USE OF PSYCHOPHYSICAL METHODS TO ASSESS MOISTURE SENSATION IN CLOTHING: A FEASIBILITY STUDY

By

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CHAPTER I

INTRODUCTION

Background

Clothing comfort is an extremely complex phenomenon and is a result of numerous interactions between physiological, physical and psychological factors. It has been defined as "a state of satisfaction indicating physiological, psychological and physical balance among the person, his/her clothing, and his/her environment" (Branson & Sweeney, 1987, p. 14). The many factors impacting judgments of clothing comfort have been the topic of study to investigators in a variety of disciplines including physiology, psychology and ergonomics (Attia, Engel & Hillebrandt, 1980; Holmer & Elnas, 1981; Newburgh, 1949; Vokac, Kopke & Keul, 1972, 1973, 1976), as well as textiles and clothing (Fourt & Hollies, 1970; Hollies, 1977; Slater, 1977, 1986; Sontag 1986). As a result of these diverse research efforts, there have been several approaches to assessing clothing comfort and/or the variables contributing to it. While much attention has been given to the methodologies of assessing the physiological and physical factors of clothing comfort, less attention has been focused on the methods of assessing its subjective components.

The emergence of the functional design process as a holistic approach to creating apparel (Watkins, 1984) has intensified the need for methodologies that can be used to assess the critical factor of thermal comfort in clothing. Whether functional apparel is intended for protection from a stressful or hazardous environment, or whether it is intended for wear during intense physical activity, moisture build-up within the clothing and microclimate is a persistent problem with regard to clothing comfort. While this problem is well documented in wearer studies, there is no measure available that allows a quantitative assessment of the relationship between moisture stimuli and moisture sensation.

Significance

The sensorial aspects of clothing comfort pertain to the wearer's satisfaction with how a fabric or garment is perceived by the senses of the wearer (Textile Horizons, 1985; Branson and Sweeney, 1987). For example, one's comfort may be affected by how a garment feels against the skin, how it looks to the eye, how it sounds when one moves, how it smells, and possibly how it tastes. Each of these sensations can be elicited by specific physical stimuli and can thus be manipulated and controlled under experimental conditions. The typical thermal comfort and thermal sensation measures obscure the relationships between physical stimuli and psychological sensations because they attempt to tap complex sensations that are elicited by a host of physical and nonphysical stimuli that are not inclusively under the control of the investigator. While thermal comfort is a vital component of clothing comfort, it is conceptualized as a subset of sensorial comfort (Figure 1).

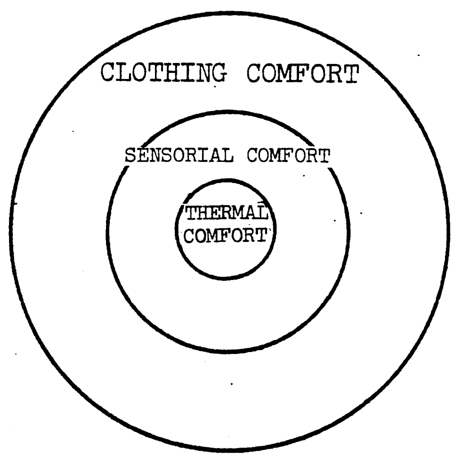

Figure 1. Conceptualization of Clothing Comfort Components. From Clothing Comfort Conceptualization and Measurement: Toward a Metatheory by D. H. Branson and M. Sweeney, 1987, paper presented at meeting of the Association of College Professors of Textiles and Clothing Central Region (ACPTC-CR), Dearborn, MI.

Psychophysical measures, on the other hand, involve the measurement of a single sensation in relation to its initiating physical stimulus. Thus, the relationship between stimulus intensity and psychological sensation can be quantified. Psychophysical scaling methods have recently been utilized in an attempt to "build a bridge of understanding between objective and subjective measurement" of tactile properties of fabrics (Elder, Fisher, Hutchison, and Beattie, 1985, p. 442). Psychophysical scaling of sensations offers the clothing comfort investigator a potent tool for assessing the relationship between physical stimulus variables and the psychological sensations that are evoked by them.

The use of psychophysical methods also aids investigators in evaluating the contribution of specific sensations to overall judgments of clothing comfort. Thus, its use will serve to advance the level of specificity in the subjective assessment of clothing comfort. For example, one's level of clothing comfort may depend not only on one's satisfaction with the thermal environment (general), but also on the intensity of moisture or texture (specific) one senses under certain conditions. While the psychophysical relationship investigated in this study is that of moisture and moisture sensation, it is the contention of this researcher that the methods detailed hereinafter may be used for any clothing comfort sensation that has a direct physical correlate.

Theoretical Framework

Psychophysics, the scientific study of the relation between stimuli in the physical domain and sensations in the psychological domain (Gescheider, 1976) provided the theoretical framework for this study. It has been the theoretical foundation for research in the sensory realm (olafactory, auditory, visual, taste, tactual) and is now beginning to receive attention from researchers in the apparel and textile field. Because clothing comfort is defined, in part, in terms of sensations "felt" in response to a physical property (i.e., temperature, wetness), a psychophysical approach to its assessment is a logical one.

Psychophysical determinations involve quantifying the relationship between variables belonging to continua from two completely different worlds, physical and psychological. The physical continuum is measurable in physical units representing a single change in some physical property, i.e., temperature, pressure, weight. Corresponding to the physical continuum is a psychological continuum that represents a well recognized sensation, i.e., warmth, softness, heaviness (Guilford, 1954).

Quantification of the relationship between the continua is dependent upon the communication of the sensation experienced. This takes place by means of an observable response or "judgment" by the subject (Bock and Jones, 1968). Psychophysical methods establish experimental conditions that maintain a close correspondence between the sensation experienced and the judgment expressed. D'Amato (1970) suggested that the sequence of events in any psychophysical determination can be illustrated as:

Stimulus --> Sensation --> Judgmental Response

Purpose

The overall purpose of this study was to explore the use of psychophysical methods as a means of quantifying the assessment of one component of clothing comfort, that of moisture sensation. This particular aspect of sensorial comfort was chosen because it is often cited as the reason for dissatisfaction with the comfort properties of clothing. It is especially a problem with functional apparel because this type of clothing is frequently worn under stressful environmental conditions where moisture from the body, the atmosphere, or both, accumulates on the skin and within the clothing layers and results in wearer discomfort. The upper back area of the body was chosen as the site to be tested. This location was selected because it is one area of the body in which most clothing has high contact with the skin, regardless of garment design.

Objectives

The specific objectives that guided this study are as follows:

1. To determine absolute threshold values of moisture sensation in subjects for one body location using one fabric type.

2. To determine difference threshold values of moisture sensation in the same.

3. To use a magnitude estimation approach to assess the relationship between moisture stimuli and moisture sensation in subjects for one body location using one fabric type.

Conceptual Definitions

Clothing Comfort

Clothing comfort is defined as a state of satisfaction indicating physiological, psychological and physical balance among the person, his/her clothing, and his/her environment (Branson and Sweeney, 1987).

Sensorial Comfort

Sensorial comfort is defined as a state of satisfaction with how a fabric or garment is perceived by the senses of the wearer (Branson and Sweeney, 1987).

Thermal Comfort

Thermal comfort is a condition of mind which expresses satisfaction with the thermal environment (ASHRAE, 1981).

Psychophysics

Psychophysics is the scientific study of the relationship between stimuli in the physical domain and sensations in the psychological domain (Gescheider, 1976).

Absolute Threshold (AL)

The absolute threshold is the minimum value of a physical stimulus that will evoke a sensation. It is operationally defined statistically; it is the stimulus value that is detected on 50 percent of its presentations to the subject (Gescheider, 1976).

Difference Threshold (DL)

The difference threshold is the minimum amount of physical stimulus change required to produce a sensation difference. Like AL, its value is determined statistically. The stimulus values that are judged "greater" than a comparison stimulus on 25 and 75 percent of their presentations to the subject are averaged to give the difference threshold (Gescheider, 1976).

Magnitude Estimation

A method of direct psychophysical scaling whereby the subject makes direct numerical estimations of the sensory magnitudes produced by various intensities of a stimulus that are randomly presented to the subject (Stevens, 1975).

Organization of Chapters

Following this introductory chapter is a review of the literature in Chapter II. The findings for objectives 1 and 2 will be found in Chapter III entitled, "A Psychophysical Method to Assess Moisture Sensation in

Clothing." Findings for objective 3 will be found in Chapter IV entitled, "A Magnitude Estimation Approach to the Assessment of Moisture Sensation." Chapter V includes a summary of all of the findings as well as implications and recommendations for further study.

CHAPTER II

LITERATURE REVIEW

Clothing and Thermal Comfort

Under most circumstances, the major part of a person's heat exchange with the environment takes place through clothing. Clothing, therefore, interacts with the thermoregulating system of the human body (Mecheels & Umbach, 1977). One of the purposes of clothing is to maintain a uniform body temperature and this has been shown to be a critical factor in deciding comfort (DeMartino, Yoon, Buckley, Becker & Jackson, 1984). Thermal comfort is regarded as a condition in which the heat balance within the body is maintained. The body is in a state of thermal comfort when the mean skin temperature is approximately 33-35 C and body temperature regulation is completely accomplished by vasomotor control (Hardy, 1970).

The clothed person's physical and physiological responses to the environment have been examined in numerous studies with regard to thermal comfort. While there is general agreement that the movements of heat, moisture, and air through a fabric are the most critical factors governing thermal comfort, a more thorough understanding of clothing comfort can be achieved when the psychological factors are examined.

Almost universally, scaling techniques have been used to measure an occupant's feeling or response toward the environment (Rohles, Konz, McCullough & Milliken, 1983). The process of making judgments from our sensory perception of the world is termed psychological scaling. The psychological scaling utilized in clothing comfort involves a commonly recognized sensation or combination of sensations that are defined in the prospective rater's language of perception. Hollies (1977) states that the most meaningful psychological scale work has resulted from studies in which the observer is allowed free use of the language he/she considers appropriate to describe the attribute under study. However, clothing comfort investigations which permit such allowances can not be found in the literature.

A review of the clothing comfort literature reveals that instruments designed to measure comfort sensations used to date have focused on tapping those sensations that relate to temperature perception, those that deal with the clothing/skin/interface, and finally, those that assess an overall, or global comfort level. The methodologies utilized to assess these subjective components of clothing comfort have varied widely and illustrate the lack of programmatic research toward this objective.

Thermal Comfort: Affectively Defined

The American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc. (ASHRAE), defines thermal comfort as "that condition of mind which expresses satisfaction with the thermal environment" (1981, p. 2). The "condition of mind" premise implies that a quantitative assessment of thermal comfort must involve the measurement of affectivity, or how one feels. Comfort has also been defined as a sensation of contented well-being and the absence of unpleasant feelings (Fuzek & Ammons, 1977). Unlike the physical and physiological factors that are objectively measured, comfort sensation is subjective. Furthermore, comfort is dynamic, continually changing as we become accustomed to changes in fibers, fabrics, fashions, etc.

Subjective estimation of thermal comfort has been assessed on various verbal scales describing the sensation in ordinal terms of "temperature", "pleasantness" or "comfort." Gagge, Stolwijk, and Hardy (1967) however, showed that these three verbal scales were not the same and perhaps discriminated different sensations.

Thermal Sensation

ASHRAE (1981) defines thermal sensation as "a conscious feeling commonly graded into categories of cold, cool, slightly cool, neutral, slightly warm, warm and hot" (p. 2). The Institute for Environmental Research at Kansas State University under ASHRAE contracts has conducted extensive research on the thermal sensation of clothed subjects since 1963 utilizing this seven-point nominal scale. In thermal comfort research, it is the most predominant subjective measure of thermal sensation although it has often been extended to nine points to include "very hot" and "very cold" (Fig. 2, Rohles & Laviana, 1985).

( ) VERY HOT
( ) HOT
( ) WARM
( ) SLIGHTLY WARM
( ) NEUTRAL
( ) SLIGHTLY COOL
( ) COOL
( ) COLD
( ) VERY COLD

Figure 2. Nine Category Thermal Sensation Scale. From "Indoor Climate: New Approaches to Measuring How You Feel" by F. H. Rohles and J. E. Laviana, 1985, Proceedings of CLIMA 2000, 4, p. 2. Copyright 1985 by the World Congress of Heating, Ventilating and Air Conditioning. Reprinted by permission.

The McGinnis Thermal Scale (Fig. 3) has been shown to be highly reliable for thermal stress assessment in both hot and cold climates (Hollies, 1977). It has most recently been used by Hollies, Custer, Morin, and Howard (1979) and DeMartino et al. (1984) for assessing the metabolic preconditioning of test subjects and the repeatability of the microclimate conditioning protocol. This simple linear scale is an example of a subjective measure that makes "maximum use of man's innate ability to perceive and measure complex phenomena" (Hollies, 1977, p. 114).

I AM:

1. So cold I am helpless
2. Numb with cold
3. Very cold
4. Cold
5. Uncomfortably cool
6. Cool but fairly comfortable
7. Comfortable
8. Warm but fairly comfortable
9. Uncomfortably warm
10. Hot
11. Very hot
12. Almost as hot as I can stand
13. So hot I am sick and nauseated

Figure 3. McGinniss Thermal Scale. From "A Human Perception Analysis Approach to Clothing Comfort" by N. R. S. Hollies, A. G. Custer, C. J. Morin, and M. E. Howard, 1979, Textile Research Journal, 49, p. 559. Copyright 1979 by the Textile Research Institute. Reprinted by permission.

A psychophysical approach was used by Stevens and Stevens (1960) in exploring the human bounds of temperature perception. A magnitude estimation approach was utilized to determine whether the detection of heat and cold formed a continuum of sensation as measured at the skin. Twelve subjects were asked to let the number 10 stand for the subjective warmth of an aluminum cylinder at 39.0°C presented to the anterior surface of the forearm followed by random presentations between 35.0° and 47.2°C to the same location. Each subject made three magnitude estimates of each stimulus intensity. The geometric means of the 36 estimates are represented by the points in Figure 4. It was found that temperature sensation grew as a power function of the intensity of the aluminum stimuli. No attempt has since been made to relate these findings to clothing comfort. However, Hollies (1977) included this work as an example of measurement techniques in comfort sensation assessment.

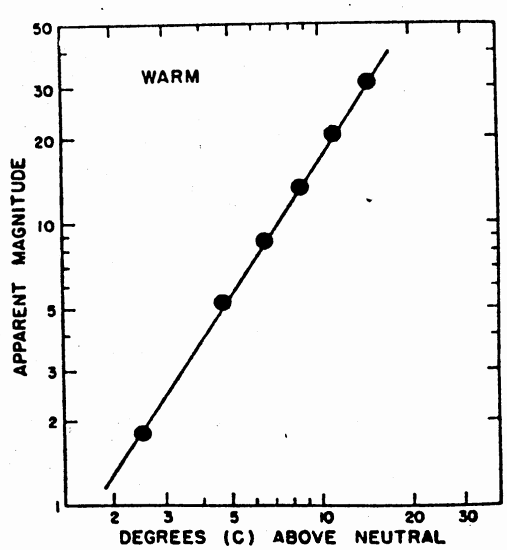

Figure 4. Magnitude Estimates of Warmth Sensations. From "Psychological Scaling in Comfort Assessment" (p. 113) by N. R. S. Hollies, 1977. In N. R. S. Hollies & R. F. Goldman (Eds.), Clothing Comfort, Ann Arbor, MI: Ann Arbor Science. Copyright 1977 by Ann Arbor Science.

Clothing/Skin Interface Sensations

Features of apparel that greatly influence comfort sensations are 1) the ability of clothing to handle moisture at the skin interface and 2) the nature of the clothing contact with the skin (Hollies, 1965). The nature of clothing contact with the skin, or tactility, may be perceived in a number of ways. Generally, those perceptions dealing with wetness in next-to-skin clothing are distinct from those dealing with fabric "hand" or degrees of stiffness, roughness, thickness or other tactual descriptors.

The perception of moisture in next-to-skin clothing depends, in part, upon the water content of the fabric. Hollies (1977) utilized a subjective comfort rating (SCR) of: 1) dry 2) slightly damp 3) moderately damp and 4) wet, to assess wearers' perceptions of moisture in shirts that were chemically treated to change their rates of drying (Figure 5). The results illustrate the accuracy of wearers' perceptions of moisture to actual water contents. Other researchers investigating the perception of fabric wetness (Holmer 1985; Vokac, Kopke, & Keul, 1976) have used five point rating scales with similar descriptors.

Fabrics that come into contact with warm, moist, sweating skin give a heightened intensity of sensation at the skin surface. Even a small amount of moisture in the ambient air can cause a sensation of discomfort as shown in

Figure 6 (Hollies, 1971). The results indicate a strong relationship between the water content of the clothing due to sweating, the water content of air or relative humidity of the comfort test room and the subjective comfort rating (SCR) assigned to the garment worn. Consequently, as moisture in the clothing and atmosphere increases, the comfort rating of the garment decreases.

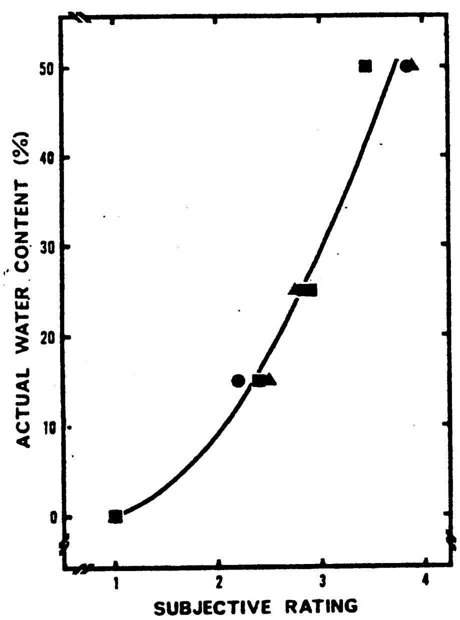

Figure 5. Perception of Moisture in Clothing. From "Psychological Scaling in Comfort Assessment" (p. 115) by N. R. S. Hollies, 1977. In N. R. S. Hollies & R. F. Goldman (Eds.), Clothing Comfort, Ann Arbor, MI: Ann Arbor Science. Copyright 1977 by Ann Arbor Science.

Several researchers investigating the human tactile perception of clothing (DeMartino et al., 1984; Hollies, et al., 1979; Hollies, DeMartino, Yoon, Buckley, Becker &

Jackson, 1984; Vokac et al., 1976) have used the methods for documenting contact sensations originally developed in a study conducted by Hollies (1965) for the United States Department of Agriculture. A list of descriptors was developed and refined by repeated experiments in which participants were asked to describe the sensations they were experiencing. The final list of descriptors are words that are used to report comfort sensations in the raters' language of perception. A four point intensity scale was developed to accompany the list with which subjects are to rate the sensations (Figure 7).

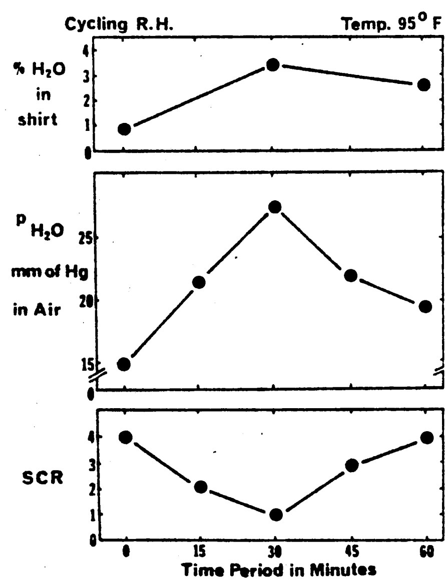

Figure 6. Subjective Comfort Rating (SCR) of Clothing in Moisture Environments. From "Psychological Scaling in Comfort Assessment" (p. 116) by N. R. S. Hollies, 1977. In N. R. S. Hollies & R. F. Goldman (Eds.), Clothing Comfort, Ann Arbor, MI: Ann Arbor Science. Copyright 1977 by Ann Arbor Science.

During the run you will be asked to fill in this chart under an appropriate time period. Please rate the intensity of the comfort sensations for the garments you are wearing. If any of the comfort descriptors listed below are sensed, put a rating in the appropriate box according to the intensity of the sensation, when requested by the panel operator. If you perceive additional sensations due to wearing the garments, please note these comments at the bottom of the page and the time period in which they were noticed.

Use this intensity scale: 4 (partially)
3 (mildly)
2 (definitely)
1 (totally)

Rating Periods

	1	2	3	4	5	6	7	8	9
Snug									
Loose									
Heavy									
Light weight									
Stiff									
Staticy									
Sticky									
Non-Absorbent									
Cold									
Clammy									
Damp									
Clingy									
Picky									
Rough									
Scratchy									
From the chart at your table, write in the number of your McGinnis Scale Rating.									

Comments on the locations that feel uncomfortable__________

Additional sensations noted__________

Figure 7. Comfort Sensation Intensity Scale. From "A Human Perception Analysis Approach to Clothing Comfort" by N. R. S. Hollies, A. G. Custer, C. J. Morin, and M. E. Howard, 1979, Textile Research Journal, 49, p. 558.

