Property of Apparel Fabrics," (This paper was presented at the workshop held in Nara Women's University), 1985, p 44.

24. Elder, H.M., Fisher, F. and Hutchison, G., "Fabric Stiffness, Handle, and Flexion", Journal of Textile Institute, No.2, 1984, p 99.

25. Elder, H.M., Fisher, F. and Hutchison, G., "Fabric Stiffness, Handle, and Compression", Journal of Textile Institute, No.1, 1984, p 37.

26. Elder, H.M., Fisher, F. and Hutchison, G., "A Psychological Scale for Fabric Stiffness", Journal of Textile Institute, No.6, 1985, p 442.

27. Barker, R.L., From Fabric Hand to Thermal Comfort: The Evolving Role of Objective Measurements in Explaining Human Comfort Response to Textiles, Center for Research on Textile Protection and Comfort, North Carolina State University, Raleigh, NC.

28. Johnson, A., The Theory of Coloration of Textiles, the Society of Dyers and Colourist, 1989.

29. Shore, J., Cellulose Dyeing, Society of Dyers and Colourists, 1995.

30. Aspland, J.R., "Reactive Dyes and Their Application", Textile Chemist and Colorist, Vol. 24, No. 5, 1992, p 31.

31. Hall, A.J., A Hand Book of Textile Finishing, The National Trade Press LTD, 1952.

32. Marsh, J.T., Introduction to Textile Finishing, 2nd edition, Champ and Hall LTD, 1966.

33. Finch, C.A., Polyvinyl Alcohol Properties and Application, John Wiley & Sons, 1973

34. Tomasino, "Chemistry and Technology of Fabric Preparation and Finishing", NCSU Copy center, spring 1995.

35. Patwardhan, S., Gangakhedkar, N.S., Gupte, V.C., Fundamentals of Computer Color Matching, Color group of India, 1984.

36. Hunt, R.W.G., Measuring Color, 3rd edition, Fountain Press, 1998.

37. Haslam, S.A. and McGarty, D., Doing psychology: an Introduction to Research Methodology and Statistics, Thousand Oaks, Calif. Sage Pub;ications, 1998.

38. Anderson, D.R., Sweeney, D.J. and Williams, T.A., Introduction to Statistics: Concepts and applications, 3rd edition, West Publications, 1994.