INFLUENCE OF FABRIC AND ENVIRONMENT ON PERCEIVED CLOTHING COMFORT AND RELATED SENSATIONS OF EXERCISING SUBJECTS

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CHAPTER 1

INTRODUCTION

Background

Exercise has become very commonplace in our society as a result of its contribution to a longer and healthier life. Business has responded to the increased demand for attractive and appropriate exercise-wear by providing a marketplace full of specialized apparel to accommodate almost every form of activity. In addition to specialized design and styling of the garments, specially engineered fibers and fabrics have been developed and are promoted to consumers. Much of this promotional advertising declares that these special fibers and fabrics will "facilitate" a person in their quest of becoming more physically fit by keeping them more comfortable during exercise.

While exercising, the body is constantly trying to maintain a steady body temperature or heat balance for critical bodily functions. This is accomplished by dissipating excess heat by one or a combination of physiological methods of heat exchange including sweating, evaporation, conduction, convection, radiation, or behavioral type actions such as removing clothing to expose more skin. Clothing acts as a barrier to the thermoregulatory process, protecting the body from the environment and also trapping heat in the microclimate. Heat exchange must occur through clothing to ensure proper balance with the environment (Mecheels & Umbach, 1977; DeMartino, Yoon, Buckley, Evins, Averell, Jackson, Schultz, Becker, Booker, & Hollies, 1984).

Branson and Sweeney (1991) define clothing comfort as "the state of satisfaction indicating physiological, psychological, and physical balance among the person, his/her clothing, and his/her environment" (p. 99). It is generally agreed that the major factors that influence clothing comfort are the movement of heat, moisture, and air through fabric (Slater, 1977; Mehta & Narrasimham, 1987). In turn, these factors are affected by fabric/fiber characteristics such as moisture transport properties, mechanical properties, and surface features that interact to influence clothing comfort sensations.

The ability of a fabric to transport moisture from the skin/clothing interface is very important for comfort acceptability (Hollies, 1977). A fabric transports moisture in either a liquid or vapor phase. Mass liquid moisture transport occurs through fabric or along the plane of the fabric and is known as wicking. However, wicking rarely occurs during actual wear because garments do not usually get completely wet (Hong, Hollies, & Spivak, 1988). The other method of moisture transport is moisture vapor permeability and it is the most common way for moisture to be transported through fabric (Hollies, 1977). Vapor passage occurs most often through the air spaces of the fabric (Wehner, Miller, & Rebenfeld, 1988; Mehta & Narrasimham, 1987).

It is known that as moisture content of clothing increases, comfort ratings decrease. A very small amount of moisture can affect comfort ratings when skin is interfaced with fabric (Hollies, 1965; 1971; Scheurell, Spivak, & Hollies, 1985). The contact or interface sensation between fabric and skin is the most important determinant of how fabric feels to an individual (Barker, Radhakrishnaiah, Woo, Hatch, Markee, & Maibach, 1990). Fabric characteristics like the number and type of contact points and ridges, yarn type, thickness, bulk density, porosity, and fiber content affect tactile contact sensations like texture, fuzziness, drape, stiffness, drag, and roughness. Generally, the greater the contact (or cling) the more uncomfortable the garment, due to greater air movement and/or convective heat loss (Barker et al., 1990). The contact sensation may change when wet fabric lies against the skin causing friction/adhesion when fabric is moved (Yamakawa & Isaji, 1987; Gwosdow, Stevens, Berglund, & Stolwijk, 1986).

Another barrier for the body, in addition to clothing, is the stratum corneum (SC). The SC is the outside layer of skin and consists of 12 to 15 layers of dead cells forming the epidermis. The SC controls water passage through the skin (Hatch, Wilson, & Maibach, 1987). "Changes in relative humidity alter water content and evaporation in a complex manner. The relationship is nonlinear, with skin water evaporation decreasing as relative humidity increases" (Hatch et al., 1987, p. 584).

Recently, psychophysics has been used successfully by Sweeney and Branson (1990a, b), Mord (1990), and Branson, Mord, and Gatros (unpublished) to assess moisture sensation in fabrics suitable for exercise-wear. Psychophysics is the scientific study of the relationship between stimulus and sensation (Gescheider, 1976). These authors used the psychophysical method of constant stimuli and obtained absolute thresholds (ALs) for a total of eight different fabrics. The AL is the "stimulus value that evokes a sensation fifty percent of the time" (D'Amato, 1970, p. 119). The ALs were determined by presenting subjects with stimuli in the form of small swatches of fabric with known amounts of moisture, and having them respond "yes" or "no" as to whether they detected moisture or not. In these psychophysical studies, moisture was applied to the back side of fabrics which are held in glass, moisture-proof bottles until their use. The physical characteristics and AL values of the eight different fabrics used in Mord (1990) and Branson et al. (unpublished) can be found in Table 1.