Clothing comfort investigations utilizing these methods (DeMartino et al., 1984; Hollies, et al., 1979; Hollies, DeMartino, Yoon, Buckley, Becker & Jackson, 1984; Vokac et al., 1976) reveal that changes in the clothing microclimate produce corresponding sensations described with words such as sticky, clingy, clammy, damp and nonabsorbent. The intensity of the discomfort sensations is directly influenced by the amount of moisture at the clothing-skin interface, and the buildup of moisture on clothing next to the skin (Scheurell, Spivak & Hollies, 1985). However, for normal wearing conditions in which the heat balance within the body is maintained with vasomotor control, differences in the tactile properties of clothing are not found with this approach to assessment unless fabrics are unusually textured (Hollies et al., 1979).

More recently, researchers investigating the influence of skin wettedness on the perception of fabric texture and pleasantness utilized line scales with sensation descriptors on either ends (Gwosdow, Stevens, Berglund, & Stolwijk, 1986). Subjects were asked to record their sensations by placing a mark on each line scale as each of the test fabrics were pulled across the inside of their forearm under different environmental conditions (Figure 8). The subjective responses were quantified as distances (mm) from the subject's mark to a given zero point. Thus, within the parameters of the end point descriptors, subjects were able to determine their own spacing on the scales by indicating the degree of fabric texture or pleasantness experienced. Findings from this study were in agreement with other studies of contact sensations. As moisture on the skin surface increased, so did ratings of perceived degree of texture, while ratings of fabric pleasantness decreased.

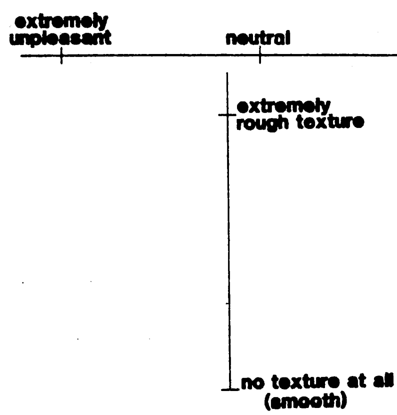

Figure 8. Subjective Rating Chart. From "Skin Friction and Fabric Sensations in Neutral and Warm Environments" by A. R. Gwosdow, J. C. Stevens, L. G. Berglund, and J. A. J. Stolwijk, 1986, Textile Research Journal, 56, p. 575. Copyright 1986 by the Textile Research Institute. Reprinted by permission.

"Global" Comfort Sensations

While it may be assumed that the main components of the perception of clothing comfort are the thermal and tactile sensations, a global assessment of subjective comfort has been sought using a five or six point "comfortable" to "uncomfortable" scale (Holmer, 1985; Vokac et al., 1976). However, the comfort ballot presented in Figure 9 has more recently been employed in comfort research and is detailed by Laviana and Rohles (1987). This measure was derived using the semantic differential scale with values ranging from 1 to 9 assigned to each space along the continuum. Originally, a thermal comfort score was calculated by summing the values assigned to each of the descriptors. More recently, factor analytical scaling techniques have been applied and a thermal comfort score is computed by multiplying each response by its respective loading and summing the products. A thermal comfort score is then computed in the form of a percentage.

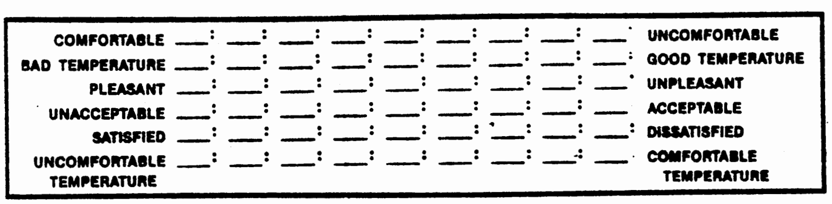

Figure 9. Thermal Comfort Scale in Semantic Differential Format. From "Thermal Comfort: A New Approach for Subjective Evaluation" by J. E. Laviana and R. H. Rohles, 1987, <u>ASHRAE Transactions</u>, <u>93</u>(1), p. 1077. Copyright 1987 by the American Society for Heating, Refrigerating and Air Conditioning Engineers. Reprinted by permission.

Implicit in the use of this scale (Figure 9) is the assumption that the descriptors comprising the adjective-pairs are bipolar; that is, the adjectives will have a correlation of -1. If this assumption is met, each adjective-pair should define a specific psychological continuum. If the assumption fails, then its validity may be questioned. Laviana and Rohles (1987) assert that research has not supported the assumption that bipolar pairs are truly bipolar.

As an alternative to the thermal comfort scale presented in Figure 9, Laviana and Rohles (1987) suggest the use of a multiple item scale for assessing subjective responses to the thermal environment (Figure 10). On this scale, the rater evaluates each of the descriptors of the thermal environment individually without an implied relationship. As detailed by the authors, an analysis of variance is conducted on each adjective and the residuals are then used to compute a correlation matrix to be used in factor analysis. The resulting factors will generate the final scales. This approach encourages investigators to alter the descriptors used in the ballot and to derive their own scales from the resulting factor analyses.

Another approach to subjective measurement of the thermal comfort of the environment utilized a normalized certainty scale to measure comfort of various body parts when seated in office chairs (Rohles & Laviana, 1985). The scale has the unique features of measuring the "certainty" of the comfort judgment and weighting the eleven possible responses according to the normal probability curve. The normalized certainty scale was also used in the sensory assessment of fabric hand by Winakor and Kim (1980) and was found to be highly sensitive.

THERMAL ENVIRONMENT BALLOT

Instructions: Below is a list of words that can be used to describe the thermal environment. We would like you to rate how accurately the words below describe the THERMAL ENVIRONMENT of this place. Use the following 1-7 scale for your answer for each word.

7 = very accurate
6 = accurate
5 = slightly accurate
4 = NEUTRAL, neither accurate nor inaccurate
3 = slightly inaccurate
2 = inaccurate
1 = very inaccurate

THE THERMAL ENVIRONMENT

1. uncomfortable .... ____	12. good .... ____	23. intolerable .... ____
2. content with .... ____	13. unacceptable .... ____	24. disagreeable .... ____
3. agreeable .... ____	14. enjoyable .... ____	25. adequate .... ____
4. tolerable .... ____	15. great .... ____	26. desirable .... ____
5. unpleasant .... ____	16. distressful .... ____	27. unsatisfactory .... ____
6. inadequate .... ____	17. bad .... ____	28. gratifying .... ____
7. annoying .... ____	18. acceptable .... ____	29. pleasing .... ____
8. undesirable .... ____	19. discontent with .... ____	30. poor .... ____
9. satisfactory .... ____	20. pleasant .... ____	31. appealing .... ____
10. miserable .... ____	21. dissatisfied with .... ____	32. delightful .... ____
11. satisfied with .... ____	22. comfortable .... ____	

Figure 10. Thermal Environment Ballot. From "Thermal Comfort: A New Approach for Subjective Evaluation" by J. E. Laviana and R. H. Rohles, 1987, ASHRAE Transactions, 93(1), p. 1078 Copyright 1987 by the American Society for Heating, Refrigerating and Air Conditioning Engineers. Reprinted by permission.

Psychophysical Determinations

Psychophysics is the study of sensations and how their magnitudes are related to the intensities of the initiating stimuli (D'Amato, 1970). As in the determination of clothing comfort, psychophysical determinations involve two continua which belong to completely different realms:

a psychological continuum

and

a physical continuum

Skin and body core temperatures, humidity of the microclimate, sweat rate, activity level, heart rate, environmental conditions and the clothing characteristics of fiber/yarn/fabric/finish composition and design are critical factors in determining clothing comfort that belong to the physical continuum and are thus, more easily quantified. The sensations that these factors elicit in the wearers belong to the psychological continuum and are less easily quantified.

Quantification of the relationship between the continua is dependent on the communication of information regarding the subject's sensation. This takes place by means of an observable response or "judgment" by the subject (Bock & Jones, 1968). The sequence of events in any psychophysical determination can thus be illustrated as:

Stimulus -> Sensation -> Judgmental Response

The goal of psychophysical determination is congruence between the sensation experienced and the judgment expressed (D'Amato, 1970).

The relationship between stimuli in the physical domain and sensations in the psychological domain has been an intense subject of study for over a century, though the methods seem to have eluded researchers in the clothing area until recently. Hollies' (1977) mention of magnitude estimation of thermal stimuli was an attempt in this area, but the connection to clothing was not made. More recently, however, investigators in the area of fabric handle have attempted to "build a bridge of understanding between objective and subjective measurement" with the use of psychophysical methods (Elder, Fisher, Hutchison, & Beattie, 1985, p. 442). Elder et al. (1985) established a scale of stiffness for fabrics that allows conversion between the physical parameter of drape coefficent and the subjective assessment of fabric stiffness as determined by magnitude estimation.

Since the dimensions involved and the sequence of events in psychophysical determinations are the same as those involved in the assessment of clothing comfort, the evolution of the laws believed to govern psychophysical relationships will be reviewed.

Psychophysical Laws

Psychophysical laws relate psychological sensation to the physical stimulus responsible for evoking the sensation (D'Amato, 1970). E.H. Weber, a psychophysicist in the early nineteenth century, proposed what is now known as Weber's Law. After conducting numerous experiments involving various sensations and physical stimuli, Weber concluded that the intensity of a stimulus must be increased by a constant fraction of its starting intensity in order for subjects to notice a difference in sensation from the initial sensation. Thus, Weber's Law states that in order for a change in a stimulus to become "just noticeable", a fixed percentage must be added. Accordingly, the "just noticeable difference" (JND) grows larger in direct proportion to the size of the stimulus. Weber's prediction has been confirmed for a wide range of stimulus intensities and sensory modalities. However, it does not hold for low stimulus intensities; the fraction tends to grow disproportionately at very low intensities. Nevertheless, it is an extremely useful calculation providing an index of sensory discrimination which can be compared across different conditions and different modalities (Gescheider, 1976; Engen, 1971).

In 1860, Gustav Fechner, another psychophysicist, proposed that sensation magnitude could be indirectly quantified by relating the stimulus intensity values on the physical scale to corresponding values on the psychological scale (Fechner, 1966). In other words, he conceptualized Weber's findings on a psychological dimension which could be lawfully related to a physical dimension. He proposed that each time a JND is added to the stimulus, the psychological sensation increases by a jump of a constant size. For Fechner, all steps, or jumps, were subjectively equal by assumption. He considered the JND a standard unit of sensation magnitude because it is the smallest detectable increment in a sensation and therefore always psychologically the same size. Building upon Weber's work and now known as Fechner's law, Fechner proposed that the magnitude of a sensation grows in proportion to the logarithm of the stimulus (Stevens, 1975).

Today, Fechner's law is not regarded as an accurate statement of the relationship between stimulus intensity and sensation magnitude. His law is based on two assumptions which have been shown to be inaccurate. First, that Weber's fraction is a constant of the starting intensity of the stimulus, and secondly, that the JND is an equal unit of sensation at all levels of stimulus intensity. Both have been proven to be false under certain conditions (Engen, 1971). However, the importance of Fechner's work lies in the direction he took in the concept of measurement in psychological investigation (Stevens, 1975).

Fechner's logarithmic law was replaced in the 1950s by a new psychophysical law that emerged as a result of renewed interest in psychophysical research. S.S. Stevens (1975) proposed that a power function defines the relationship between sensation magnitude (ψ) and stimulus intensity (ϕ). His law states that sensory estimations increase in proportion to the stimulus intensity raised to a power. The power depends on the sensory modality and the stimulus condition. The function may be written as:

$$\psi = k\phi^{a} \quad (1)$$

or in its logarithmic form:

$$\log \psi = \log k + a \log \phi \quad (2)$$

where k is a constant of proportionality whose value depends on the choice of units for the measurement of ψ and ϕ ; and the exponent a reflects the rate at which sensation magnitude grows with respect to the stimulus. The size of a varies depending on the sensory modality and the conditions of stimulation (Gescheider, 1976).

Methods of Psychophysics

The concept of a sensory threshold is integral to the study of psychophysical methods. The absolute "threshold" or limen (its Latin equivalent) is defined as the minimum value of a physical stimulus that will evoke a sensation. It is usually abbreviated as AL. The difference threshold (DL) is the minimum amount of stimulus change required to produce a sensation difference, referred to as the just noticeable difference on the sensation continuum. For example, if the stimulus is 20 units and the stimulus has to be increased to 25 units to produce a just noticeable increment in the sensation, the difference threshold would be 5 units.

Three psychophysical methods have gained particular prominence in investigating the laws relating sensory experience to initiating physical stimuli. They are:

1) the method of limits
2) the method of constant stimuli and
3) the method of adjustment.

An important feature of the three methods is that they ask the subject to make the simplest possible judgements: to detect the presence or absence of a sensation or to decide whether two sensations are equal in magnitude or different. These discriminations are among the most reliable judgments of which organisms are capable (Gescheider, 1976). The first two methods will be explored.

Method of Limits. Determination of the absolute threshold/limen (AL) is calculated by rapid initial testing. A stimulus is presented to the subject of such intensity that higher values of it are clearly above threshold and lower values of it are well below threshold. Further, the stimuli are chosen so that they are separated by a constant and relatively small difference in value (D'Amato, 1970).

Stimuli are presented to the subject in a decreasing or an increasing order, starting from a point where the stimulus is well above (or below) the threshold. Upon presentation of the stimulus, the subject is asked to respond as to whether the stimulus is present or not. The procedure is repeated until the subject can no longer detect the stimulus (i.e., if a descending order was used). At this transition point the series is terminated. The absolute threshold on any series is assumed to lie midway between the two values of the stimuli over which the response reversal occurred.

The same procedure is repeated for several different series, half of the series descending (D) and half ascending (A). The starting point of a series varies among the A series and among the D series. After completing a total of n series, the mean of the absolute thresholds is determined to be the AL.

Unlike AL, which is an indicator of absolute sensitivity, the difference limen (DL) is a measure of differential sensitivity, i.e., the ability to discriminate differences between stimuli. In determining the DL by the method of limits, two stimuli are presented to the subject on every trial - a standard stimulus (St) and a variable stimulus (Sv). On successive presentations the Sv is changed by a small amount in the direction of the St. The subject's task is to judge whether the magnitude of the sensation evoked by the Sv is greater than, less than, or equal to that elicited by the St.

The "upper threshold" or UT is the midpoint between the two stimuli where the response changes from "greater than" to "equal". The lower difference threshold, or LT, is the midpoint between the adjacent stimuli where the response of "equal" changes to "less than." The range over which the subject cannot perceive a difference between the Sv and the St is called the interval of uncertainty (IU) and is computed by subtracting the mean LT from the mean UT. The DL is defined as the mean of the difference thresholds, or half of the IU. The point of subjective equality (PSE) is the point at which the subject determines the Sv to be equal to the St. It is calculated by locating the midpoint between UT and LT (see example, Table 1).

Method of Constant Stimuli. The name for this method is derived from the fact that the same set of stimuli are used repeatedly throughout the experimental procedures. The advantage of this method over the method of limits is that it eliminates the errors of habituation and anticipation, i.e., the series-direction variable. The disadvantage is that threshold determination is tedious and time-consuming because every stimulus must be presented a large number of times.

In determining the absolute threshold of sensation by this method, the first step is to choose a range of four to eight stimuli that include the value of the AL in the middle of the range as estimated by prior testing. The

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	STIMULUS PRESENTED FIRST							
SERIES	S_t		S_v		S_v		S_t	
DIRECTION	D	A	A	D	D	A	A	D
S_v (mm)								
64	+							
62	+				+			+
60	+			+	+			+
58	+			+	+			+
56	+			+	+			+
54	=			=	=		+	=
52	=		+	+	=	+	=	=
$S_t = 50$	=	+	=	=	=	−	=	=
48	−	−	=	=	−	=	=	−
46		−	−	−		−	−	
44		−	−			−	−	
42		−	−			−	−	
40		−	−			−	−	
38		−					−	
36		−						
UT	55	49	51	55	55	51	53	55
LT	49	49	47	47	49	47	47	49
$IU = 2DT$	6	0	4	8	6	4	6	6
PSE	52	49	49	51	52	49	50	52

$DL = \overline{DT}$ $\quad \overline{IU}/2 = 2.50$ mm

$DL_D = 3.25$ mm $\quad DL_A = 1.75$ mm $\quad DL_t = 2.25$ mm $\quad DL_v = 2.75$ mm

$\overline{PSE} = 50.50$ mm $\quad \overline{PSE_t} = 50.75$ mm $\quad \overline{PSE_v} = 50.25$ mm

Table 1. Determination of Difference Threshold by Method of Limits. From Experimental Psychology: Methodology, Psychophysics and Learning (p. 126) by M. R. D'Amato, 1970, New York: McGraw-Hill. Copyright 1970 by McGraw-Hill. Reprinted by permission.

range of stimuli, unlike the method of limits, should not include values that are clearly superthreshold and subthreshold. One end should encompass a value that will be perceived on a little more than zero percent of the trials. The other end should contain a value up to a magnitude that will be perceived somewhat less than 100 percent of the time.

The subject is presented with each stimulus a relatively large number of times in random order. The number of "yes" or "no" responses for each stimulus intensity is recorded. For each stimulus value the proportion of "yes" responses is computed. A psychometric function graph is constructed with stimulus intensity plotted on the abscissa and the proportion of yes responses on the ordinate. The AL is the stimulus value that evokes a "yes" response on one half of its presentations to the subject. The best fitting curve for the data points is an S-shaped function. Psychometric functions often follow a particular S shape called an ogive, which is a cumulative form of the normal distribution (Gescheider, 1976) (Figure 11).

In determining the DL by this method, the St and the Sv are presented to the subject in random order. The subject judges whether one member of the pair is greater than or less than the other. The values of the comparison stimuli are chosen so that the stimulus of greatest magnitude is almost always judged greater than the standard and the stimulus of least magnitude is almost always judged less than the standard. A psychometric function is obtained with the proportion of "greater" responses plotted against values of the comparison stimuli (Figure 12). The .5 on the psychometric function is the point of subjective equality (PSE) and represents the value of the comparison stimulus which over a large number of trials is subjectively equal to the standard stimulus. The difference between the .75 point and the PSE yields the upper difference threshold, or UT. The lower difference threshold, LT, is determined by finding the difference between the .25 point and the PSE. The LT and UT are averaged to give one difference threshold (DL) for a particular standard stimulus (Gescheider, 1976).

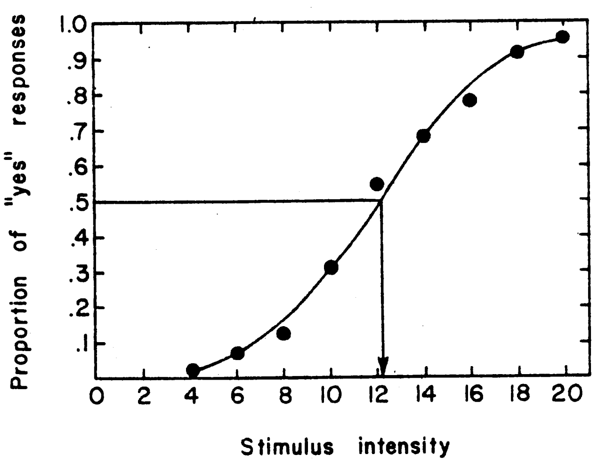

Figure 11. Determining Absolute Threshold by the Method of Constant Stimuli. From Psychophysics: Method and Theory (p. 21) by G. A. Gescheider, 1976, New Jersey: Lawrence Erlbaum. Copyright 1976 by Lawrence Erlbaum Associates. Reprinted by permission.

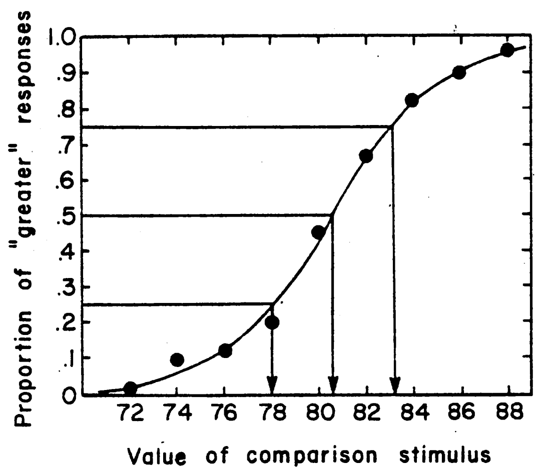

Figure 12. Determining Difference Threshold by the Method of Constant Stimuli. From Psychophysics: Method and Theory (p. 26) by G. A. Gescheider, 1976, New Jersey: Lawrence Erlbaum. Copyright 1976 by Lawrence Erlbaum Associates. Reprinted by permission.