An AOV of AL values yielded a significant difference between the eight fabrics ($p < .03$). Table 2 shows the results of an LSD multiple comparison test which indicated no significant differences between fabrics PP/SP and P/SP, and between fabrics C/P, N/C, N/SP, and C. All other fabric combinations were significantly different. Fabrics P, P/SP, and PP/SP had the lowest ALs, meaning that moisture was detected at very small amounts. These fabrics contained polyester as their major fiber content. In contrast, fabrics C and C/SP had the highest ALs, meaning that moisture was detected only at substantially higher amounts, and both contain cotton as their major fiber content. In other words, there were significant differences by fiber content.

Hong et al. (1988) found fiber content differences between cotton and polyester when they studied vapor pressure-time curves and dynamic surface wetness of both inner and outer fabric surfaces with laboratory tests. They discovered that the rates of change in moisture concentration were faster for 100% polyester than for 100% cotton. In wear trials, where the conditions are dynamic, cotton is usually favored over polyester. "Humans feel drier and more comfortable when vapor pressures at inner fabric surfaces were low" (Hong et al., 1988, p. 704). A slow rate of increase in moisture vapor pressure does not appear to trigger uncomfortable sensations as does a fast rate of increase or change because it allows the wearer more time to physiologically adjust (Hong et al., 1990).

To date, psychophysical methods have not been used to assess clothing comfort or thermal sensations, only wetness. In addition, psychophysical moisture sensation research has only been performed in a comfortable environment while subjects were at rest. Assessing these sensations in a dynamic wear trial is very different because the subject is exercising and producing sweat that will be absorbed by the fabric. Wearing a sweaty garment probably produces different sensations of wetness, contact, etc... than a small swatch of already wetted fabric placed on the top of subject's hands. Fabrics P, P/SP, C, and C/SP were singled out at the two AL extremes to be tested further in this study, a wear trial (see Table 2). It was believed that these fabrics would produce different clothing comfort and related sensations due to their differing absolute thresholds of moisture sensation.

Purpose

The purpose of this study was to assess the influence of fabric and environment on female subjects' perceived sensations of overall clothing comfort, thermal sensations, wetness sensations, and contact/tactile sensations.

Objectives

This study:

1. Explored how fabric differences affected perceived clothing comfort and related sensations and skin temperature.

2. Explored how three different environmental conditions (comfortable, hot-dry, and hot-humid) affected perceived clothing comfort and related sensations and

skin temperature.

3. Explored how time affected perceived clothing comfort and related sensations and skin temperature during the study's protocol that includes exercise.

4. Sought to relate perceived sensation data from the comfortable environmental condition to the psychophysical absolute threshold of moisture sensation data obtained by Mord (1990) and Branson et al. (unpublished).

Hypotheses

H_1: There will be significant differences in perceived clothing comfort and related sensations and skin temperature by fabric.

H_2: There will be significant differences in perceived clothing comfort and related sensations and skin temperature by environmental conditions.

H_3: There will be significant differences in perceived clothing comfort and related sensations and skin temperature by time.

H_4: There will be significant differences in wetness sensation data in the comfortable environment and the psychophysical data obtained by Mord (1990) and Branson et al. (unpublished).

General Acronyms

<u>AL</u> -- absolute threshold

<u>DL</u> -- difference threshold

<u>AOV or ANOVA</u> -- analysis of variance

<u>LSD</u> -- least significant difference

<u>SC</u> -- stratum corneum

C -- comfortable environment (23^0 C, 73.4^0 F)

H-D -- hot-dry environment (32.2^0 C, 90^0 F)

H-H --hot-humid environment (32.2^0 C, 90^0 F)

RH -- relative humidity

Fabric Acronyms

C -- 100% cotton

C/SP -- 94% cotton/6% spandex

P* -- 100% polyester (specially engineered with a four channel fiber)

P/SP* -- 90% polyester/10% spandex (specially engineered with a four channel fiber)

C/P -- 50% cotton/50% polyester

N/C -- 100% nylon/100% cotton (double sided fabric)