Psychophysical Scaling

The problem of psychophysical scaling is summed up by Trygg Engen (1971) in the following statement:

> In order to understand behavior in relation to physical energies which may elicit or control that behavior, it is valuable to know the relationship between perceived (or response) magnitude and physical stimulus magnitude. Thus, psychophysical scaling involves the measurement of a sensation in relation to its initiating stimulus. Such methods are designed to generate

a numerical scale of sensory magnitude. (p. 48)

Psychophysical scaling can be approached from either direct or indirect methods. Both methods can be utilized to establish sensory scales in which numbers are assigned to the intensity of sensations. The first psychological scales were based upon discrimination ability. Fechner's JND, or the DL, as a unit of sensation is an example of an indirect approach to measuring sensation. Once the JND has been determined for a given stimulus and sensory modality, a scale of sensory magnitude can be developed using the mathematical formula derived from Fechner's law:

$$\psi = k \log \phi \qquad (3)$$

where ψ is the sensation magnitude, ϕ the intensity of the stimulus in units above absolute threshold, and k is a constant that depends upon the value of the Weber fraction (Gescheider, 1976, p. 9).

In contrast to the indirect method, the direct approach utilizes Steven's Power Law in establishing a psychophysical scale. With this approach, an individual is required to make a direct estimation of the relative strength of his/her sensations. Magnitude estimation is an example of a direct psychophysical scaling whereby the subject makes direct numerical estimations of the sensory magnitudes produced by various stimuli that are presented in random order (Stevens, 1975). The sensory attributes that have been scaled by means of magnitude estimation include: loudness of white noise; tonal volume; apparent brightness of visual stimuli; warmth and cold; apparent roughness of sandpaper; apparent length of lines; and intensity of salt solutions (Engen, 1971).

An example of instructions to the observer is provided by Stevens (1975):

> You will be presented with a series of stimuli in irregular order. Your task is to tell how intense they seem by assigning numbers to them. Call the first stimulus any number that seems appropriate to you. Then assign successive numbers in such a way that they reflect your subjective impression. There is no limit to the range of numbers that you may use. You may use whole numbers, decimals, or fractions. Try to make each number match the intensity as you perceive it. (p. 30)

Stevens and Marks (1971) investigated the relationship between stimulus intensity and body area for warmth sensations. Magnitude estimation was used to quantify warmth sensations for stimuli of various intensities above threshold and various areal extents. Stimuli were applied to the subjects' foreheads by the heat of a projector lamp and its intensity was varied by regulating its voltage. Areal extent of radiation was varied by the use of different sized aluminum masks placed between the lamp and the skin. During each session, a stimulus was presented to the subject every 30 seconds. Eighteen subjects made two magnitude estimations of each stimulus. They were asked to judge how warm each stimulus felt by assigning numbers to stand for the amount of apparent warmth. It was found that the degree of apparent warmth grows approximately as a power function of intensity level.

The magnitude functions for stimuli of various sizes are shown in Figure 13. The data presented in this figure are the geometric means of the magnitude estimates plotted on double logarithmic axes. Because the power function becomes a linear function when a logarithmic transformation is perfomed on each side of the equation (see Equation 2), the method of least squares can be used to find the constants log k and a in the power equation which best fit the data. The determination of the exponent of the power function, a, is then used in establishing the sensory scale (Gescheider, 1976).

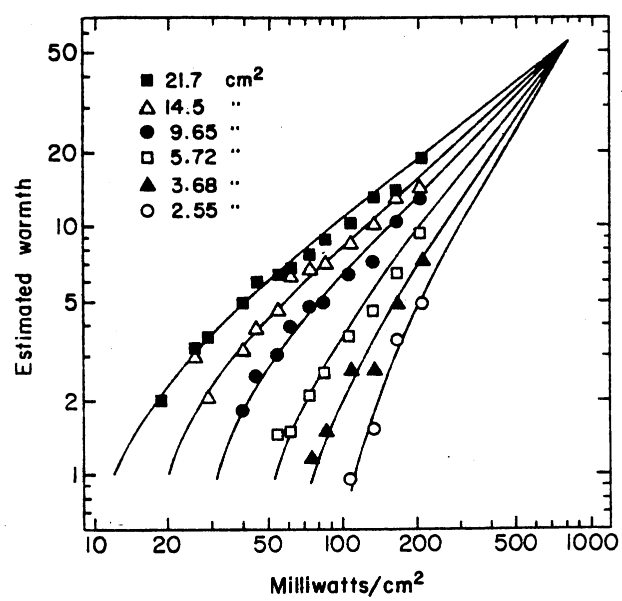

Figure 13. Magnitude Estimation of Warmth for Heat Stimuli of Various Areal Extents. From "Spatial Summation and Dynamics of Warmth Sensation" by J. C. Stevens, and L. E. Marks, 1971, Perception and Psychophysics, 9, p. 392. Copyright 1971 by the Psychonomic Society. Reprinted by permission.

Elder, Fisher, Armstrong and Hutchison (1984a) used a magnitude estimation approach to establish the relationship between subjective and objective measures of fabric softness. Words used to describe the various properties of fabric handle, such as softness, often have more than one meaning and this creates a problem for investigators. To clarify this point, the authors point out the difference between the meaning of the word "softness" to describe elderdown and the same word to describe silk. The word used to describe the sensation that each of the fabrics evoke is the same, but the meaning is different. Thus, a direct psychophysical approach utilizing magnitude estimates of softness was used to circumvent this problem of terminology.

In this study (Elder et al., 1984a) subjects were asked to use numbers to describe the softness of fabric samples that were compared to a standard fabric sample with a given softness of "12". Softness was defined by the investigators as "ease of yielding to pressure" (p. 37) and was measured objectively by compression tests on an Instron Tensile Tester. Their findings revealed that subjects were able to discriminate between levels of compressional softness by the method of magnitude estimation. The geometric means of the softness estimates were plotted against the compressional values in a log-log plot (Figure 14). The logarithmic values of softness and compression were found to correlate linearly, thus demonstrating that a power law governs the relationship.

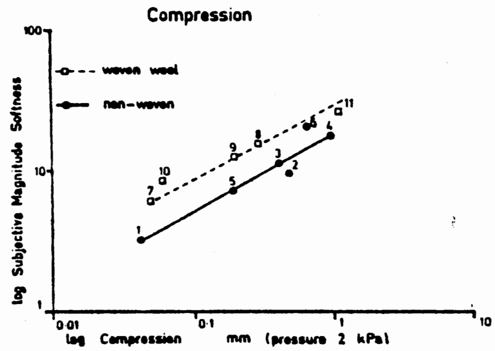

Figure 14. Logarithmic Relation Between Subjective Magnitude of Softness and Compression. From "Fabric Softness, Handle and Compression" by H. M. Elder, S. Fisher, K. Armstrong, and G. Hutchison, 1984, <u>Journal of the Textile Institute</u>, <u>75</u>, p. 42. Copyright 1984 by the Textile Institute. Reprinted by permission.

In another study of fabric handle by the same authors (1984b), the relationship between objective and subjective measures of fabric stiffness was investigated using a similar methodology. Fabric stiffness is an important property for a variety of end products, yet judgments of the property using words often result in confusion over meanings of the words. Elder et al. (1984b) point out the common use of such words as firm, harsh, crisp and boardy as synonymous with stiffness. Winakor and Kim (1980) used the word "flexible" as a polar adjective to the word "stiffness" in a semantic differential while Elder et al. (1984b) report that "not stiff" has been used to mean soft. It is clear that scaling techniques which utilize words to measure the property of fabric stiffness will not be reliable if the same meanings of the words used in the scales are not shared by all subjects.

In this investigation of fabric stiffness, magnitude estimates of candidate fabrics were made using the same procedure as in the previous study. An objective measure of stiffness, termed flexural rigidity, was made on a Shirley Cyclic Bending Tester. Geometric means of the magnitude estimates were plotted against the values of flexural rigidity in a log-log plot. Figure 15 demonstrates the linearity of the relationship and further evidence that sensations of fabric handle can be psychophysically scaled. These authors' work served as a foundation in the present study to undertake a psychophysical approach to the assessment of moisture sensation.

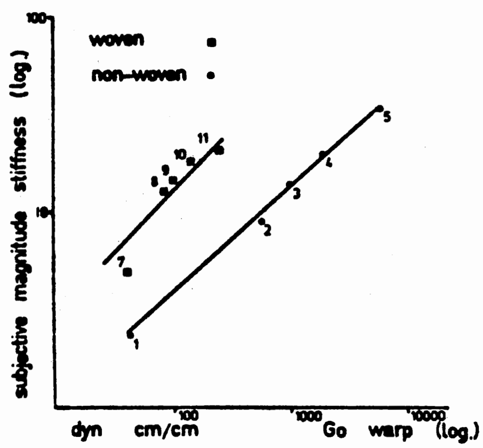

Figure 15. Logarithmic Relation Between Subjective Magnitude of Stiffness and Flexural Rigidity. From "Fabric softness, handle and compression" by H. M. Elder, S. Fisher, K. Armstrong, and G. Hutchison, 1984, Journal of the Textile Institute, 75, p.102. Copyright 1984 by the Textile Institute. Reprinted by permission.

CHAPTER III

MANUSCRIPT I

A Psychophysical Method to Assess Moisture Sensation in Clothing

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ABSTRACT

This study was undertaken to explore the feasibility of using psychophysical methods to assess one component of clothing comfort; that of moisture sensation. The psychophysical method of constant stimuli was used to assess the absolute and difference thresholds of moisture sensation in the upper back area of 12 female volunteers. 2 X 2 wetted fabric swatches applied to the skin served as the stimuli. The absolute threshold of moisture sensation was found to be 0.024 ml and the difference threshold was determined to be 0.0385 ml moisture. The psychometric functions for these determinations exhibited linear trends similar to those found in other areas of sensory testing utilizing psychophysical methods. It is anticipated that this study might provide the first step in a programmatic research effort toward the use of psychophysical methods to assess the contribution of moisture sensation to judgments of clothing comfort.

A Psychophysical Method to Assess Moisture Sensation in Clothing

Clothing comfort is an extremely complex subject. A recent overview and position paper regarding the conceptualization of clothing comfort [3] defined it as a "state of satisfaction indicating physiological, psychological, and physical balance among the person, his/her clothing, and his/her environment" (p. 14).

Given the breadth of factors that impact clothing comfort, it is not surprising that a wide variety of techniques have been utilized to measure it. In the assessment of how a garment/fabric is perceived by the senses of the wearer, psychological scaling techniques have been the most universal approach. In studies involving clothing comfort, investigators have most generally used various nominal and/or ordinal scales describing comfort sensations in terms of temperature, wetness, fabric hand, pleasantness, or comfort. Gagge, Stolwijk and Hardy [8] demonstrated that verbal scales of temperature, pleasantness and comfort were not the same and perhaps discriminated different sensations, thus emphasizing the importance of the choice of words for comfort scales.

In contrast to psychological scaling, psychophysical scaling involves the measurement of a sensation <u>in relation</u>

to its initiating physical stimulus. Physical stimuli of known intensities are used to evoke the sensations under investigation. With a psychophysical scale, the subject is asked to make the simplest possible judgments, such as to detect whether a sensation is present or absent or to decide whether two sensations are equal in intensity or different. These discriminations are among the most reliable judgments that people are capable of making [5].

The overall purpose of this study was to explore the feasibility of using psychophysical methods to assess one aspect of clothing comfort, that of moisture sensation. This particular aspect was chosen because it is often cited as the reason for dissatisfaction with the comfort properties of clothing. It is especially a problem with functional apparel because this type of clothing is frequently worn under stressful environmental conditions where moisture from the body, the atmosphere, or both, accumulates on the skin and within the clothing layers and results in wearer discomfort. The upper back area of the body was chosen as the site to be tested. This location was selected because it is one area of the body in which most clothing has high contact with the skin, regardless of garment design. Specifically, this study was undertaken to 1) determine the absolute threshold value of moisture sensation in subjects for one body location using one fabric type, and 2) to determine the difference threshold value of moisture sensation in the same.

Theoretical Framework

Psychophysics, the scientific study of the relationship between stimuli in the physical domain and sensations in the psychological domain [7,9] has provided the theoretical foundation for research in the sensory realm (olafactory, auditory, visual, taste) and is now beginning to receive attention from researchers in the apparel and textiles field [6]. Psychophysical determinations involve quantifying the relationship between variables belonging to continua from two completely different worlds, physical and psychological. The physical continuum is measurable in physical units representing a single change in some physical property, i.e., temperature, pressure, weight. Corresponding to the physical continuum is a psychological continuum that represents a well recognized sensation, i.e, warmth, softness, heaviness [10]. Psychophysical methods establish experimental conditions that maintain close correspondence between the sensation experienced and the judgment expressed [5].

The concept of a sensory threshold is integral to the study of psychophysical methods. The absolute "threshold" or limen (its Latin equivalent) is defined as the minimum value of a physical stimulus that will evoke a sensation. It is usually abbreviated as AL and represents the first landmark on the psychological continuum.

The difference threshold (DL) is the minimum amount of stimulus change required to produce a sensation difference, referred to as the just noticeable difference (JND) on the psychological continuum. E. H. Weber, a 19th century physiologist, determined that the stimulus intensity must be increased by a constant fraction of its value in order to be just noticeably different from its starting intensity. Weber's Law is written as :

$$\Delta\phi/\phi = c$$

where $\Delta\phi$ is the change in stimulus intensity required to be just noticeably different, and c is a constant fraction of the starting stimulus intensity [9]. Weber's prediction has been confirmed for a wide range of stimulus intensities and sensory modalities and has been shown to be an extremely useful calculation providing an index of sensory discrimination which can be compared across different conditions and modalities.

Three psychophysical methods have gained particular prominence in investigating the laws relating sensory experience to initiating physical stimuli. They are 1) the method of limits, 2) the method of constant stimuli and 3) the method of adjustment [5, 7, 9, 10]. All three methods demand that the subject respond simply "yes" or "no" or "greater" or "less" to sensations elicited by stimulus intensities under the control of the investigator. The method of constant stimuli, so named because the same stimuli are used throughout the experiment, was used in this study. Thorough discussion of the method of constant stimuli is given by D'Amato [5], Engen [7], Gescheider [9] and Guilford [10].

Method

Test Facility

All testing took place in an environmentally controlled Lab-Line Instruments, Inc., chamber at Oklahoma State University. Environmental conditions within the test chamber were specified to simulate a thermally comfortable environment for lightly clothed subjects at rest. ASHRAE Standard 55-1981 [2], which specifies environmental conditions for thermal comfort in the built environment, was examined to determine temperature and relative humidity chamber conditions. Based on information provided by the standard, the test chamber was maintained at 26°C ±1° and 50% RH ±2% and an air movement of less than .15 m/s.

Subjects

Fifteen female volunteers were recruited from a large undergraduate class to serve as test subjects. Subjects were required to meet weight criteria as specified by the Metropolitan Life Insurance Company for their given height and frame size. Subjects were also required to pass a pre-screening test before being accepted for participation in the study. This was conducted as described below because a preliminary investigation in an uncontrolled environmental laboratory had shown that some subjects could not detect the presence of moisture on their backs [12]. (See Appendix D). The final twelve test subjects ranged in age from 19 to 23 with a mean age of 19.5. Subjects were paid five dollars for the pre-screening and twenty dollars in addition to that fee for participation in the study.

Pre-screening

Mapping. Two areas of each subject's backs were mapped for moisture sensitivity. The upper back of each individual was studied to determine a 4 X 4 inch square area on which clothing would likely be in contact with the skin. The exact location of the square area depended on the configuration of bone, muscle, and fat in the scapular region of each individual. The area was generally identified as 2 to 3 inches down the spinal column from the top of the seventh cervical vertebrae (C7) and approximately 1 1/2 inch on either side of the column. 4 X 4 inch grids containing sixty-four 1/2 X 1/2 inch squares were transferred to the right and left scapular regions of the back (see Figure 16). Data sheets containing facsimilies of the grids were used to record each subject's responses (Appendix C).

Figure 16 about here

Fabric Stimuli. One hundred twenty-eight 1/2 X 1/2 inch fabric swatches of a 50/50 cotton polyester blend in a lightweight plain knit fabric structure (T-shirt fabric) served as the stimuli. The fabric swatches were wetted by pipetting 0.10 ml of water to each. Preliminary testing had shown that this amount of moisture was easily detected by the majority of subjects [12]. (See Appendix A).

Procedure. The subjects were asked to respond "yes" or "no" to whether they detected the presence of moisture on their back as each of the fabric stimuli was applied to a random location on the grid. Dry fabric swatches were applied intermittently. This pattern was repeated until moisture sensation in the 4 X 4 inch areas on the right and left scapulas had been assessed. Two of the fifteen subjects were excluded from the study because they did not sense moisture over a 2 X 2 inch area within the grid on one or both scapulas. Maps of those subjects who qualified for the remainder of the study were retained to determine placement of the experimental stimuli (Appendix H).

Stimuli

2 X 2 inch swatches were cut from the same fabric used in the pre-screening and served as the stimuli. The fabric

swatches were placed in small glass moisture-proof containers. All moisture was removed from the swatches according to Procedure 1 of ASTM Method D 2654 [1]. Distilled water at room temperature was applied to the surface of the fabrics inside of the uncapped glass containers with a Hamilton Microliter syringe. Prior testing revealed that the specimens did not gain moisture from the atmosphere in the ten seconds or less it took to wet the swatches and seal the container. The syringe was held at a constant angle and distance from the surface of the swatches.

Preparation of stimuli for AL determination. Fabric swatches containing amounts of moisture expected to be perceived little more than zero percent of the time on the one end, and less than 100 percent of the time on the other end served as the stimulus range. The amounts of moisture applied to the fabrics were chosen on the basis of prior testing [12]: 0.01, 0.02, 0.03, 0.04, and 0.05 ml. (See Appendix A).

Preparation of stimuli for DL determination. The fabric swatches prepared for the determination of the difference threshold (DL) included the following amounts of moisture: 0.03, 0.05, 0.07, 0.09, 0.11, 0.13, 0.15 ml. The middle value, 0.09 ml, served as the standard stimulus (St) to which each of the variable stimuli (Sv) were compared. A problem with one set of the fabric samples prepared for one subject resulted in discarding that subject's results.

Procedure

Subjects entered the test chamber and changed into shorts, socks, sneakers and a T-shirt constructed of the same stimulus fabric and altered to expose the right and left scapular regions of the back. The exact location of the 2 X 2 inch square areas on the right and left scapular regions defined for the presentation of stimuli was determined by studying the subject's pre-screening map which designated areas of moisture sensitivity (Appendix H). A template was used to mark the 2 X 2 inch square on each scapula.

Absolute Threshold. Prior to beginning testing, subjects were given an orientation to the process including the feel/sensation of a wet and dry fabric swatch. Subjects were reminded to respond to the sensation of moisture, not temperature. The absolute threshold of moisture sensation was determined by presenting the subject with each stimuli for five seconds. Subjects were asked to respond "yes" if they felt the presence of moisture and "no" if they did not. A total of thirty trials were made with each subject, including five trials with swatches containing no moisture.

Difference Threshold. For the determination of DL, the application of a pair of stimuli to the subject constituted a "trial". The standard stimulus (St) was presented to the subject for five seconds, and then the variable stimulus (Sv) was presented on the opposite scapula for five seconds. The order of presentation for each of the stimuli was alternated with the standard stimulus being presented first on one half of the trials. After the application of the second stimulus, the subject was asked to indicate whether the variable stimulus was "greater" or "less" than the standard stimulus. Thirty-five trials were made with each subject.

Results

Absolute Threshold. The percentage of "yes" responses was computed for each stimulus value (Appendix K) and converted to a z score (Table 2). The z scores were plotted on the Y axis against the corresponding stimulus values on the X axis to examine the psychometric function. If the psychometric function is an ogive (a cumulative form of the normal distribution) it will exhibit a linear function when transformed in this way [9].

Table 2 about here

The method of least squares was used to determine the psychometric function more precisely. The constants for the straight line equation that best fit the data ($Y = -.714016 + 30.005X$) were used to draw the line in Figure 17. The data in Figure 17 illustrate the closeness of the observed data points to those predicted by linear regression. Ninety-one percent of the total amount of variation in the data was accounted for by the linear regression of Y on X (r^2 =.91). The linear relationship was significant at the .01 level of probability, $F(1,3)$ = 29.616. Thus, the psychometric function for determining the absolute threshold of moisture sensation is an ogive as predicted by psychophysical theory [9].

Figure 17 about here

The absolute threshold value was determined by solving for X when z = 0 in the following equation:

$$z = a + bX \qquad \text{(Equation 1)}$$

and was found to be 0.024 ml. This represents the stimulus quantity that resulted in detection of moisture 50 percent of the time. Theoretically, it represents the first quantifiable landmark on the psychological continuum; the absolute threshold of moisture sensation.

<u>Difference Threshold</u>. A psychometric function for the determination of the difference threshold (DL) was obtained by converting the percentage of "greater" responses for each of the variable stimulus values (Appendix K) to z scores (Table 3) and plotting them against the variable stimulus intensities on the abscissa as shown in Figure 18.

Table 3 about here

The straight line equation that best fits the data was obtained by the method of least squares ($Y = -1.320498 + 17.5074X$) and was used to examine the psychometric function more precisely. Again, support for a linear relationship was highly significant ($p < .0004$) at $F(1,5) = 67.989$. The proportion of variance accounted for by the linear regression of Y on X was ninety-three percent ($r^2 = .93$).

Figure 18 about here

The Point of Subjective Equality (PSE) was determined by solving for x when z = 0 in Equation 1. Theoretically, the PSE represents the value of the variable stimulus which is perceived as subjectively equal to the standard stimulus [7]. This value was found to be 0.075 ml. The standard stimulus for this test was 0.09 ml. The difference between the PSE and the value of the standard stimulus is the constant error (CE) and reflects the effects of some uncontrolled factors which systematically influence the results. This is a typical phenomenon in psychophysical experiments which involve the successive presentation of two stimuli to two different locations [9]. Although the presentation of the standard and variable stimuli were randomized for each trial in this experiment, a CE of

-0.015 was found. Negative CE's are often found in experiments when the standard stimulus is presented first and are thus referred to as time errors. Time errors are reported to exist in most psychophysical experiments although their occurrence is not readily explainable [4].

The upper difference threshold (DLu) and lower difference threshold (DLl) were determined by solving for X when z = +.67 and -.67, respectively (see Equation 1). These z values represent the judgment of the Sv as greater than the St 75 and 25 percent of the time. The upper difference threshold represents the range of stimulus intensities from the PSE (0.075 ml) to 0.114 ml of moisture. The difference between these values, 0.039 ml, represents one DL above the standard stimulus. The lower difference threshold represents the range of stimulus intensities from 0.037 ml to the PSE. The value of 0.038 ml represents the value of the variable stimulus perceived to be one DL below the standard stimulus. The DLu and DLl were averaged to give an overall value for the difference threshold. Based on this calculation, the DL was found to be 0.0385 ml moisture. Thus, in order to detect a difference in moisture sensation when the standard is 0.09 ml, the stimulus would have to differ in moisture by 0.0385 ml.

Discussion

From a practical standpoint, the most basic questions to be answered by this type of investigation might be:

1) How much moisture must accumulate in the clothing before one senses it?
2) Once moisture is sensed, how much <u>more</u> moisture must accumulate before one perceives a difference in moisture sensation?
3) How does moisture sensation relate <u>quantitatively</u> to judgments of clothing comfort?

The absolute threshold of moisture sensation is a concept that can be used in the approach to answering the first question and is relevant in answering the other questions as well. The pre-screening showed evidence that there may be some areas on the surface of the body that are not as sensitive to moisture as others and this may differ greatly from person to person. Sensitivity to moisture in clothing has not been considered previously in clothing comfort investigations. Past studies have quantified the percentage of moisture in clothing and related these amounts to sensations of comfort, pleasure, etc., but the amount that must accumulate in the first place before one even detects it has not been quantified. It took 0.024 ml of moisture to be detected on a 2 X 2 inch square in this study. However, this does not imply that 0.024 ml on a

T-shirt or other garment can be detected. The absolute threshold of moisture sensation must be determined for each garment and area of the body of interest.

The difference threshold (DL) concept, in addition to the AL, may be used in answering the second question. The difference threshold of moisture sensation for the conditions tested in this experiment was determined to be .0385 ml of moisture. If the size of the DL is a linear function of stimulus intensity as Weber's law predicts, the difference threshold is $\Delta\phi/\phi$ (0.0385/0.09), or, 42.7% of the starting stimulus intensity at all intensity levels (Figure 19; Appendix L). Because Weber's fraction is a unitless measure, it serves as an index of sensory discrimination which can be compared across different conditions [4]. If one wanted to examine moisture sensitivity using different fabric stimuli, for example, the values of the Weber fractions could be compared to examine the effect of fabric stimulus on moisture sensitivity. Weber's fraction, however, should only be considered an approximation of differential sensitivity since it has been found to increase dramatically at levels of stimulus intensities near absolute threshold [9].

Figure 19 about here

Regarding the third question posed above, no attempt was made in this study to relate sensations of moisture to judgments of clothing comfort. Moisture sensation is only one of the many sensations that contribute to clothing comfort. However, there is a vast literature that attests to moisture sensation as a leading cause of discomfort in clothing. It is anticipated that this study might provide the first step in a programmatic research effort toward the investigation of the use of psychophysical methods to assess the contribution of moisture sensation to judgments of clothing comfort.

Summary and Recommendations

This study was undertaken to explore the feasibility of using psychophysical methods to assess one component of clothing comfort; that of moisture sensation in clothing. The psychophysical method of constant stimuli was used to assess the absolute and difference thresholds of moisture sensation in the upper back area of 12 female volunteers. 2 X 2 wetted fabric swatches applied to the skin served as the stimuli. The absolute threshold of moisture sensation was found to be 0.024 ml and the difference threshold was determined to be 0.0385 ml moisture. The psychometric functions for these determinations exhibited linear trends similar to those found in other areas of sensory testing utilizing psychophysical methods.

The results of this investigation are presented to the scientific community of clothing and textile researchers as empirical evidence that a psychophysical approach to quantifying moisture sensation is feasible. However, much further investigation is needed in order to provide more complete answers. For example, this study was limited to testing only one area of the body. Investigations of mechanoreceptors and thermoreceptors found in the skin show that the skin is not a uniform sensory surface. Its sensitivity is affected not only by the intensity of the stimulus but by the site of stimulation, areal extent and duration of stimulation as well [11]. Future investigations of moisture sensation could examine the effects of various levels of these factors on subject sensitivity.

For the conditions tested in this experiment, AL was found to be 0.024 ml of moisture and DL was found to be 0.0385 ml. However, the protocol for the determination of AL and DL calls for a range of response probabilities to the stimulus values chosen to span from a little more than 1% to a little less than 100%. In examining Table 2, it can be seen that the range reported is from 28% to 77% and thus did not capture the full range necessary for a definitive determination of absolute threshold. A similar problem exists for the difference threshold. The range reported for DL is 18% to 85% (Table 3). Since the absolute and difference thresholds are determined statistically, the values found for each must be considered with these limitations in mind. These results indicate that more extensive preliminary testing under identical environmental conditions are necessary in determining the stimulus value ranges for AL and DL determinations.

In this study, mapping of the back for sensitivity to moisture provided a pictoral representation of how sensitivity varied by site of stimulation. However, mapping performed under uncontrolled environmental conditions in a preliminary investigation revealed subjects to be less sensitive to the same moisture stimuli as was used in the present investigation [12]. (See Appendix D). Thus, environmental conditions of room temperature, humidity, and air movement must be controlled during all phases of testing so that these factors do not systematically influence the results of the investigation.

Another factor of interest which may have had some bearing on these results was that subjects were paid for their participation in this investigation while subjects in a preliminary investigation where less sensitivity was exhibited were not [12]. (See Appendix D). Another question to be answered in future investigations might be, "Did the reward of monetary payment have an effect on subject 'sensitivity' to the moisture stimuli?"

In conclusion, it appears that a psychophysical approach to the assessment of clothing comfort factors is one that is feasible. Although moisture sensation involves more than one sense modality (mechanoreception, thermoreception) as do most of the factors affecting clothing comfort, it appears that subjects' responses to the stimulation of wetted fabric swatches follows a trend that is similar to those found in other sense modalities investigated using psychophysical methods. Thus, there is much that can be gleaned from the psychophysical literature in assessing those sensations that are also of interest in studies of clothing comfort. Quantification of the relationship between moisture stimuli and the sensations they evoke will lead to answers to the questions posed above as well as to make an important contribution to methods of assessing clothing comfort factors.

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Stimulus Intensity (ml)*	Percentage of Detection	Z
.01	28	-.58
.02	55	.13
.03	55	.13
.04	70	.52
.05	77	.74

*Each level of stimulus intensity was presented five times to each of twelve subjects.

Table 2. Absolute Threshold of Moisture Sensation Data.

Variable Stimulus (Sv) Intensity (ml)*	Percentage "greater"	Z
.03	18	-.92
.05	38	-.31
.07	43	-.18
.09	53	.08
.11	80	.84
.13	88	1.17
.15	85	1.04

*Each variable stimulus (Sv) was compared to a standard stimulus (St) containing .09 ml water. Each of twelve subjects made five comparisons of each Sv to the St.

Table 3. Difference Threshold of Moisture Sensation Data.

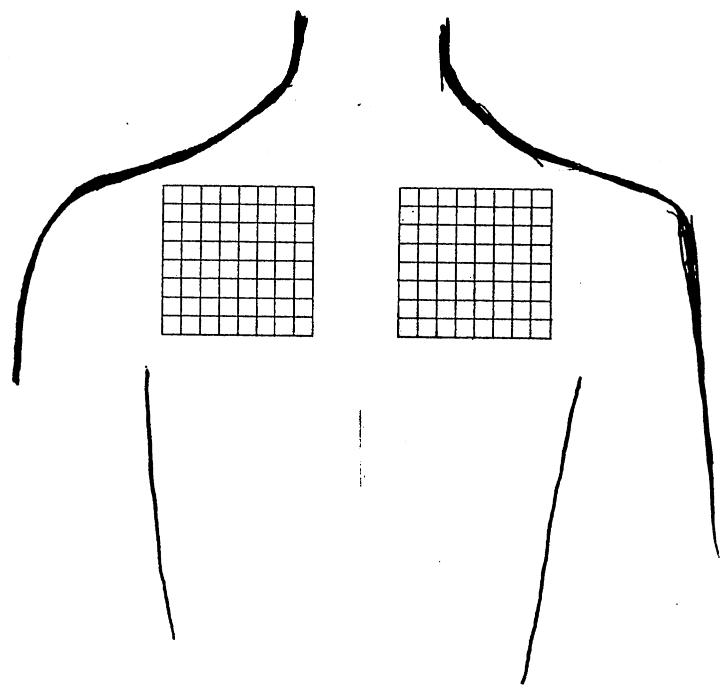

Figure 16. Mapping of the right and left scapular regions for sensitivity to moisture.

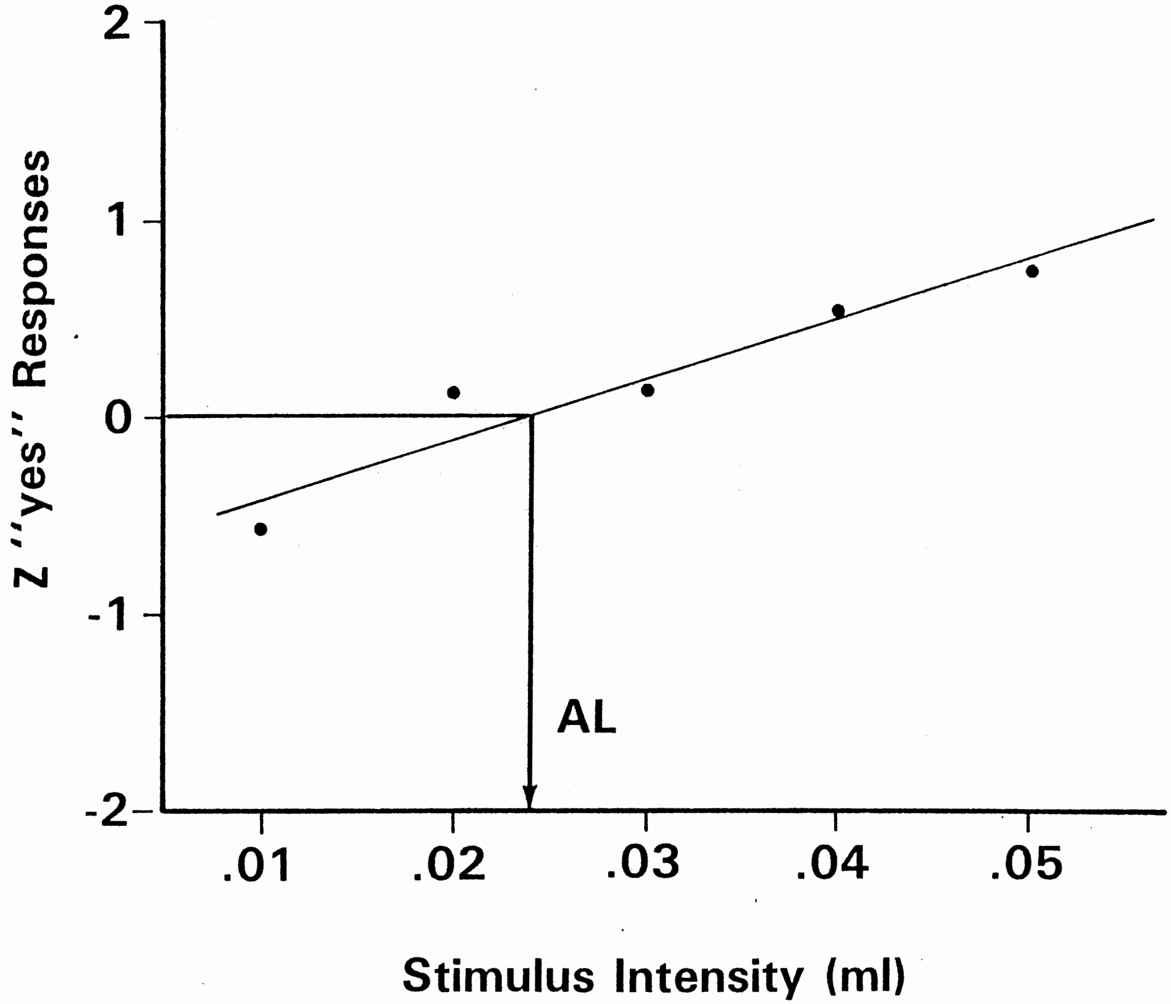

Figure 17. Psychometric Function for the Determination of the Absolute Threshold of Moisture Sensation

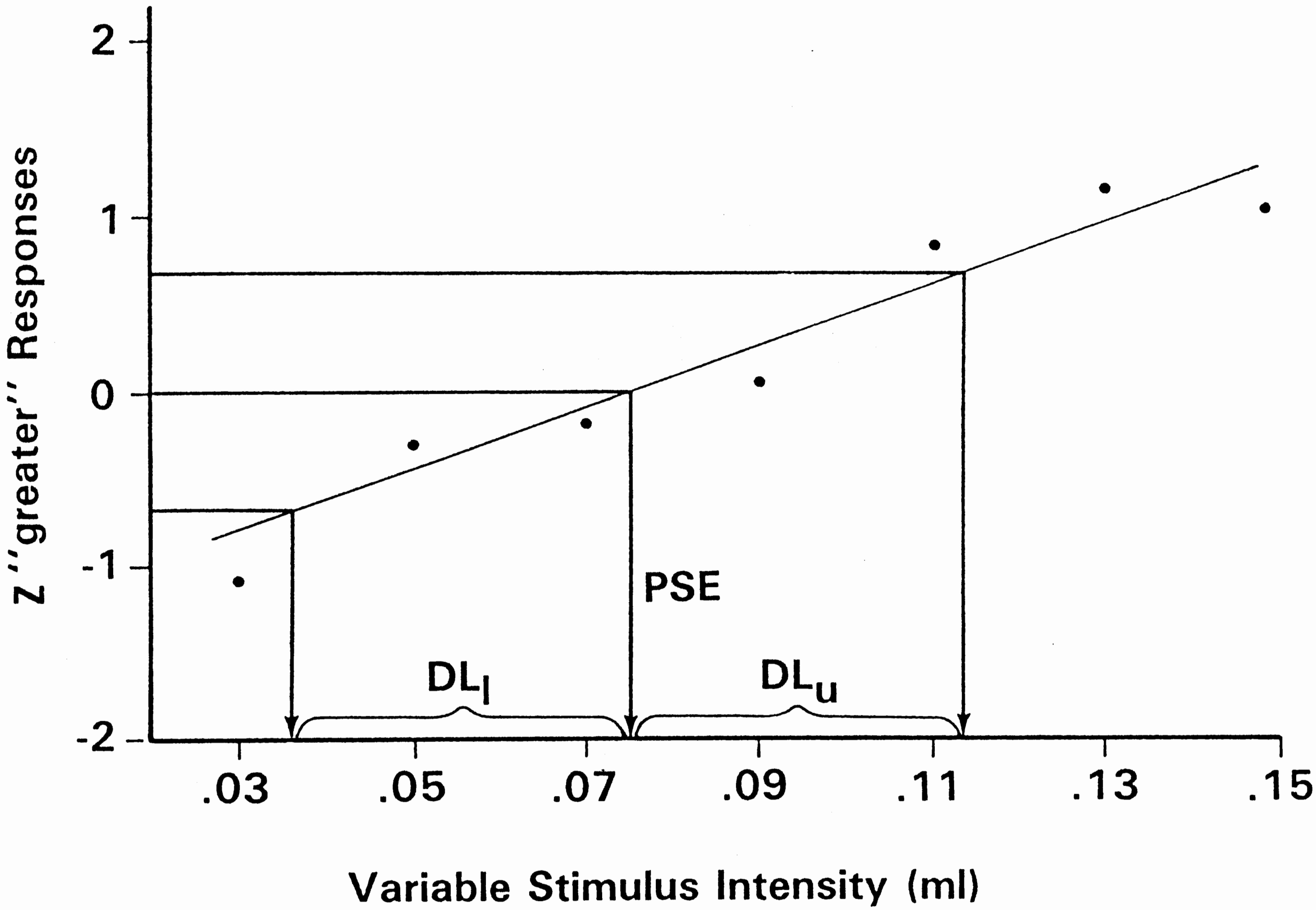

Figure 18. Psychometric Function for the Determination of the Difference Threshold of Moisture Sensation.

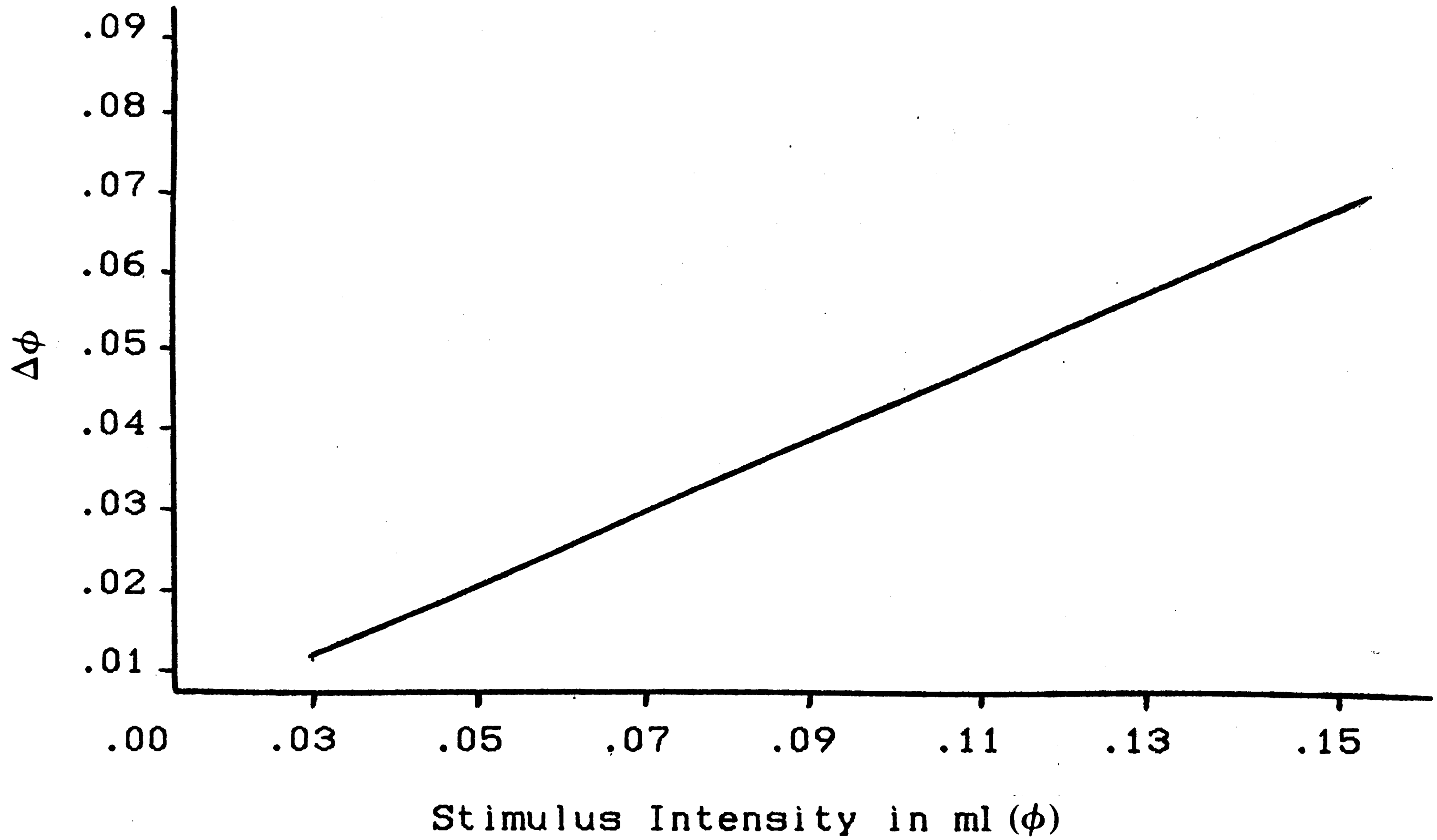

Figure 19. Relationship Between $\Delta\phi$ and ϕ According to Weber's Law.