PP/SP -- 90% polypropylene/10% spandex

N/SP -- 80% nylon/20% spandex

TABLE 1

FABRIC CHARACTERISTICS

Fabric	Fiber Content	Yarn Count (cm)	Thickness (mm)	Construction	Yarn Type and Twist	Fiber Type	AL (ml)
C/P	50/50 cotton, polyester	Wales 16 Courses 14	.2337	plain	single Z twist	staple	.018
C	100% cotton	Wales 17 Courses 13	.3848	plain	single Z twist	staple	.025
P*	100% polyester	Wales 19 Courses 17	.0889	plain	single Z twist	staple	-.012
N/C**	100% nylon 100% cotton	Wales 19 Courses 17	.3696	double-knit	multifilament 0 twist single Z twist	filament staple	.021

*Fabric P had a special four channel fiber engineered to promote wicking.
**Fabric N/C was a double-sided fabric with 100% nylon on the back side and 100% cotton on the front.

TABLE 1 (Continued)

FABRIC CHARACTERISTICS

Fabric	Fiber Content	Yarn Count (cm)	Thickness (mm)	Construction	Yarn Type and Twist	Fiber Type	AL (ml)
C/SP	94/6 cotton, spandex	Wales 25 Courses 14	.0145	plain	single S twist	staple	.044
P/SP*	90/10 polyester, spandex	Wales 21 Courses 16	.0130	plain	multifilament Z twist	filament	.009
PP/SP	90/10 polypropylene, spandex	Wales 30 Courses 17	.0078	plain	multifilament S twist	filament	.009
N/SP	80/20 nylon, spandex	Wales 26 Courses 17	.0100	plain	multifilament	filament	.021

*Fabric P/SP polyester had a special four channel fiber engineered to promote wicking.

TABLE 2

LSD COMPARISON TEST
FOR FABRIC AL VALUES

	Fabrics P -.012	PP/SP .0085	P/SP .009	C/P .018	N/C .0206	N/SP .021	C .025	C/SP .044
AL Values		———	———					
				———	———	———	———	

*Fabrics connected by a line were not significantly different.
**$p < .05$, DF = 56

CHAPTER 2

LITERATURE REVIEW

This chapter is organized into four major sections. The first section introduces comfort and explains what it is, discusses comfort models, and distinguishes the several types of comfort as they relate to clothing. Section two focuses on how the different types of comfort are measured and evaluated using psychological scaling and other techniques. The third section addresses the importance of clothing and fabric to comfort, covering the physical characteristics of fabrics that affect comfort like moisture transport, mechanical properties, and surface features. Finally, section four considers the role of human skin as it relates to comfort.

Comfort

General Comfort

General comfort has been defined as "a pleasant state of physiological, psychological, and physical harmony between a human being and the environment" (Slater, 1985, p. 4). Other definitions describe general comfort as a state of well-being or neutral sensation (Sontag, 1985-1986; Mehta & Narrasimham, 1987).

While there is no disagreement on the exact definition of comfort, there is a lack of unity or commitment to a single meaning. Researchers strive to understand and explain the concept through various experiments and are continually adding to the body of knowledge. What is understood about comfort is that it is an extremely complex synthesis of human perceptions and responses that are dynamic over time.

Clothing Comfort Models

To better understand comfort as it applies to the person and clothing, some clothing comfort models will be discussed. Fourt and Hollies (1970) envisioned comfort as a triad involving the environment, the person, and clothing. The triad concept of comfort represents a balance between the environment and the person that is "modified by the intervention of clothing" (p. 1).

A model developed by Pontrelli (1977) termed "Comfort's Gestalt," involves both physical and psycho-physical stimuli filtering through a screen of stored modifiers (Figure 1). The purpose of this model is to "establish the comfort concept as a subjective response to stimuli and not as an inherent property of fibers, fabrics, or garments" (Branson & Sweeney, 1991). Pontrelli used the term "gestalt" in the model's title to demonstrate that a comfort judgment does not come from physical, psychological, and physiological stimuli assessments alone, but from the interaction between them and the stored modifiers of each individual person. A major criticism of this model is that the names/labels of the two major input categories are unclear and do not apply accurately to the variables within (Branson & Sweeney, 1991).

Sontag (1985-1986) developed a human comfort model that was directed toward comfort perception and behavioral response with the triad in three concentric circles labeled person, clothing, and environmental attributes (Figure 2). This model includes the stored modifiers from Pontrelli's (1977) model in the inner circle of person attributes. The arrow labeled "perception/response" running through all three circles represents the balance a person seeks between how they are perceived by others in the environment and their own perception of themselves. When the two perceptions are unequal a person responds by becoming more comfortable or less uncomfortable (Branson & Sweeney, 1991).

Sontag's approach to human comfort is ecological in nature with three dimensions of comfort: physical, psychological, and social. When the model was tested, data did not support a differentiation between the psychological and social comfort dimensions (Sontag, 1985-1986).

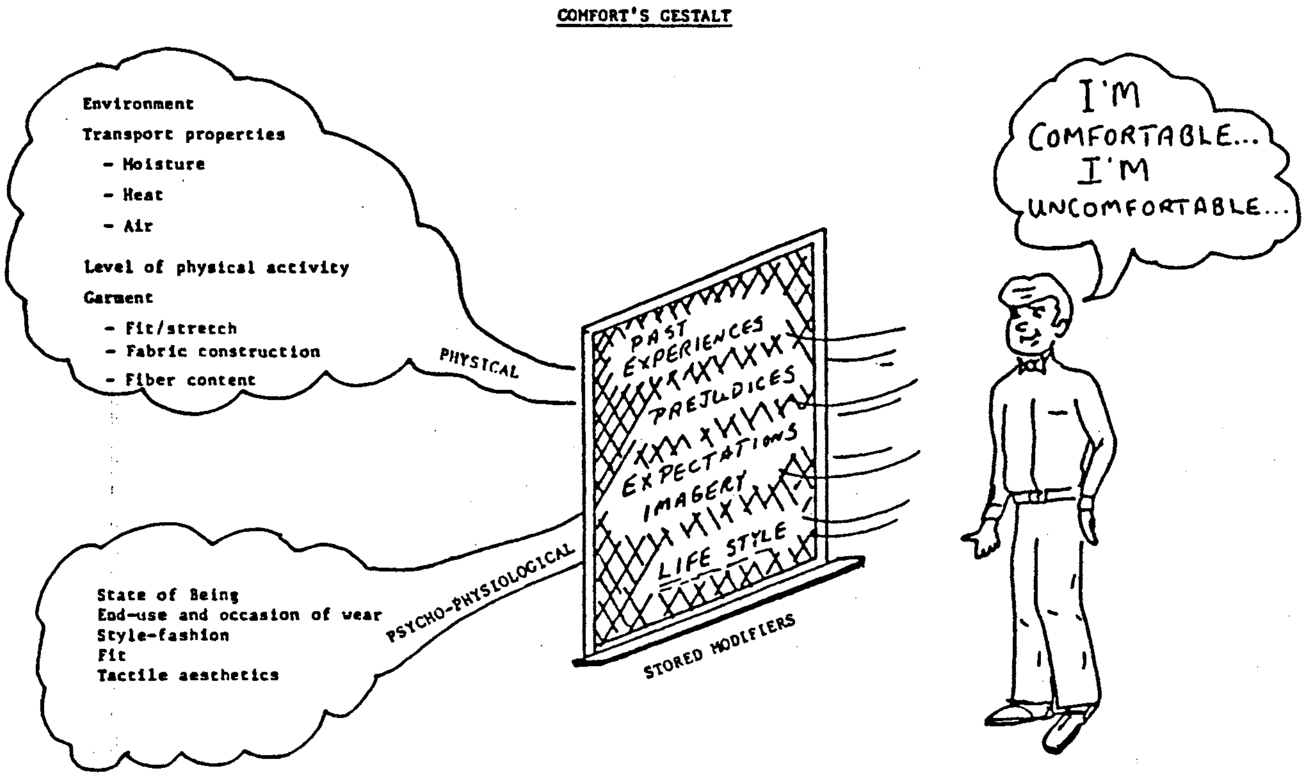


Figure 1. Comfort's Gestalt. From "Partial Analysis of Comfort's Gestalt" (p.72) by G. J. Pontrelli, 1977. In N. R. S. Hollies & R. F. Goldman (Eds.), Clothing Comfort, Ann Arbor, MI: Ann Arbor Science.