CHAPTER IV

MANUSCRIPT II

A Magnitude Estimation Approach to the Assessment of Moisture Sensation

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ABSTRACT

The assessment of clothing comfort involves a multitude of factors that requires both objective and subjective evaluation. The purpose of this study was to use a magnitude estimation approach to assess the relationship between moisture stimulus intensity and moisture sensation in subjects for one body location and using one fabric type. Thirteen subjects used the method of magnitude estimation to assess the intensities of moisture stimuli applied to a 2 X 2 inch square on their backs. Results showed that subjects were in good agreement on the rank order of the moisture levels. Highly significant differences between magnitude estimates of the moisture levels were found. The relationship between moisture stimulus (ϕ) and moisture sensation (ψ) was found to demonstrate a psychophysical power function of the form: $\psi = 31.62\phi^{.53}$

A Magnitude Estimation Approach to the Assessment of Moisture Sensation

Definitions of comfort abound but there appears to be general agreement that the concept involves physiological, psychological, and physical factors [15, 3]. Because of the apparent multidimensional nature of comfort, it is extremely difficult, if not impossible, to quantify. There are, however, many ways in which factors relating directly or indirectly to clothing comfort can be assessed. These include objective methods to measure the physical and physiological components, and subjective methods to measure the psychological components.

While it is clear that a complete assessment of clothing comfort should involve both subjective and objective evaluations, correspondance between these evaluations is not always clear. For example, wearer trials are an important contribution to the assessment of clothing comfort and the only means by which both subjective and objective measures under the same experimental conditions can be assessed and compared. However, results are often equivocal with some finding high correspondence between the responses, and others finding none [12, 13, 19, 20, 21]. Often objective measures such as skin temperature, sweat rate, etc. are not good predictors of thermal comfort or thermal sensation. The problem lies with the fact that several stimuli are contributing to these subjective assessments and it is difficult, if not impossible, to isolate all of the relevant variables due to the numerous interactions occurring among them.

Since comfort is defined as a "condition of mind" [2], it implies that a quantitative assessment of it must involve the measurement of affectivity. This aspect of clothing comfort can only be assessed subjectively. The most widely used technique for this type of assessment is psychological scaling which involves a commonly recognized sensation or combination of sensations that are defined in the prospective rater's language of perception. Subjects are asked to respond to semantic differentials or Likert-type scales according to their sensory perceptions of "comfort", temperature, wetness, and/or other tactile properties of clothing. The disadvantage of using such scales as Hollies [10] pointed out, is that the subjects are not permitted free use of the language he or she considers appropriate to describe the attribute under study.

More recently, psychophysical methods have been utilized in an attempt to "build a bridge of understanding between objective and subjective measurement" of tactile properties of fabrics [7]. Psychophysical scaling involves the measurement of a single sensation <u>in relation to its</u>

initiating physical stimulus. Magnitude estimation is an example of direct psychophysical scaling whereby the subject is asked to make direct numerical estimates of the sensory magnitudes produced by the random presentation of defined physical stimuli [16]. Elder [6] and Elder, Fisher, Armstrong and Hutchison [4, 5] found that the relationship between objective and subjective measures of two fabric handle properties, stiffness and softness, demonstrated a power function that has been shown to govern a wide range of perceptual continua.

Many of the sensations that contribute to clothing comfort have direct physical correlates; yet a psychophysical approach to scaling these sensations is often overlooked. Moisture sensation in clothing as a result of heat stress is probably one of the leading factors contributing to clothing discomfort. The purpose of this study was to use a magnitude estimation approach to assess the relationship between moisture stimuli and moisture sensation in an effort toward psychophysical scaling of moisture sensation.

Materials and Methods

Independent Variable

The test fabric was a blend of 50/50 cotton and polyester in a plain knit structure (t-shirt knit). 2 X 2 inch swatches were cut from the test fabric and were prepared in the following manner to serve as the stimuli. First, they were placed in small glass moisture-proof containers and all moisture was removed from the swatches according to Procedure 1 of ASTM Method D 2654 [1]. Secondly, distilled water at room temperature was applied to the surface of the fabrics with a Hamilton Microliter syringe. The syringe was held at a constant angle and distance from the surface of the swatches.

The following amounts of water (in ml) were added to the fabric swatches: 0.04, 0.06, 0.08, 0.10, 0.12, 0.14, 0.16. Several considerations guided the selection of these intensities. First, the size of the swatch limited the amount of moisture that could be applied and held constant without moisture leaving the swatch and condensing inside of the container. Secondly, the amounts had to be above the subjects' absolute threshold of moisture sensation which was determined in an earlier component of the study [17, 18]. Thirdly, for ease of analysis and because there were no other studies on which to base this one, the decision was made to use equal stimulus spacing. Stimulus range and spacing have been shown to influence the results of scaling experiments but their overall effect is not large and further, does not influence sensory-physical relations [14].

One set of swatches was prepared for each of the subjects containing five replications of the seven variable stimuli. Five additional swatches containing .10 ml were prepared for each subject to serve as the standard stimuli to which all variable stimuli would be compared.

Test Facility

All testing took place in an environmentally controlled Lab-Line Instruments, Inc., chamber at Oklahoma State University. Environmental conditions within the test chamber were specified to simulate a thermally comfortable environment for lightly clothed subjects at rest [2]. The temperature was maintained at 26°C ±1°, the relative humidity at 50% ±2% and the air movement was less than .15 m/s.

Dependent Variable

The assessment of moisture sensation was made by the method of magnitude estimation. Each subject was presented with a standard stimulus containing 0.10 ml of water and assigned a number of "10". The wetted fabric swatches were applied to an area of the upper back previously tested for moisture sensitivity [18]. (See Appendix H). Subjects were asked to make magnitude estimations of each of the variable stimuli relative to the perceived magnitude of the standard stimulus.

Experimental Design and Sample

A single factor repeated measures design with five replications was used. Treatment levels within each replication were randomized. Thirteen college females, ages ranging from 19 to 23, participated in this study. All subjects underwent a sensory mapping procedure to assure sensitivity to moisture on the areas of the back to be tested before being allowed to participate. The protocol followed for moisture sensitivity mapping is detailed elsewhere [17, 18]. (See Appendix C).

Test Protocol

Subjects entered the environmental chamber and changed into shorts, socks, sneakers, and a T-shirt made of the same fabric as the test stimuli and modified to expose the right and left scapular regions of the back. They signed a consent form (Appendix G), filled out a brief questionnaire eliciting demographic data (Appendix E), and were given a brief orientation to the investigation. Testing for the determination of the absolute and difference thresholds of moisture sensation was performed first and is reported elsewhere [17, 18]; therefore, subjects were in the chamber for at least one hour before this testing began.

The standard stimulus, containing 0.10 ml of water, was presented first for approximately three seconds and assigned a number of "10". The seven variable stimuli were presented to the subject, each for about three seconds, in succession following the standard stimulus at the rate of aprroximately two per minute. Directions to the subject were based on Stevens [16] and given as follows:

> I am going to present to you a series of fabric swatches with varying amounts of moisture on them in an irregular order. I want you to tell me how moist they feel by assigning numbers to them. I will begin by placing a standard fabric swatch on your back which I will call "10". After I remove the swatch and wipe your back, I will place another fabric swatch on your back. Your task will be to estimate the amount of moisture on the swatch in relation to the standard. For example, if the swatch feels more moist, assign a number greater than ten; if it feels less moist, assign a number less than 10 such that it matches the intensity as you perceive it. Use whatever numbers seem appropriate to you, such as a fractions, decimals or whole numbers. (p. 30)

Moisture on the back remaining after the presentation of each stimulus was removed with clean, dry toweling. Each of the subjects made thirty five magnitude estimates of perceived moisture.

Results

The geometric means of the five magnitude estimates made by each subject for each of the fabric stimuli are presented in Table 4. The use of geometric as opposed to arithmetic means is necessitated with magnitude estimation data to prevent an aberrant judgment from casting too much of an influence on the results [14]. Level of agreement between subjects on the rankings of the magnitude estimates, indicated by Kendall's coefficient of concordance was found to be moderately high, accounting for 66% of the total variance in the rank sums (Table 5).

Table 4 about here

Table 5 about here

The form of the relationship between stimulus intensity and sensation magnitude is the essence of psychophysics. Therefore, trend analysis (also called the method of orthogonal polynomials) using the geometric mean data was performed to quantitatively assess the shape of the function relating the dependent and independent variables [11]. Linear, quadratic, and cubic trend components were assessed for their potential contribution to the function relating moisture sensation to moisture stimuli. Results are shown in Table 6 and reveal that the linear trend component accounted for over 98% of the overall treatment variability observed in the experiment.

Table 6 about here

Trend analysis also revealed the overall treatment effects to be highly significant (see Table 6). Pairwise comparisons were made on the entire set of means using the Student Newman Keuls procedure to determine where exact differences between the treatment effects occurred. The results are shown in Table 7 and indicate that differences were divided into three groups of stimulus intensities that were significantly different from each other at the .05 level of confidence: 1) 0.04, 0.06 and 0.08 ml, 2) 0.10, 0.12, and 0.14 ml, and 3) 0.14 and 0.16 ml.

Table 7 about here

To determine whether the relationship between moisture and moisture sensation demonstrated a power function as predicted by psychophysical theory [8, 9, 16], the magnitude estimates (ϕ) were plotted against the moisture stimulus values (ψ) in log-log coordinates (Figure 20). The method of least squares, where log ψ is Y and log ϕ is X, was used to find the constants for the straight line equation that best fit the data. The regression of ψ on ϕ

explained ninety-six percent of the total variance (r^2=.96). Thus, the power function relating sensation magnitude and stimulus intensity as proposed by Stevens [16] applies to the relationship between moisture and moisture sensation as follows:

$$\psi = 31.62\phi^{.53}$$

where 31.62 is a constant of proportionality based on the measurement units of ψ and ϕ; and the exponent .53 reflects the rate at which sensation magnitude grows with respect to the stimulus.

Figure 20 about here

Discussion and Conclusions

There are at least two major advantages to the use of magnitude estimation in investigations of clothing comfort. First, the problem of choosing the number of categories or points on a scale from which subjects are to guage their sensations is alleviated. With magnitude estimations, subjects use their own "scale" by matching numbers of their own choosing to the intensity of the sensation their are experiencing. Secondly, and closely associated with the first advantage, is that the use of magnitude estimation eliminates the problem of using words to name the intensities of sensations or to name polar adjectives of comfort sensations. The choice of words for psychological scaling has been a particular problem in the area of fabric handle where it is unlikely that words such as crisp, sleazy, firm and silky have shared meanings among nonexpert raters.

In this study, thirteen subjects used the method of magnitude estimation to judge a range of moisture stimuli that was applied to a 2 X 2 inch square of fabric on their backs. Subjects were in good agreement on the rank order of the moisture levels in spite of the fact that they used their own sense of numbers with which to rate the perceived intensities of moisture sensation. It was observed by this investigator that subjects concentrated very hard in guaging the intensities of stimuli and in matching numbers to reflect those perceived sensations. It is possible that the increased level of subject involvement that this method demands may result in a more sensitive measure than those methods requiring subjects to simply circle a number or check a box.

Highly significant differences were found between the magnitude estimates of the moisture stimuli. Multiple comparisons showed that differences occurred between three groups of magnitude estimates. This information is useful in determining the spacing of stimuli for future investigations.

A psychophysical power function has been shown to apply to numerous perceptual continuua that involve variations in sensory magnitude [8, 9, 16]. In this study, the relationship between moisture stimulus and moisture sensation was found to demonstrate a power function. The exponent found in this study, .53, means that if the stimulus magnitude were increased by a factor of 10:1, or one logarithmic unit, the corresponding increase in response magnitude would only be .53 expressed in logarithmic units, or a factor of 3.4:1. Thus, for the stimulus conditions tested in this study, moisture sensation grows slowly as moisture stimulus intensity is increased.

Exponents of the power functions found in other psychophysical studies range from .33 for brightness and loudness to 3.5 for electric shock on the fingertip [16]. It should be pointed out that values of exponents obtained for various sensory modalities are dependent on stimulus conditions. In fact, examining changes in the power function exponents as stimulus conditions are changed is one strategy for learning more about the sensory mechanisms involved in the sensation of moisture. For example, what impact does changing the size of the fabric stimulus have on the value of the exponent? How do differences in fiber, yarn and fabric structures, fiber contents, ranges of moisture intensity, site, size and duration of stimulation, etc., affect the value of the exponent?

If it can be assumed that magnitude estimation data provide a direct measure of sensation magnitude [9], direct psychophysical scaling provides the clothing comfort investigator with an extraordinarily useful tool. The method offers the advantage of maintaining closer correspondance between objective and subjective measures over the usual psychological scaling methods. The results of this investigation suggest that the method of magnitude estimation can be used to measure the subjective assessment of moisture sensation. For this and other clothing comfort sensations that have direct physical correlates and for which there exist objective methods of quantifying, it is suggested that magnitude estimates of the intensities of those stimuli can provide quantitative assessment.

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Moisture Stimulus (ml)	.04	.06	.08	.10	.12	.14	.16
Subject							
1	6.38	7.07	8.91	9.51	14.36	13.53	13.44
2	7.34	7.50	8.10	10.76	10.58	13.92	13.07
3	6.73	5.45	6.80	11.47	8.64	8.86	14.86
4	6.85	5.33	5.50	7.39	17.49	16.53	13.27
5	6.47	6.58	6.40	10.03	7.36	9.64	9.94
6	3.10	2.76	4.55	8.31	5.04	12.11	12.84
7	6.18	6.70	9.29	7.04	9.37	10.70	13.22
8	6.23	8.31	11.19	8.50	8.08	10.79	11.33
9	8.88	9.68	10.43	10.77	13.16	12.53	12.47
10	5.19	5.57	8.77	9.89	11.13	8.35	10.57
11	4.10	6.70	5.09	10.56	7.20	5.41	16.41
12	5.99	6.63	8.77	8.65	8.61	9.92	8.36
13	6.94	8.80	7.26	11.49	10.89	12.88	13.34
Grand Mean	6.18	6.70	7.77	9.57	10.15	11.17	12.55

[a]Each subject made five estimates of each stimulus intensity level

Table 4. Geometric Means of Magnitude Estimates

Moisture (ml)	Geo. Mean	Std Dev	Mean Rank Sums[a]
.04	6.18	1.44	1.38
.06	6.70	1.75	2.15
.08	7.77	2.05	3.23
.10	9.56	1.48	4.85
.12	10.15	3.35	4.92
.14	11.17	2.86	5.46
.16	12.55	2.10	6.00
Total	9.15	3.09	

[a]W=.66, χ^2=51.66 with 6 df, p<.0000

Table 5. Geometric Mean Magnitude Estimates of Moisture Stimuli

Source	SS	df	MS	F
Between Groups	435.13	6	72.52	14.36[a]
Linear	429.01	1	429.01	84.95[a]
Quadratic	.41	1	.41	<1
Cubic	.48	1	.48	<1
Within Groups	424.22	84	5.0503	
Total	859.35	90		

[a] $p<.0000$

Table 6. Summary of Trend Analysis

Moisture Stimuli (ml)	.04	.06	.08	.10	.12	.14	.16
Mean Magnitude Estimates[a]	6.18	6.70	7.77	9.57	10.15	11.17	12.55

[a]Means connected by the same line are not significantly different at $p<.05$

Table 7. Multiple Comparisons of Mean Magnitude Estimates

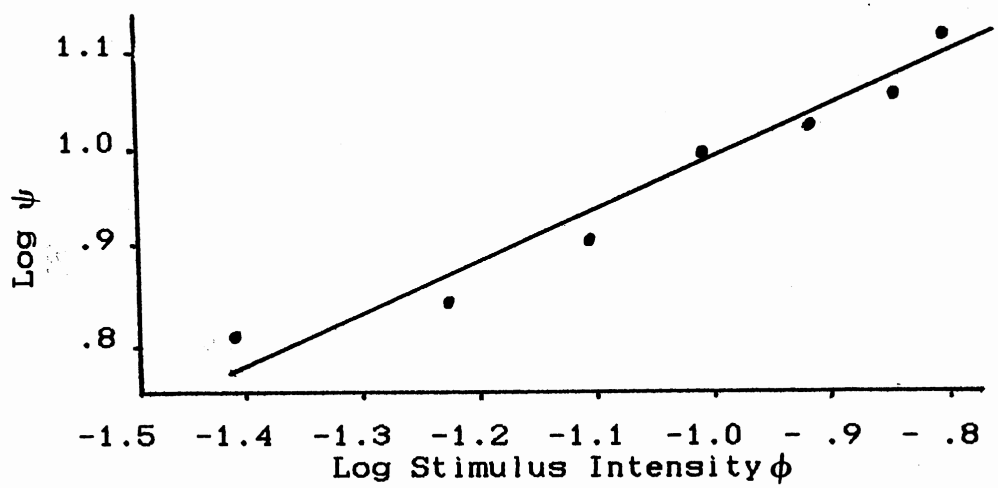

Figure 20. Log Log Plot of Magnitude Estimates (ψ) of Moisture Stimuli (φ)

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

Clothing comfort is an extremely complex phenomenon. Although it has been a topic of interest to researchers for over fifty years, there is yet no universal definition of it. The many factors impacting clothing comfort are still being elucidated by researchers in a variety of disciplines. The most recent definition broadly characterizes clothing comfort as "a state of satisfaction indicating physiological, psychological and physical balance among the person, his/her clothing, and his/her environment" (Branson & Sweeney, 1987, p. 14).

There have been several approaches to assessing clothing comfort and/or the variables contributing to it. However, methods of assessment for the physiological and physical components have advanced beyond those for the psychological. Approaches to the subjective assessment of clothing comfort are many and varied. Yet, it is often the sensations that clothing evokes in wearers, and thus "subjective", that are responsible for a wearer's rejection of, or dissatisfaction with, an item of apparel.

Functional apparel designed for one's protection from a stressful or hazardous environment, or intended for wear during intense physical activity (Watkins, 1984), has intensified the need for methodologies that can be used to assess the critical factor of thermal comfort in clothing. One of the most persistent problems with functional apparel is moisture build-up within the clothing and microclimate. Present methods of assessing the sensations associated with these conditions generally include descriptors of the sensations with an accompanying intensity scale.

The overall purpose of this study was to investigate the use psychophysical methods as a means of quantifying moisture sensation in clothing. Psychophysical methods establish experimental conditions that maintain close correspondence between the sensation experienced and the judgment expressed (D'Amato, 1970). It was the intention of this investigator that the psychophysical methods detailed in this study, could also apply to other clothing comfort sensations. However, the methods can only be applied to assess those sensations that are elicited by intensities of a physical stimulus that can be objectively measured.

Moisture is a complex stimulus; there is no single end organ for sensing it. Moisture is sensed through a combination of both mechanoreceptors and thermoreceptors in the skin. Thus, the practical problem of determining how one senses and assesses moisture in clothing had to be broken down into a more manageable problem. It was decided that a psychophysical approach to assessing moisture sensation would be limited to one area of the body and using one fabric type. The upper back area of the body was chosen as the site to be tested. This location was chosen because it is one area of the body in which most clothing has high contact with the skin, regardless of garment design.

Objectives

Three objectives guided the conduct of this investigation. The first two objectives were undertaken to determine the absolute and difference threshold of moisture sensation, respectively, in subjects for one body location and using one fabric type. The absolute threshold is the minimum value of a physical stimulus that will evoke a sensation. The difference threshold is the minimum amount of physical stimulus change required to produce a sensation difference. The third objective of the study was to use the method of magnitude estimation to assess the relationship between moisture stimuli and moisture sensation in subjects for one body location using one fabric type. Magnitude estimation is a method of direct psychophysical scaling whereby the subject makes direct numerical estimations of the sensory magnitudes produced by various intensities of a stimulus that are randomly presented to the subject (Stevens, 1975).

Test Facility, Subjects

All testing took place in a climate controlled chamber where conditions were maintained for a thermally comfortable environment for subjects lightly clothed and at rest (26°C ±1 , 50% ±2% RH, air movement <.15 m/s). Preliminary testing had shown that some individuals could not detect the presence of moisture on their backs so a pre-screening for moisture sensation was required of all subjects before they could participate in the study. The pre-screening resulted in the elimination of two of the fifteen subjects tested. Thirteen college females with ages ranging from 19 to 23 participated in this study. However, a problem with a set of stimuli prepared for the absolute and difference threshold determinations prevented the data of one of the subjects from being used in the analysis.

Fabric Stimuli

The test fabric was a 50/50 cotton and polyester blend in a plain knit fabric structure (t-shirt knit). 2 X 2 inch fabric swatches were wetted with known amounts of moisture and applied to a moisture sensitive area (as demonstrated by the pre-screening) on the scapular regions of the back.

Psychophysical Methods

The psychophysical method of constant stimuli was used to assess the absolute and difference thresholds (AL, DL) of moisture sensation in the upper back area of 12 female volunteers. To meet the third objective of the overall investigation, the psychophysical method of magnitude estimation was used to assess the relationship between moisture and moisture sensation.

Absolute Threshold. The following amounts of moisture were applied to the 2 X 2 inch fabric stimuli for the determination of the AL: 0.01, 0.02, 0.03, 0.04, 0.05 ml. Five replications of this range of stimuli, with stimuli randomized within each replication, were presented to the subject. Subjects responded "yes" if they detected the presence of moisture in the five seconds that each stimuli was presented, or "no" if they did not.

Difference Threshold. The following amounts of moisture were applied to the 2 X 2 inch fabric stimuli for the determination of the DL: 0.03, 0.05, 0.07, 0.09, 0.11, 0.13, 0.15 ml. The amount of 0.09 ml served as the standard stimulus to which each of the stimuli in the range were compared. Five replications of this range, with stimuli randomized within each replication, were presented to the subject. Each stimulus was paired with the standard stimulus (0.09 ml) for successive presentation to the subject who responded "greater" or "less" to the perceived intensities of the variable stimuli.

Psychometric functions of the responses to the presentation of stimuli for the determination of AL and DL were used to determine those values. For the absolute threshold, the "yes" responses, indicating moisture detection, were graphed against the physical values of the moisture stimuli. For the difference threshold, "greater" responses were graphed against the physical values of the variable stimuli.

Magnitude Estimation. The following amounts of moisture (in ml) were added to the fabric swatches: 0.04, 0.06, 0.08, 0.10, 0.12, 0.14, 0.16. Five replications of this range of moisture stimuli, with stimuli randomized within each replication, were prepared for each subject. Each subject was presented with a standard stimulus containing 0.10 ml of water and assigned by the investigator a number of "10". Subjects were asked to make magnitude estimations of each of the variable stimuli relative to the perceived magnitude of the standard stimulus.

The geometric means of the magnitude estimates for each of the moisture stimuli were calculated and used in the analysis to quantify the relationship between the objective and subjective assessment of moisture.

Findings

Absolute Threshold. The absolute threshold of moisture sensation is operationally defined as the stimulus value that is detected on 50 percent of its presentations to the subject. The absolute threshold of moisture sensation in a 2 X 2 inch area of the back was found in this study to be 0.024 ml of moisture. The psychometric function for this determination was found to exhibit an ogive which is predicted by psychophysical theory (Gescheider, 1976).

Difference Threshold. The variable stimulus values that were judged "greater" than the standard stimulus (0.09 ml) on 25 and 75 percent of their presentations to the subject were averaged to give the difference threshold. The difference threshold of moisture sensation in the upper back area of the back tested was determined to be 0.0385 ml of moisture. Similar to the AL finding, the psychometric function for the DL determination was found to exhibit the ogive curve which is predicted by psychophysical theory (Gescheider, 1976).

Weber's law (Engen, 1971; Gescheider, 1976) predicts that the size of the difference threshold is a linear function of stimulus intensity. The Weber fraction was determined by the ratio of the difference threshold to the standard stimulus value used in its determination (Coren, Porac, and Ward, 1978). The Weber fraction was found to be 0.0385/0.09, or 42.7% of the starting stimulus intensity at all intensity levels. Because it is a unitless measure, it can be used as an index of sensory discrimination which can be compared across different conditions and different modalities (Engen, 1971; Gescheider, 1976).

Magnitude Estimation. Using the method of magnitude estimation to assess the perceived intensities of moisture stimuli, subjects were able to discriminate between the moisture levels. Three groups of moisture stimuli were responsible for the highly significant treatment effect: 1) 0.04, 0.06 and 0.08 ml; 2) 0.10, 0.12, 0.14 ml; and 3) .14 and .16 ml moisture. The analysis also revealed that subjects were in good agreement on the rank order of the moisture intensities. Further, the power function relating sensation magnitude and stimulus intensity as proposed by Stevens (1975) was found to apply to the relationship between moisture and moisture sensation as follows:

$$\psi = 31.62\phi^{.53}$$

where 31.62 is a constant of proportionality based on the measurement units of ψ and ϕ; and the exponent .53 reflects the rate at which sensation magnitude grows with respect to the stimulus.

Limitations

1. This study was limited to thirteen female college students, aged 19 to 23, at Oklahoma State University, in the fall of 1988.

2. Students were recruited through an announcement by the investigator to a large undergraduate class which was on the general education curriculum and were paid $25 total for their participation. This method of acquiring a sample and the size of the monetary payment may have influenced the subjects responses to the subjective measures.

3. This study was limited to testing one small area of the upper back with one type of fabric. Investigations of mechanoreceptors and thermoreceptors found in the skin show that the skin is not a uniform sensory surface. Its sensitivity is affected not only by the intensity of the stimulus but by the site of stimulation, areal extent of stimulation, and duration of stimulation as well. Therefore, findings can not be generalized to other areas of the body or to other fabric stimuli or sizes of fabric stimuli. Furthermore, they cannot be generalized to durations of stimulation different from those used in this investigation.

4. The values for the absolute threshold and difference thresholds of moisture sensation were calculated despite the fact that responses to the moisture stimuli did not

capture a range starting near 1% and ending near 100% as called for by the protocol in the determination of each.

Implications

It is anticipated that clothing comfort will continue to be a topic of interest to researchers in a variety of disciplines. The findings of this study have implications for investigators planning to assess subjective components of clothing comfort. If one's intention is to assess clothing comfort sensations that can be evoked by physical stimuli, it would behoove the investigator to have an understanding of psychophysical methods. Such methods offer the advantage of maintaining closer correspondance between objective and subjective measures over the usual psychological scaling procedures.

Findings from this study suggest that a psychophysical approach to the assessment of clothing comfort factors is one that is feasible. Although moisture sensation involves more than one sense modality (mechanoreception, thermoreception) as do most of the factors affecting clothing comfort, it appears that subjects' responses to the stimulation of wetted fabric swatches follows a trend that is similar to those found in other sense modalities investigated using psychophysical methods.

In this study, mapping of the back for sensitivity to moisture provided a pictoral representation of how sensitivity varied by site of stimulation. However, mapping performed under uncontrolled environmental conditions revealed subjects to be less sensitive to the same moisture stimuli. Thus, the importance of environmental conditions such as room temperature, humidity, and air movement, is evidenced by the impact these factors have on moisture sensation. It is likely that their impact is as dramatic for other clothing comfort sensations as well.

The results of this investigation relative to the use of magnitude estimation, suggest that this method can be used to measure the subjective assessment of moisture sensation. One advantage of using this method is that the investigator is alleviated of the difficult task of choosing the number of categories or points on a scale from which subjects are to rate the intensities of sensations. With magnitude estimation, subjects use their own "scale" by matching numbers of their own choosing to the perceived intensity of the sensation. Another advantage of using the method of magnitude estimation, and closely associated with the first, is that its use eliminates the problem of using words to name the sensations, or intensities of sensations, or polar adjectives of comfort sensations. The choice of words for psychological scaling has been a particular problem in the area of fabric handle where it is unlikely that words such as crisp, sleazy, firm and silky have shared meanings among nonexpert raters.

A third possible advantage to using the method of magnitude estimation is suggested by this investigator as a result of observations made during the testing sessions. It appeared that subjects enjoyed using the method of magnitude estimation and concentrated very hard in gauging the intensities of moisture stimuli and in matching numbers to reflect those perceived sensations. It is possible that the increased level of subject involvement that this method demands may result in a more sensitive measure than those methods requiring subjects to simply circle a number or check a box.

Lastly, if it can be assumed that magnitude estimation data provide a direct measure of sensation magnitude (Gescheider, 1976), direct psychophysical scaling provides the clothing comfort investigator with an extraordinarily useful tool. Many of the sensations that contribute to clothing comfort have direct physical correlates; yet a psychophysical approach to scaling these sensations is often overlooked. For the sensation of moisture and other clothing comfort sensations that have direct physical correlates and for which there exist objective methods of quantifying, it is suggested that magnitude estimates of the intensities of those stimuli can provide quantitative assessment.

Recommendations

1. It is recommended that future work be directed toward examining moisture sensitivity using various:

    a) areas of the body in which clothing has high contact

    b) fabric stimuli (fiber, yarn, fabric constructions)

    c) moisture levels

    d) duration of stimulation (>5 seconds)

For example, what is the impact of any of the above on the Weber fraction, and/or the value of the exponent for the power function relating moisture and moisture sensation?

2. It is recommended that an investigation be conducted to examine the influence of age, sex, and physical fitness on moisture sensation.

3. It is recommended that different environmental conditions (air temperature, relative humidity, air movement) be examined for their impact on moisture sensation.

4. It is recommended that the effect of monetary payment on the sensitivity of subjects to moisture stimuli be examined.

5. It is recommended that the sensory mechanisms underlying moisture sensation (hot/cold, pressure/touch receptors) be investigated. For example, how does

temperature of the moisture stimulus affect moisture sensation? How does the weight of the fabric stimulus affect moisture sensation?

6. Less concrete, but of practical importance, it is recommended that a psychophysical approach be undertaken to:

a) determine the absolute and difference thresholds of moisture sensation in a given garment, and

b) determine how the sensation of moisture contributes to the overall judgment of clothing comfort.

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APPENDIXES

APPENDIX A

PILOT STUDY #1

The purpose of this pilot study was to define the mechanics and determine the feasibility of assessing the absolute threshold (AL) and difference threshold (DL) of moisture sensation by the method of constant stimuli. Experimentation covered the gamut from determining the size of the fabric swatch to mapping a site on the body for sensitivity to moisture.

Methods and Materials

Stimuli

Fabric. The fabric chosen for testing moisture sensation was a 50/50 cotton polyester in a light-weight knit fabric structure. This particular fabric was chosen for two reasons. First, since the subjects to be tested were selected from a university population, this fabric was appropriate because wearing apparel made of it (i.e., t-shirts) is popular with college students and would therefore be familiar to them. Secondly, this fabric had been selected as the prototype fabric for a temperature adaptable finish that was to be investigated in wearer trials. Using this particular fabric would provide the opportunity for results of this investigation to be used in a later assessment of the comfort of test garments made from the same fabric, both with and without the temperature adaptable finish.

Because the skin is not a uniform sensory surface, it was desireable to test for moisture sensation in only a small area. 2 X 2 inch swatches were cut from the fabric to serve as the stimuli. A 2 X 2 inch swatch of this particular fiber/fabric composition allowed a wide range of moisture to be applied to it, representing moisture contents from about 2.7% to over 30%.

Moisture. Fabric swatches were placed in pre-weighed glass moisture-proof containers. All moisture was removed from the fabric swatches according to Procedure 1 of ASTM Method D 2654. Upon cooling to room temperature in a glass dessicator, each bottle was placed on a digital scale with an accuracy of .005 gram. Moisture in the form of distilled water at room temperature was applied to the fabrics with a Hamilton Microliter syringe equipped with a 1 1/2", 24 gauge needle. The moisture was deposited from a distance of .5 mm above, and a ninety degree angle from, the surface of the fabric.

A series of mini-trials were undertaken to determine the following: 1) the amount of time necessary for moisture to be absorbed into the fabric; 2) the amount of time that moisture would stay constant; and 3) the maximum amount of moisture that the swatch would hold without moisture leaving the fabric swatch and condensing on the sides and bottom of the glass bottle. Arbitrary values of .01 ml to .20 ml were chosen to apply to the fabrics.

It was found that it took from fifteen to thirty minutes for moisture amounts to be absorbed into the fabrics. After this period of time, no droplet of moisture was visible on the surface of the fabric, but an area darkened by the wet spot was apparent on all fabric swatches containing .04 ml or greater. This was not anticipated to be a problem since subjects would not be seeing the stimuli. Moisture stayed constant in the bottles over a three hour period. When the wetted fabrics were removed from the bottles after this amount of time, only the bottles containing fabrics wetted with .17 ml or greater had increased in weight indicating that some of the deposited moisture had left the swatch and was on the interior surfaces of the bottles. Thus, the maximum amount of water that could be added to the 2 X 2 inch fabric swatches was .16 ml. Time periods longer than 3 hours were not investigated since it was estimated that testing would not involve time periods longer than this.

Site of Stimulation

Two areas of the back were identified for testing. The spine of the scapula on the right and left sides of the subjects' backs were marked with a 2 X 2 inch template to designate the areas to which the fabric stimuli would be applied. This particular area was chosen since it is one area of the body on which clothing generally has contact regardless of garment design and fabric. For the presentation of stimuli, fabric swatches were randomized and applied alternately to the right and left sides of the back.

Subjects

Five subjects volunteered to participate, two males and three females. They were all university students with ages ranging from 19 to 23. Testing took place in an air conditioned room with an ambient temperature of approximately 74° F and 50% relative humidity.

Procedure

Subjects were instructed to respond in one of two ways, depending on which threshold was under investigation. For the determination of the absolute threshold of moisture sensation (AL), their response was "yes" if they felt the presence of moisture and "no" if they did not. For the determination of the difference threshold (DL) of moisture sensation, their response was "greater" or "less" depending on how they sensed the moisture on the comparison of one fabric swatch to another. (For a detailed description of the methods for determining AL and DL, see Manuscript I in Chapter III).

AL. Twenty-four fabric swatches were prepared, three each with the following amounts of moisture in ml: .00, .01, .02, .03, .04, .05, .06, and .07. The choice of these values was arbitrary.

DL. Forty-four fabric swatches were prepared, three each with the following amounts of moisture in ml: .01, .02, .03, .04, .05, .06, .07, .08, .09, .10, and .11. The middle value, .06 ml, was designated as the standard stimulus (St) to which all variable stimuli (Sv) would be compared. The choice of these values, again, was arbitrary.

Results

AL

Frequencies and percentages of all five subjects responding "yes" to the sensation of moisture stimuli are presented in Table 1. The percentages are graphed in

Figure 1. Visual examination of the graph reveals that the psychometric function for the sensation of moisture is an ogive.

SUBJECT	1	2	3	4	5	FREQ	PERCENT
MOISTURE (ML)							
00	0	0	0	0	0	0	0
01	0	1	0	0	0	1	7
02	1	1	0	1	1	4	27
03	2	1	1	1	0	5	33
04	3	2	2	2	1	10	67
05	3	3	3	2	3	14	93
06	3	3	3	3	3	15	100
07	3	3	3	3	3	15	100

Table 1. AL Pilot Data for Five Subjects.

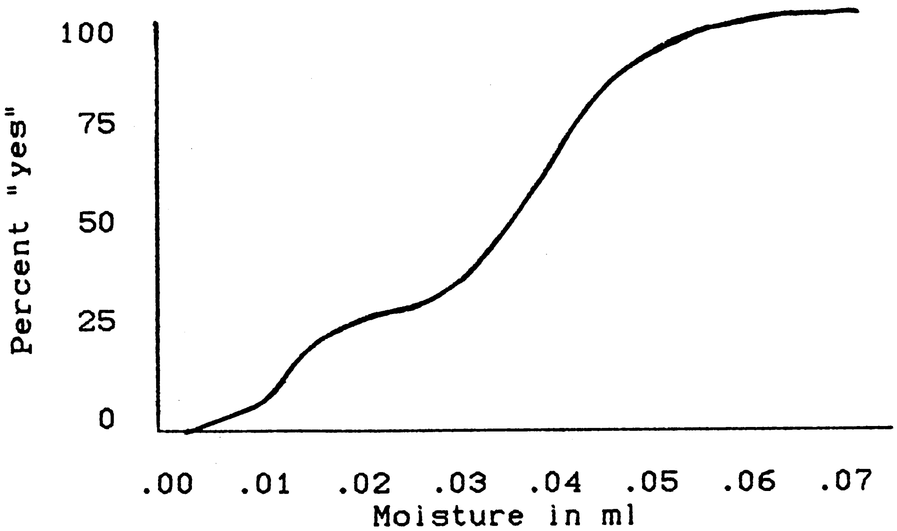


Figure 1. Psychometric Function of AL Pilot Data for Five Subjects.

DL

Frequencies and percentages of the DL data are shown in Table 2. The percentages are graphed in Figure 2. The psychometric function for the determination of the difference threshold of moisture sensation did not appear to be an ogive. The psychometric function was examined for each individual and plotted in Figures 3, 4, 5, 6, and 7. There appeared to be much variability in subjects responses.

AMT	FREQ	PERCENT
.01	1	7
.02	2	13
.03	4	27
.04	8	53
.05	10	67
.06	12	80
.07	13	87
.08	11	73
.09	13	87
.10	14	93
.11	14	93

Table 2. DL Pilot Data for Five Subjects.

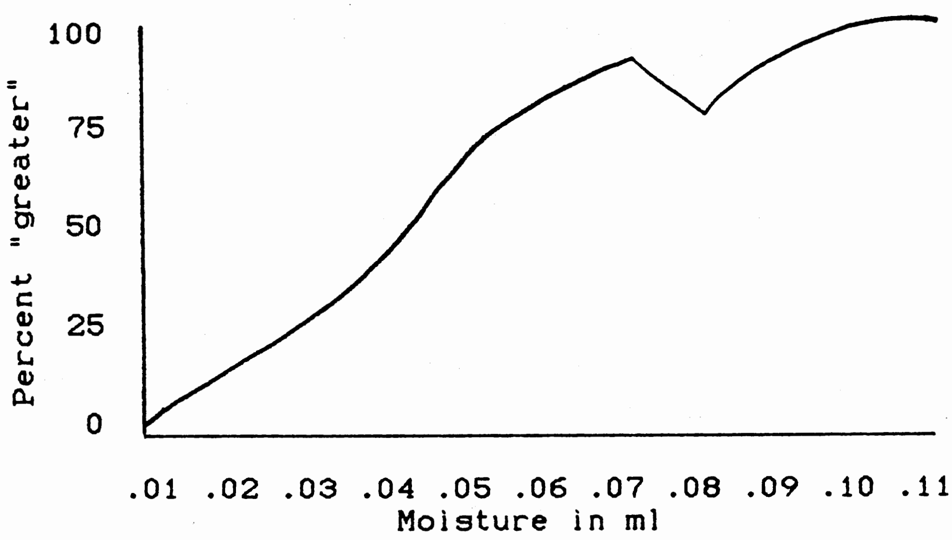


Figure 2. Psychometric Function of DL Data for Five Subjects.

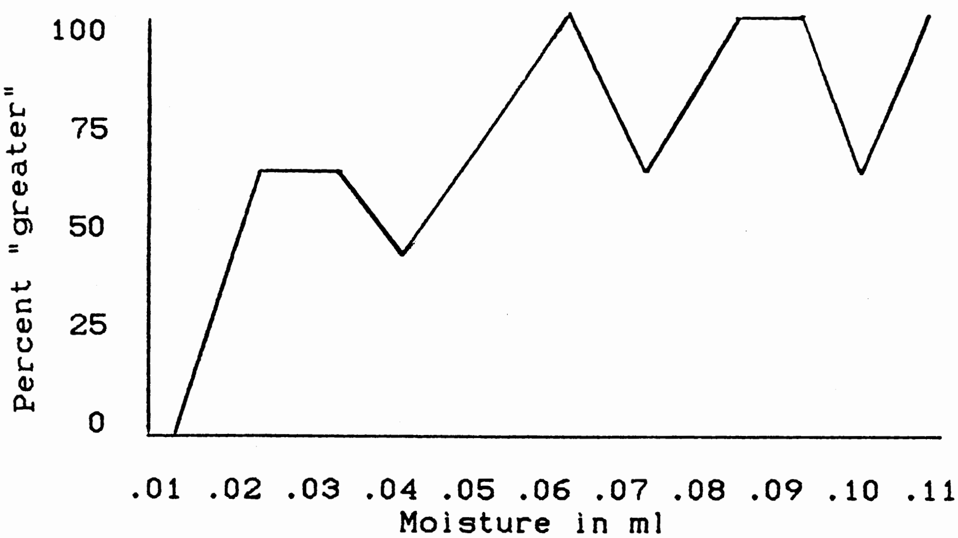


Figure 3. DL Pilot Data for Subject # 1.