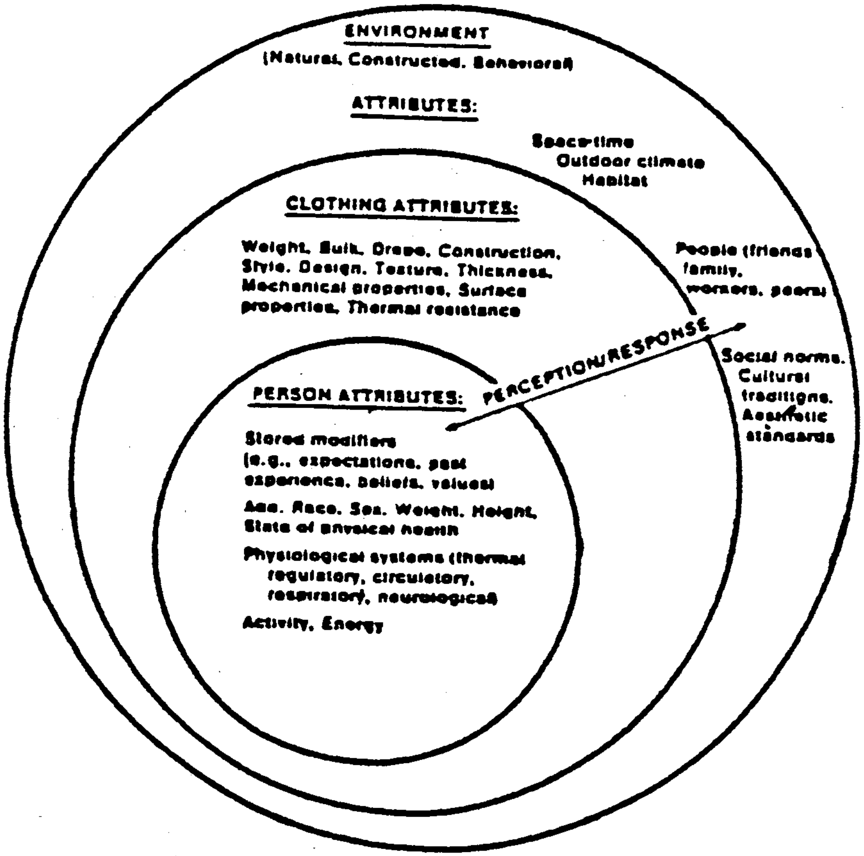


Figure 2. Attributes of the Triad (person, clothing, environment) Influential in Comfort Perception and Behavioral Response. From "Comfort Dimensions of Actual and Ideal Insulative Clothing for Older Women" by M. S. Sontag, 1985-1986, Clothing and Textiles Research Journal, 4, p. 16.

The most recent clothing comfort model (Figure 3) was proposed by Branson and Sweeney (1991) in a position paper. This ordered model proposes that the triad elements of person, clothing, and environment each have physical or non-physical and psychological dimensions that can influence the resulting response and judgment. Attributes in the physical dimension are easily measurable like age of a person, fiber content of clothing, and air temperature of the environment. Psychological attributes are very important and harder to assess, but may include one's self-concept, style of clothing, and the social norms of the environment. These attributes interact within each dimension and across dimensions to produce physiological/perceptual responses like skin temperature, sweat rate, and moisture or temperature sensations. The processing of these responses occurs in the mind in the form of Pontrelli's (1977) filtering component and the comfort judgment results. The judgment will not always be the same because a garment considered comfortable at one time may be judged uncomfortable another time (Branson & Sweeney, 1991).

The authors define clothing comfort as "the state of satisfaction indicating physiological, psychological, and physical balance among the person, his/her clothing, and his/her environment" and say further that clothing comfort has two major subdivisions of sensorial clothing comfort and thermal comfort (Branson & Sweeney, 1991).

Thermal Comfort and Sensations

Thermal comfort is defined by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) as "the condition of mind which expresses satisfaction with the thermal environment (1981, p. 2). This definition suggests that a perceptual assessment takes place, that a person feels or senses something (related to temperature) and can make a value judgment regarding those feelings or sensations (Rohles, 1971). These warm/cool sensations can be influenced by any triad component like a hot or cold environment, a heavy or lightweight garment, or individual differences of the person (Barker et al., 1990).