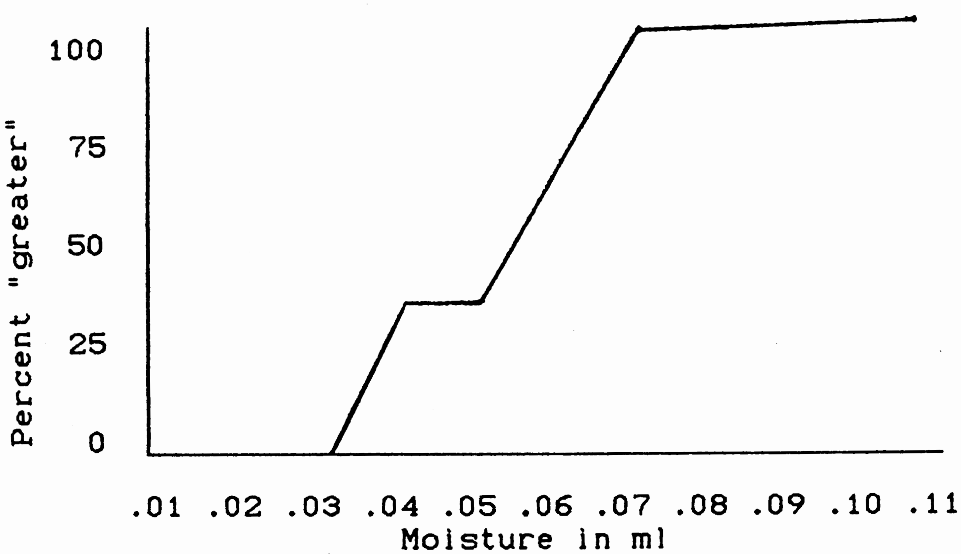


Figure 4. DL Pilot Data for Subject # 2.

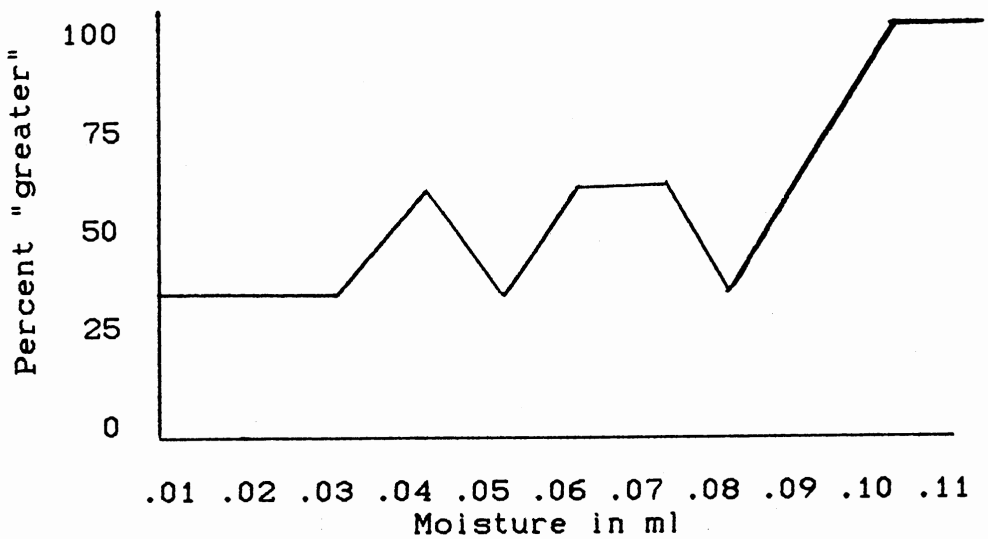


Figure 5. DL Pilot Data for Subject # 3.

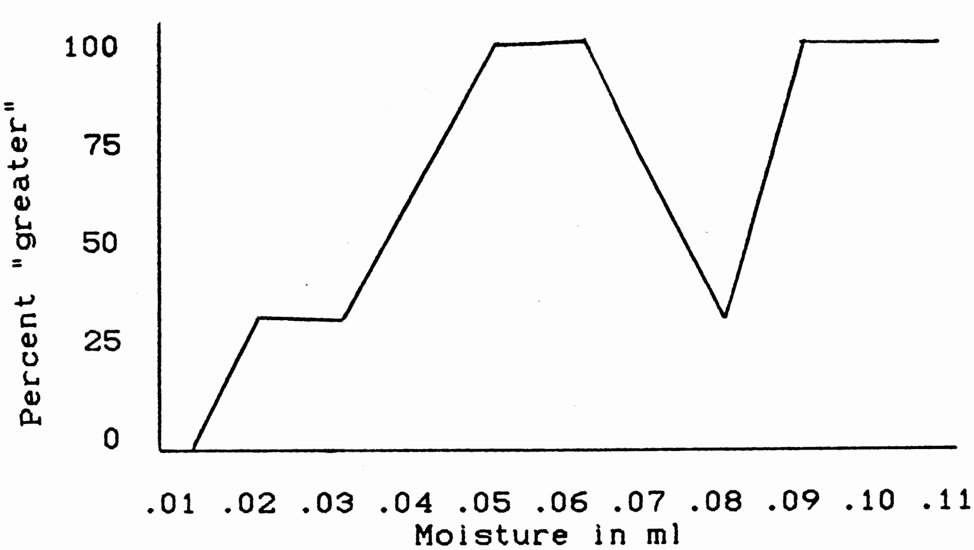


Figure 6. DL Pilot Data for Subject # 4.

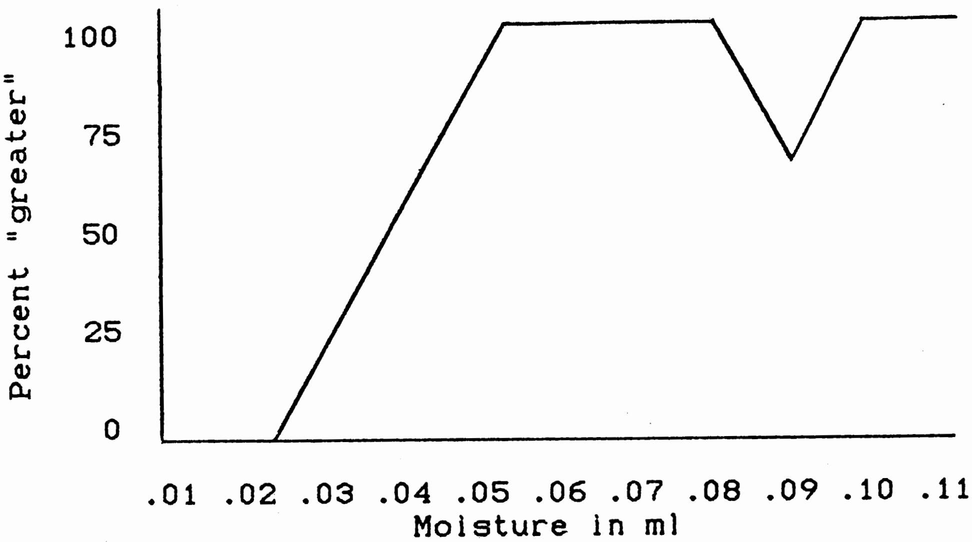


Figure 7. DL Pilot Data for Subject # 5.

Mapping

It was noted by the investigator that some of the subjects mentioned that they had a difficult time feeling the presence of any moisture at all. This led to further investigation of the sensitivity of subjects to moisture by a mapping procedure.

A 4 X 4 inch area of the right scapula of one female test subject (not previously tested) was mapped for sensitivity to moisture. A 4 X 4 inch template, composed of sixty-four 1/2" X 1/2" inch squares, was transferred to the back with a felt tip pen. Sixty four fabric swatches, 1/2" X 1/2", were pipetted with .10 ml moisture. This amount was chosen on the basis that it was an amount expected to be much above the absolute threshold of moisture sensation. This amount of moisture completely saturated the fabric swatches.

An example of a wet swatch trial and a dry swatch trial was given to the subject. The subject was asked to respond "yes" if she detected the presence of moisture and "no" if she did not. Wet fabric swatches were applied to random locations on the grid. Dry fabric swatches were applied intermittently. Responses were recorded on a data sheet bearing a facsimile of the grid (Figure 8).

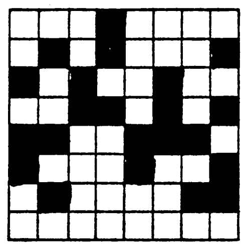


Figure 8. Map of Moisture Sensitivity in a 2" X 2" Area of the Back for One Subject.

The darkened spaces in Figure 8 represent areas of the back in which .10 ml of moisture on a 1/2 X 1/2" fabric swatch could not be detected by this subject. It can be seen by the number of darkened spaces that a 2 X 2 inch area for the placement of wet fabric swatches (for the determination of AL and DL) could not be found in the mapped area of this subject's back. In other words, this subject would not be eligible for participation in a study to determine AL and DL. Further probing of this finding with more subjects was necessary. The decision was made to investigate the sensitivity of moisture as determined by mapping in another study (Appendix B).

APPENDIX B

PILOT STUDY #2: MAPPING

Examination of results found in the first pilot study prompted the investigation of mapping a specific area of the body for sensitivity to moisture. The right and left scapular regions of the back were the areas of interest defined earlier (Appendix A). A 4 X 4 inch area was designated as the size of the area to map. It was anticipated that, within this area, a 2 X 2 inch square could be found in which subjects could detect the presence of moisture.

Materials and Methods

Stimuli

The same fabric utilized in Pilot Study #1 was used in the present study; a 50/50 cotton and polyester blend in a plain knit fabric structure. Fabric swatches 1/2" X 1/2" were cut from the fabric and assembled on a film of saran. A glass pipette, graduated by .1 ml was used to deposit .1 ml of distilled water to each swatch from a distance of .5

mm and a ninety degree angle from the surface of the fabric.

Subjects

Nine undergraduate students in a senior level textiles class participated in this study as part of a lab exercise on sensory mapping. Testing took place in the same location as Pilot Study #1; an uncontrolled laboratory environment with air conditioning and an ambient temperature of 74° F and approximately 50% RH. The subjects worked in pairs, with each testing the other member of the pair after instructions were given by the investigator.

Procedure

The investigator explained the procedure for mapping to the students and demonstrated the procedure on one of the class members. The location of the body to be mapped was explained in detail. The seventh cervical vertebrae of the spinal column (C7) served as the anatomical landmark from which to identify the area for mapping. The upper back was studied to determine a 4 X 4 inch area on which clothing would likely be in contact with the skin. This was generally identified as 2" to 3" inches down the spinal column from the top of C7 and approximately 1 1/2" on either side of the column (see Figure 16 in Manuscript I, Chapter III). The exact location of the 4" X 4" area depended on the configuration of bone, muscle and fat in the scapular region of each individual. The investigator assisted each student with determining this location. A grid template for marking the back was placed on each of the two regions to be tested and a felt tip pen was used to mark the 128 locations on which fabric swatches would be placed.

A handout (Appendix C) provided detailed directions for conducting the mapping. Each of 128 prepared fabric swatches for each student were applied to a random location on either of the grids. Subjects were to respond "yes" or "no" depending on whether they detected the presence of moisture on their backs. Dry fabric swatches were applied intermittently. Students recorded their partners' responses on a data sheet containing a facsimile of the grid (Appendix C).

Results

The grids provided a pictorial representation of each subject's sensitivity to moisture in two 4 X 4 inch areas of their backs (Appendix D). Results showed no clear pattern of sensitivity. Insensitive areas seemed to be scattered randomly throughout the locations mapped.

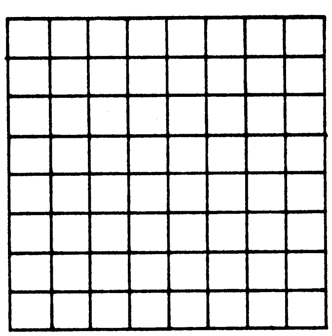
The grids were examined to determine if a 2 X 2 inch area on both sides of the back could be found which exhibited sensitivity to moisture. Five of the nine subjects exhibited such areas. Subjects 2, 5, 7 and 9 did not (Appendix D).

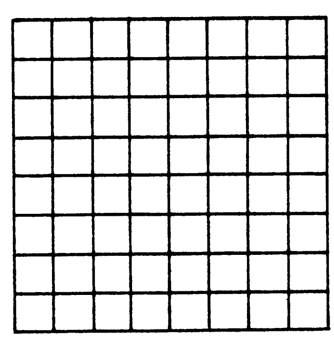
Although the results of this study are not generalizable beyond the few subjects mapped for moisture sensation, the findings do suggest that potential volunteers for the major study might not possess sufficient moisture sensitivity for the determination of the absolute and difference thresholds of moisture sensation by the procedures intended. Thus, a mapping procedure was included in the overall design of the study as a necessary pre-requisite for all subjects volunteering to be a participant in the study.

APPENDIX C

PROTOCOL FOR MOISTURE SENSATION MAPPING

1. Locate prescribed areas on the body to be mapped.
2. Lay the grid template on the body, and transfer it by placing dots in the center of each square.
3. To begin mapping, choose any location on the grid and:
   a. Apply wetted fabric swatch to one of the dots.
   b. Leave swatch on skin for 3-5 seconds.
   c. Remove fabric swatch and ask subjects "do you feel the presence of moisture on your back?"
   d. If the subject replies YES, place a "+" in the corresponding space on the grid. If the subject replies NO, place a 0 in the corresponding space on the grid.
4. Use dry paper towel to gently remove moisture from the skin after each trial.
5. Repeat steps 3 and 4 until trials have been made on all locations. Choose locations randomly.
6. Interrupt above pattern every 5 or 6 trials to apply a DRY fabric swatch to any location which has a "+" on your map. If subject replies "yes" to the question regarding the presence of moisture, place a * in the box along side the +.



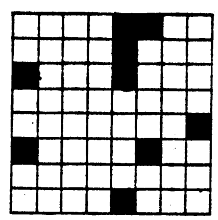


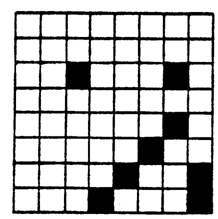
APPENDIX D

RESULTS OF MOISTURE SENSITIVITY MAPPING*
IN UNCONTROLLED ENVIRONMENT

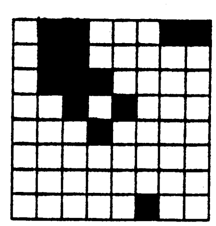
Left Scapular Region — Right Scapular Region

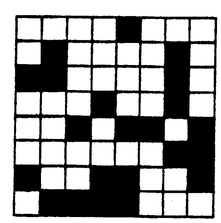
Subject 1





Subject 2

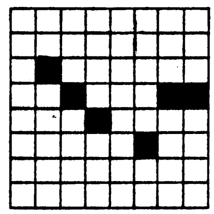


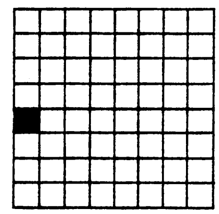


*Dark areas denote no sensitivity to moisture

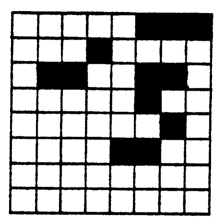
Left Scapular Region | Right Scapular Region

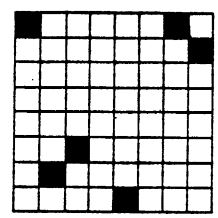
Subject 3



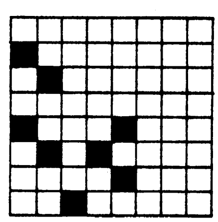


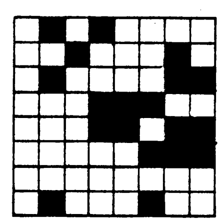
Subject 4





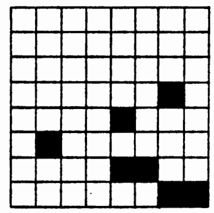
Subject 5

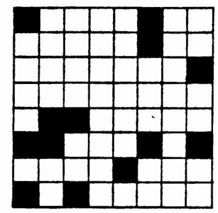




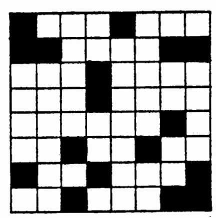
Left Scapular Region | Right Scapular Region

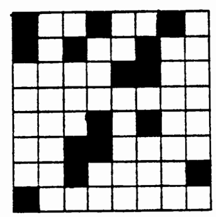
Subject 6



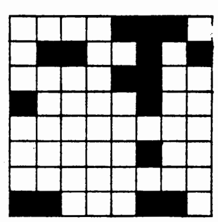


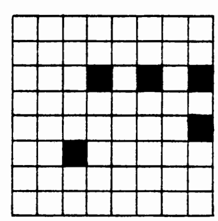
Subject 7





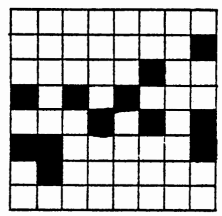
Subject 8

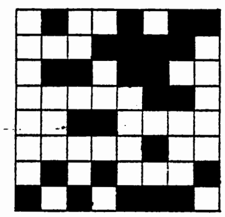




Left Scapular Region | Right Scapular Region

Subject 9





APPENDIX E

INFORMED CONSENT

I, ________________________, voluntarily agree to participate in this study entitled: Use of Psychophysical Methods to Assess Moisture Sensation in Clothing: A Feasibility Study and sponsored by Home Economics Research through the department of Clothing, Textiles and Merchandising, Oklahoma State University.

I understand that the purpose of this study is to investigate moisture sensation in individuals, and that testing will involve fabric swatches of 50/50 cotton and polyester knit, wetted with water, applied to the skin of my upper back in the area of the shoulder blade.

I understand that the procedure for assessing moisture sensation will require my participation in the following:
1. Pre-Screening: (1 hr, approx) All subjects will be pre-screened to determine sensitivity to moisture. A four inch square area over the right and left shoulder blades will be mapped for moisture sensitivity. Mapping involves placing half inch square fabric swatches on the back in the area indicated. Both wet and dry fabrics will be applied. After each application of a fabric swatch, the subject will be asked to respond,"yes" or "no" to the question: "Do you detect the presence of moisture on your back?" This pattern will be repeated until moisture sensation in the four inch square areas has been determined. Those subjects not exhibiting sensitivity to moisture will be terminated from the remainder of the study.
2. Procedure: (2 hrs total, approx) In the first session, fabric swatches will be wetted with different amounts of water and placed alternately on the subject's left and right shoulder blades (precise location determined by mapping). Subjects will be asked to respond to the same question posed above. In the second sesssion, subjects will be asked to make a comparison between swatches placed alternately on each shoulder area and to respond "greater" or "less" than to the question: Does the amount of moisture on the left (right) feel greater or less than the amount on the right (left) ?

I understand that participating in this study presents the following possible <u>benefits</u> to me:

1. knowledge of, and experience in, sensory testing
2. payment of $5.00 for my participation in the pre-screening
3. payment of $20.00 for participation in the two procedure sessions.

I understand that there are <u>no risks</u> anticipated by the investigators for participants in this study and that records of this study will be kept confidential with respect to any written or verbal reports making it impossible to identify me individually. I also understand that I can withdraw from the study at any time without negative repercussions.

I have read this informed consent document. I understand its contents and I freely consent to participate in this study under the conditions described in this document. I understand that I will receive a copy of this signed consent form.

______________	______________________________
Date	Signature of the Research Subject
______________	______________________________
Date	Signature of the Witness
______________	______________________________
Date	Signature of the Principal Investigator

APPENDIX F

PAYMENT FORM

INVOICE

Dr. Donna Branson, Professor   Date:

Clothing, Textiles & Merchandising

309 Home Economics West   Invoice #:____________

(405) 624-5036

Date	Service Performed	$/Hour	# of Hours

Name:________________________ Social Security #:__________

Street Address:________________ Telephone #:________________

City-State-Zip________________ Total Payment Due:__________

APPENDIX G

QUESTIONNAIRE

SUBJECT # _______

Age: ____________

Height: ___ft. ___in. (to the nearest whole inch, round up)

Weight: ____________

Year in College (please circle): FR SO JR SR GR OTHER

Major (or intended area of study):

Are there any particular fibers or fabrics which you avoid wearing?

Yes ____ No ____ If YES, please list them and explain why you avoid wearing them.

FIBER/FABRIC EXPLANATION

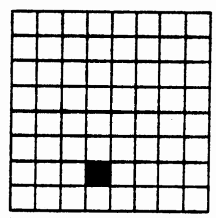
In seeking comfort in clothing that you might wear when physically active or exerting a great deal of energy, please list and describe the characteristics of the clothing that are important to you.