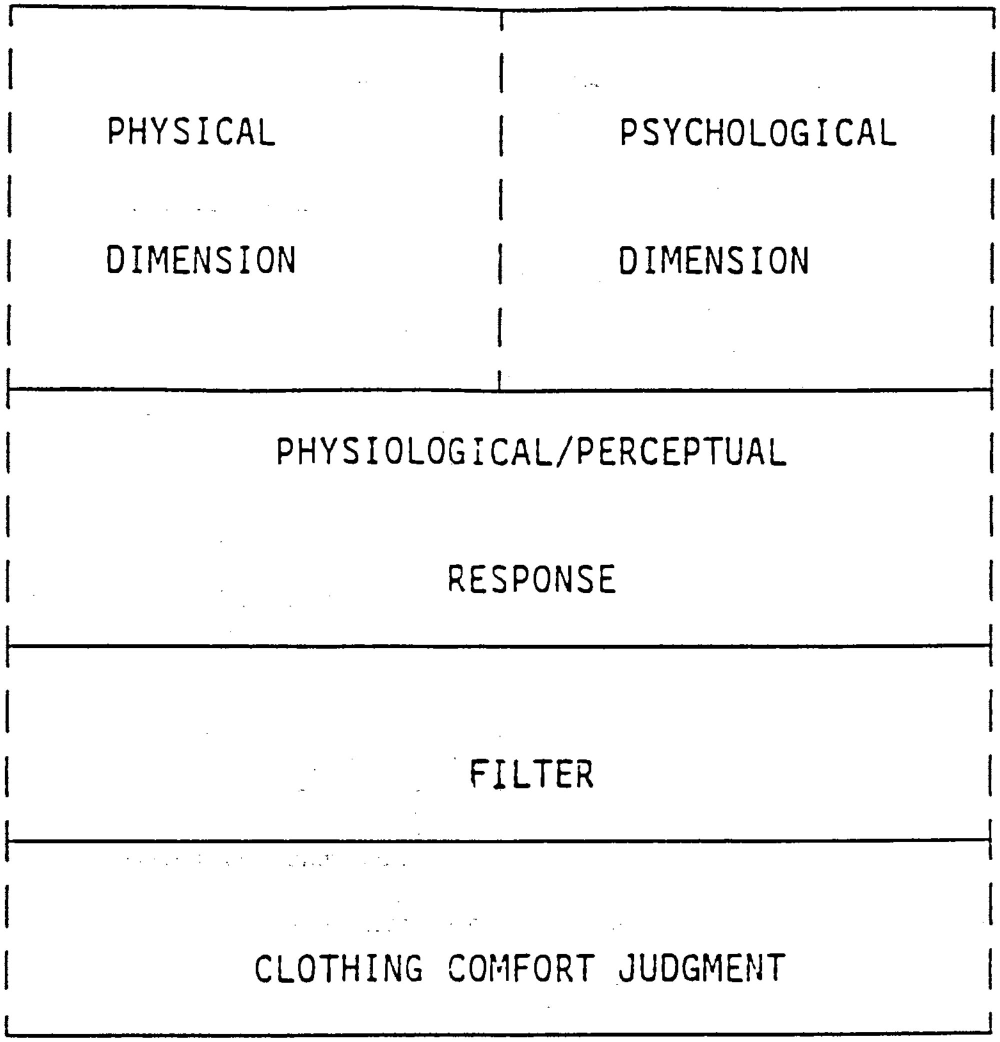


Figure 3. Proposed Clothing Comfort Model. From "Conceptualization and Measurement of Clothing Comfort: Toward a Metatheory" by D. H. Branson and M. Sweeney, 1991, <u>ITAA Special Publication Number 4 - 1991</u>, p. 94.

Sensorial Comfort/Tactile Sensations

There are other factors, besides thermal, involved in judgmental responses of clothing comfort. Branson and Sweeney (1991) define sensorial clothing comfort is "a state of satisfaction with how a fabric or garment is perceived by the senses of the wearer" (p. 99). Examples of what is meant by sensorial clothing comfort include perceptions of fabric/clothing smell, sound, and/or touch (Comfort in casuals, 1985).

Two major factors contributing to clothing comfort are wetness (moisture) sensation and tactile or contact sensations. Again, both of these types of sensations can be greatly influenced by each of the triad components. The interface (number and type of contact points) between the skin and fabric is especially important and will be discussed in more depth in the clothing and skin sections (Barker et al., 1990).

Comfort Measurement and Evaluation

Psychological Scales

"The process of making judgments from our sensory perception of the world is termed psychological scaling" (Sweeney, 1988). These scaling techniques are used to measure individuals' feelings or responses toward their environment (Rohles, Konz, McCullough, & Millikin, 1983). Comfort scaling consists of a subject recognizing a sensation, or multiple combined sensations, and rating it/them. The literature contains numerous studies conducted to assess the subjective aspect of comfort sensations using psychological scales, most focusing on those sensations dealing with thermal or temperature perception, general comfort, and more recently the tactile or contact sensation. Most of these studies are subjective wear trials in differing environmental conditions, with garments being worn of different fabrics, and with or without some form of physical activity.

Yaglou (1927) was one of the first researchers to use a psychological scale in the description of a thermal environment. Participating subjects were exposed to varying ambient temperatures and relative humidities and asked to describe their state on a five-point response scale from cold to too warm. Winslow, Herrington, and Gagge (1937) also used a five-point response scale with the terms very pleasant to very unpleasant. This scale deliberately used the term "pleasant" in an attempt to avoid reference to thermal sensations (cold or hot).

Many thermal comfort/sensation scales are based on seven or nine points with the thermal comfort sensation operationally defined to fall within that range. A seven-point scale from cold to hot, originally developed by Houghton and Yaglou (1923), was modified by changing the term "comfortable" to "neutral". This was compared to Winslow's pleasant scale and a four-point comfort sensation scale by Gagge, Stolwijk, and Hardy (1967). This scale comparison was done in an attempt to see if subjects would rate their sensations the same on all three scales. Results from this study and others indicate that the different scales prompted dissimilar responses from subjects (Vocak, Kopke, & Keul, 1976; Holmer, 1985; Morooka & Niwa, 1979).

Hollies (1965) developed a widely used comfort descriptor rating sheet with 15 comfort terms he found to be the most frequently used. An inverse intensity-rating scale was used so that the larger numbers corresponded to greater comfort and ranged from 1 "most comfortable" to 5 "uncomfortable in all areas" (Hollies, 1989). Through the years, Hollies and others have modified the intensity scale numbers and corresponding descriptors. In a recent study by Hyun, Hollies, and Spivak (1991), 'Human Perception Analysis' (HPA) was coined as a procedure by which the authors would identify new methods for assessing subjective or wearer comfort. In this study, the original comfort rating sheet was increased to 48 terms and the intensity scale ranged from 0 "not at all" to 4 "totally" (Figure 4). The "larger numbers of descriptors used in a wear test give less restrictions to subjects in expressing their sensations" (Hyun et al., 1991, p. 393). The descriptors relate to visual, tactile, and comfort sensations, and are divided into seven major categories of general comfort, warmth, fit, absorbency, weight, softness, and feel against the skin. The descriptors were also grouped as positive and negative for analyses.

Morris, Prato, Chadwick, and Bernauer (1985) and Markee, Hatch, Maibach, Barker, Radhakrishnaiah, and Woo (1990) used several different scales to assess human sensations in a

Overall Comfort Scale
1. Comfortable
2. - - - - - - - - - - - -
3. Slightly uncomfortable
4. - - - - - - - - - - - -
5. Moderately uncomfortable
6. - - - - - - - - - - - -
7. Very uncomfortable

Wetness Sensation
1. Dry
2. - - - - - - - - - - - -
3. Slightly wet
4. - - - - - - - - - - - -
5. Moderately wet
6. - - - - - - - - - - - -
7. Very wet

Thermal Sensation
1. Very cold
2. Cold
3. Cool
4. Slightly cool
5. Neutral
6. Slightly warm
7. Warm
8. Hot
9. Very hot

Contact Sensation
Stiff
Sticky
Non-absorbent
Clammy
Clingy
Picky
Rough
Scratchy
Breathable
Others

Rating scale for use with the contact sensations
0 = No contact sensation
1 = Slight
2 = ...
3 = Moderate
4 = ...
5 = Extreme