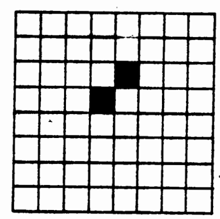
APPENDIX H

RESULTS OF MOISTURE SENSITIVITY MAPPING* IN CONTROLLED ENVIRONMENT

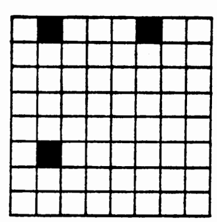
Left Scapular Region | Right Scapular Region

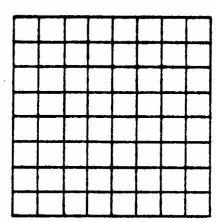
Subject 1





Subject 2

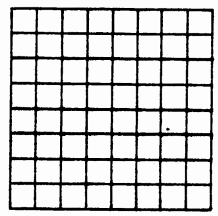
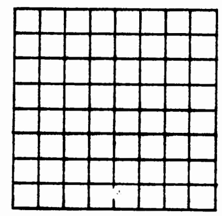




*Dark areas denote no sensitivity to moisture

Left Scapular Region | Right Scapular Region

Subject 3

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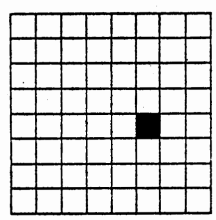
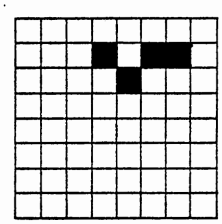

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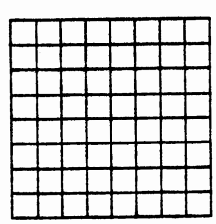
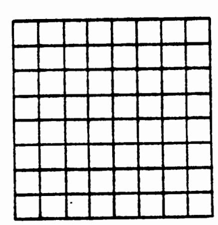
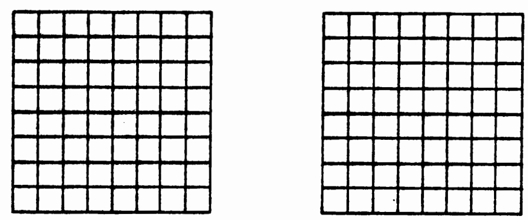



Left Scapular Region | Right Scapular Region

Subject 6



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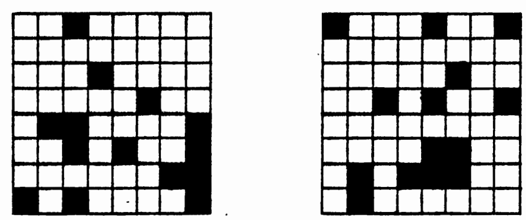
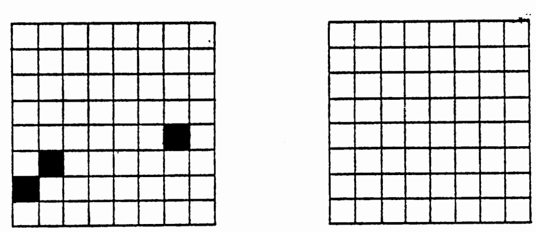
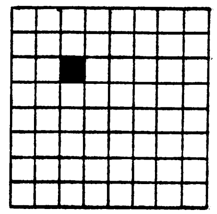
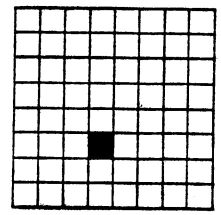


Subject 8

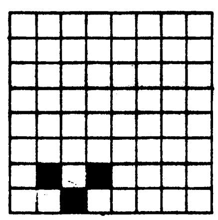
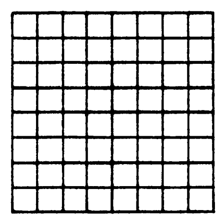


Left Scapular Region | Right Scapular Region

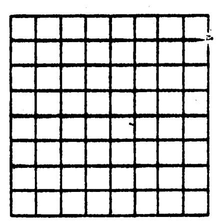
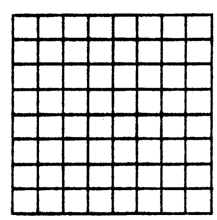
Subject 9

Subject 10

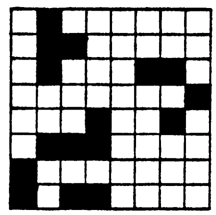



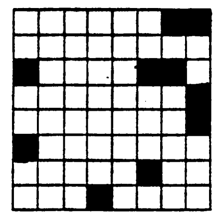
Subject 11

Left Scapular Region   Right Scapular Region

Subject 12





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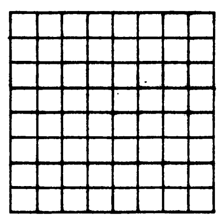
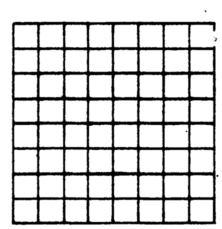
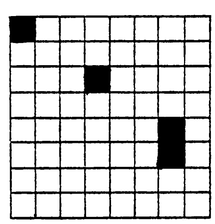
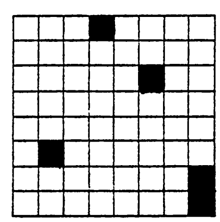




Subject 14

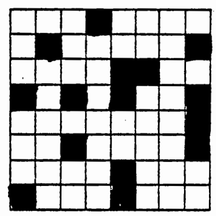


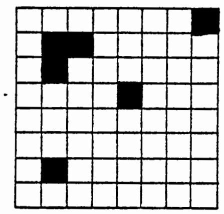


Left Scapular Region

Right Scapular Region

Subject 15





APPENDIX I

THERMAL SENSATION/COMFORT SCALES

Please use ONE of the following words to describe how you feel at this time:

VERY HOT

HOT

WARM

SLIGHTLY WARM

NEUTRAL

SLIGHTLY COOL

COOL

COLD

VERY COLD

Please use ONE of the following numbers to describe how you feel at this time:

COMFORTABLE UNCOMFORTABLE

1 2 3 4 5 6 7 8 9

APPENDIX J

DATA SHEETS I and II

SUBJECT _____
TIME _____ DATE ___/___/87
TEMP _____ HUMIDITY _____
OUTDOOR CONDITIONS:
PRE-SCREEN:

AL 1:	SKIN TEMP: L	R	PALM	TS
(1) .01 .03 .05 .02 .04 .00	___	___	___	
(2) .00 .04 .01 .03 .02 .05	___	___	___	
(3) .03 .00 .05 .01 .04 .02	___	___	___	
(4) .02 .03 .05 .00 .01 .04	___	___	___	
(5) .01 .04 .00 .02 .05 .03	___	___	___	

AL 2:	SKIN TEMP: L	R	PALM	TS
(6) .01 .03 .05 .02 .04 .00	___	___	___	
(7) .00 .04 .01 .03 .02 .05	___	___	___	
(8) .03 .00 .05 .01 .04 .02	___	___	___	
(9) .02 .03 .05 .00 .01 .04	___	___	___	
(10) .01 .04 .00 .02 .05 .03	___	___	___	
(11)	___	___	___	
(12)	___	___	___	
(13)	___	___	___	
(14)	___	___	___	
(15)	___	___	___	

DL 1:		SKIN TEMP: L	R	PALM	TS
(1)	.01 .03 .05 .02 .04 .07 .06	___	___	___	
(2)	.02 .03 .04 .06 .01 .05 .07	___	___	___	
(3)	.07 .02 .05 .01 .03 .06 .04	___	___	___	
(4)	.05 .01 .07 .02 .06 .04 .03	___	___	___	
(5)	.04 .06 .01 .03 .05 .02 .07	___	___	___	

DL 2:		SKIN TEMP: L	R	PALM	TS
(6)	.01 .03 .05 .02 .04 .07 .06	___	___	___	
(7)	.02 .03 .04 .06 .01 .05 .07	___	___	___	
(8)	.07 .02 .05 .01 .03 .06 .04	___	___	___	
(9)	.05 .01 .07 .02 .06 .04 .03	___	___	___	
(10)	.04 .06 .01 .03 .05 .02 .07	___	___	___	
	(11)	___	___	___	
	(12)	___	___	___	
	(13)	___	___	___	
	(14)	___	___	___	
	(15)	___	___	___	

WRIST

SUBJECT _____ TIME _____ DATE __/__/87
TEMP _____ HUMIDITY _____
OUTDOOR CONDITIONS:
PRE-SCREEN:

DL 3:	SKIN TEMP:	L	R	PALM	TS	TC
(1) .09 .03 .11 .05 .13 .07 .15		___	___	___		
(2) .07 .11 .09 .15 .03 .05 .13		___	___	___		
(3) .15 .07 .05 .11 .09 .13 .03		___	___	___		
(4) .03 .05 .13 .07 .11 .09 .15		___	___	___		
(5) .13 .15 .03 .11 .09 .05 .07		___	___	___		

DL 4:	SKIN TEMP:	L	R	PALM	TS	TC
(6) .09 .03 .11 .05 .13 .07 .15		___	___	___		
(7) .07 .11 .09 .15 .03 .05 .13		___	___	___		
(8) .15 .07 .05 .11 .09 .13 .03		___	___	___		
(9) .03 .05 .13 .07 .11 .09 .15		___	___	___		
(10).13 .15 .03 .11 .09 .05 .07		___	___	___		

Standard: .08	SKIN TEMP:	L	R	PALM	TS	TC
Comparison 1: .02 .06 .04 .07		___	___	___		
2: .04 .02 .06 .07						
3: .06 .04 .07 .02		___	___	___		

Standard: .10

Comparison:	1:	.05	.02	.09	.08					
	2:	.02	.09	.08	.05					
	3:	.08	.05	.02	.09	___	___	___		

Standard: .12

Comparison	1:	.03	.09	.06	.11					
	2:	.09	.03	.11	.06					
	3:	.06	.11	.03	.09	___	___	___		

Standard: .14 SKIN TEMP:

						L	R	PALM	TS	TC
Comparison	1:	.03	.10	.07	.13					
	2:	.10	.03	.13	.07					
	3:	.07	.13	.10	.03	___	___	___		

Standard: .16

						L	R	PALM	TS	TC
Comparison	1:	.06	.04	.11	.08					
	2:	.04	.11	.08	.06					
	3:	.11	.08	.06	.04	___	___	___		

Present standard stimulus: 10		L	R	PALM	TS	TC
(1) .04 .08 .06 .14 .12 .10 .16		___	___	___		
(2) .16 .12 .04 .10 .08 .06 .14						
(3) .10 .04 .16 .08 .14 .06 .12						
(4) .08 .14 .12 .04 .06 .10 .16						
(5) .06 .10 .08 .12 .04 .16 .14		___	___	___		
	(2)	___	___	___		
	(3)	___	___	___		
	(4)	___	___	___		
	(5)	___	___	___		
	(6)	___	___	___		

APPENDIX K

AL AND DL DATA

The absolute threshold of moisture sensation was determined by calculating the percentage of "yes" responses (detection) for each of the moisture stimulus values. Responses were coded "1" for yes and "0" for no.

The difference threshold of moisture sensation was determined by calculating the percentage of "greater" responses for each of the variable moisture stimulus values. Responses were coded "1" for greater and "0" for less.

These data are presented in Table 1 and Table 2. The means ($\bar{X}$) and the standard deviations (sd) of the responses to each of the moisture stimulus values by "trial", or repetition, are presented in Table 3 (AL data) and Table 4 (DL data).

ML	.00	.01	.02	.03	.04	.05
SUBJECT						
2	0	1	1	2	2	2
3	2	3	5	3	4	5
4	1	4	3	5	5	5
5	0	2	4	3	4	4
6	1	4	5	3	5	5
7	0	0	0	1	1	2
8	0	0	0	1	1	2
9	0	2	4	1	3	4
10	1	0	4	5	5	5
11	0	1	3	3	3	4
12	0	0	1	1	1	4
13	0	0	2	3	5	4
TOTAL	5	17	33	33	42	46

Table 1. Number of "Yes" Responses by Subject for Each Stimulus Value in the Determination of the AL.

ML	.03	.05	.07	.09	.11	.13	.15
SUBJECT							
2	0	2	3	3	4	4	4
3	0	0	0	2	1	5	4
4	2	2	2	3	5	5	5
5	1	2	1	3	4	4	2
6	0	3	0	2	3	3	5
7	0	1	5	3	4	4	5
8	2	1	3	2	3	5	3
9	2	1	3	3	5	5	3
10	2	3	1	3	4	4	5
11	0	3	2	3	5	5	5
12	1	2	4	1	5	4	5
13	1	3	2	4	5	5	5
TOTAL	11	23	26	32	48	53	51

Table 2. Number of "Greater" Responses by Subject for Each of the Variable Stimulus Values (Sv) used in the Determination of the DL.

TRIAL		1	2	3	4	5	TOTAL
ML							
.00	X̄	.083	.083	.167	.000	.083	.083
	sd	.289	.289	.389	.000	.289	.134
.01	X̄	.167	.250	.333	.333	.333	.283
	sd	.389	.452	.492	.492	.492	.313
.02	X̄	.417	.500	.583	.667	.583	.550
	sd	.515	.522	.515	.492	.515	.342
.03	X̄	.250	.583	.333	.833	.750	.550
	sd	.452	.515	.492	.389	.452	.271
.04	X̄	.500	.583	.750	.750	.917	.700
	sd	.522	.515	.452	.452	.289	.302
.05	X̄	.500	.750	.750	.833	1.00	.767
	sd	.522	.452	.452	.389	.00	.239

Table 3. AL Mean Responses by Trial

TRIAL		1	2	3	4	5	TOTAL
ML							
.03	X̄	.333	.083	.250	.167	.083	.183
	sd	.492	.289	.452	.389	.289	.180
.05	X̄	.083	.583	.333	.250	.167	.383
	sd	.289	.515	.492	.452	.389	.199
.07	X̄	.500	.417	.333	.250	.667	.433
	sd	.522	.515	.492	.452	.492	.306
.09	X̄	.667	.500	.833	.333	.333	.533
	sd	.492	.522	.389	.492	.492	.152
.11	X̄	.917	.750	.833	.833	.667	.800
	sd	.289	.452	.389	.389	.492	.241
.13	X̄	.833	.833	1.00	.917	.833	.883
	sd	.389	.389	00	.289	.389	.134
.15	X̄	.750	.917	.917	.917	.750	.850
		.452	.289	.289	.289	.452	.211

Table 4. Mean DL Responses by Trial

APPENDIX L

JUST NOTICEABLE DIFFERENCES (JND'S) ABOVE THRESHOLD

The difference threshold was determined in this study (Manuscript I, Chapter III) to be 0.0385 ml of moisture. This is the amount of physical stimulus change required for a sensation to be "just noticeably different" from the absolute threshold, determined in this investigation to be .024 ml of moisture. Weber's law (Gescheider, 1976) states that the change in stimulus intensity that can just be discriminated is a <u>constant fraction</u> of the starting intensity of the stimulus. This fraction, called the Weber fraction, is determined by the ratio of the <u>difference</u> threshold to the standard stimulus value used in its determination. For this study, it is determined by: 0.0385/0.09 = .427. Using this figure, the number of jnd's above threshold can be determined as follows: 0.024 X .427 + .024 = .034; .034 X .427 + .034 = .049; etc... Stimulus values corresponding to several jnd's above threshold are presented in Table 1. The data in this table are presented graphically in Figures 1 and 2.

# OF JND'S	STIMULUS INTENSITY	LOG STIMULUS INTENSITY
0	.024	-1.62
1	.034	-1.47
2	.049	-1.31
3	.07	-1.15
4	.10	-1.00
5	.143	- .84
6	.20	- .70
7	.286	- .54
8	.405	- .39
9	.585	- .23

Table 1. Number of JND'S above Threshold Corresponding to Stimulus Intensity Values.

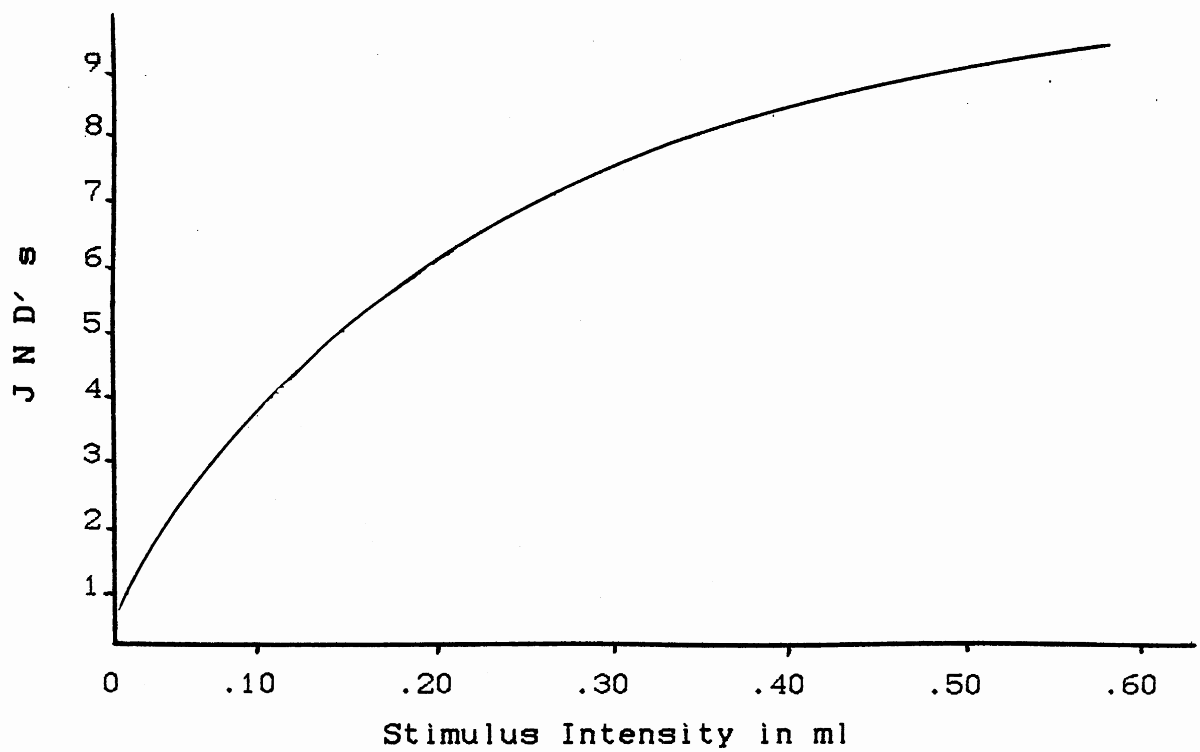


Figure 1. Number of JND's above Threshold plotted against Stimulus Intensity (based on the assumption that the Weber fraction is .427 and the AL is .024 ml

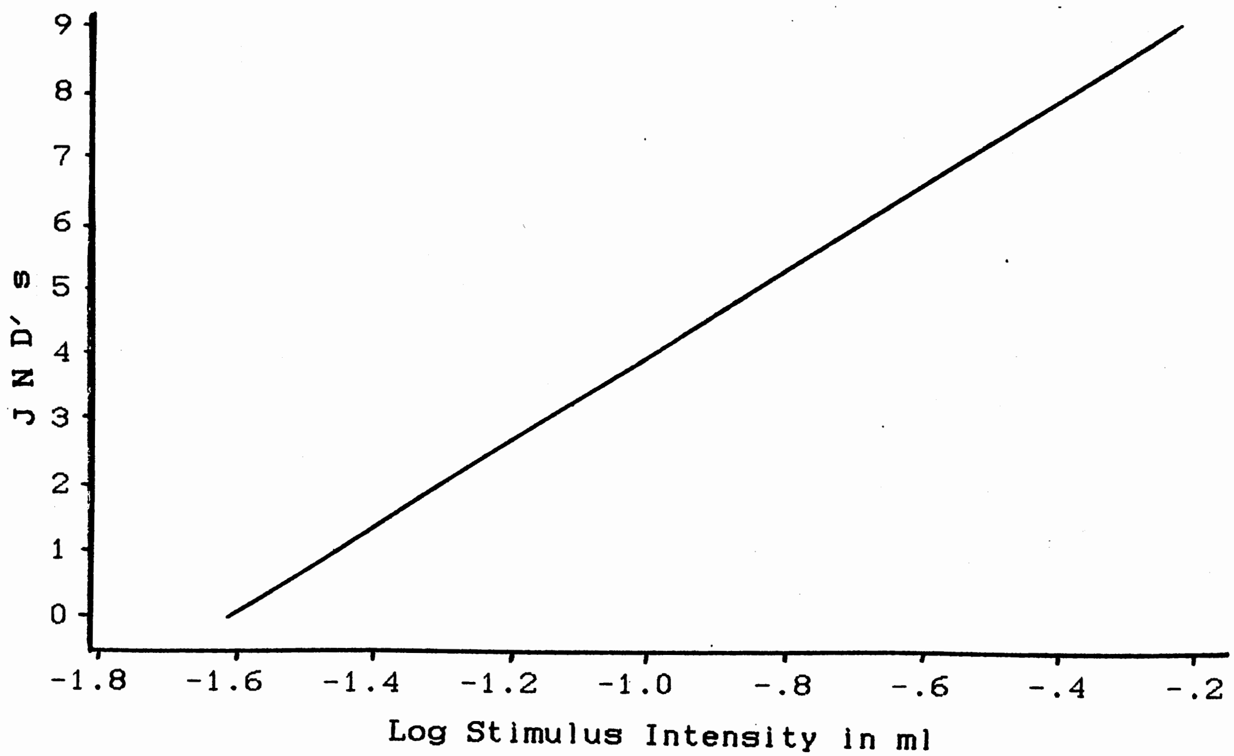


Figure 2. Number of JND's above Threshold Plotted against the Logarithm of Stimulus Intensity.

VITA

Maureen Mary Sweeney

Candidate for the Degree of

Doctor of Philosophy

Dissertation: USE OF PSYCHOPHYSICAL METHODS TO ASSESS MOISTURE SENSATION IN CLOTHING: A FEASIBILITY STUDY

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