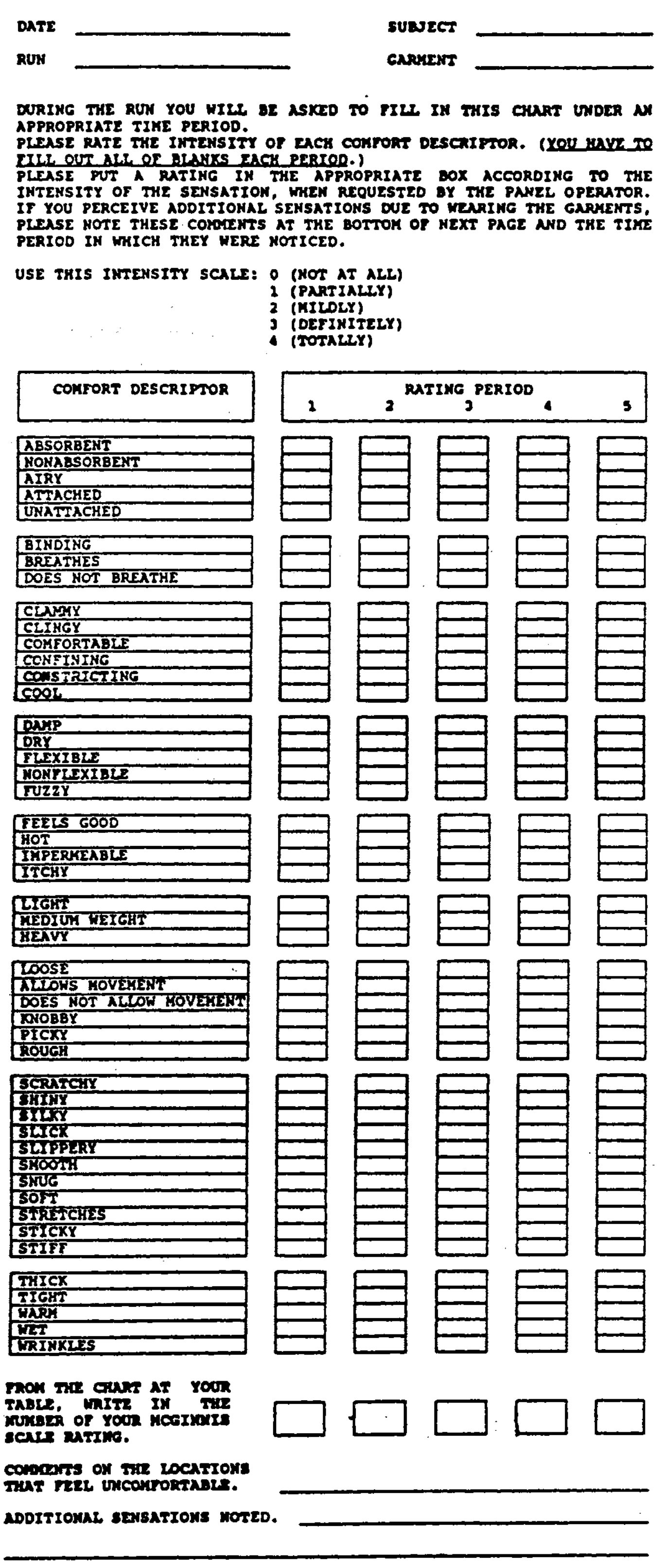
Figure 4. Comfort Scales. From "Comfort of Warm-Up Suits During Exercise as Related to Moisture Transport Properties of Fabrics" by M. A. Morris, H. H. Prato, S. L. Chadwick, and E. M. Bernauer, 1985, Home Economics Research Journal, 14, p. 165.

wear study. A seven-point overall comfort scale ranged from 1 "comfortable" to 7 "very uncomfortable" (Rohles, Millikin, & Kristic, 1979). A thermal sensation scale ranged from 1 "very cold" to 9 "very hot" (Figure 5).

The McGinniss Thermal Scale is a linear scale that was developed by Hollies (1977) to be used in both hot and cold environments for thermal stress assessment. The McGinniss Scale has been used by Hollies, Custer, Morin, and Howard (1979), DeMartino, Yoon, Buckley, Evins, Averell, Jackson, Schultz, Becker, Booker, and Hollies (1984), and Hollies, DeMartino, Yoon, Buckley, Becker, & Jackson (1984), and more recently by Hyun et al. (1991). One criticism of this scale is that it mixes comfort and thermal terms together, thereby confusing the two separate sensations.

In the specialized area of protective clothing, thermal comfort is very important for human acceptability reasons. Branson, DeJonge, and Munson (1986) used the Rohles et al. (1979) nine-point scale from very hot to very cold to assess thermal sensation under given test conditions. In addition, a thermal comfort assessment using a semantic differential scale with eight bipolar adjective pairs separated by nine spaces, developed by Rohles et al. (1983) was used to further improve the knowledge of comfort scaling techniques for protective clothing. A recent protective clothing study by Brandt and Otten (1991) used three different measures to assess the comfort felt by a person wearing cleanroom hood assemblies. The three measures consisted of the Hollies (1965) subjective comfort rating chart (with only 14 descriptors), the McGinniss Thermal Scale, and a subjective assessment of the subject's physical state (in the form of a seven-point semantic differential).

Still another psychological approach for subjectively evaluating thermal comfort, developed by Lavinia and Rohles (1987), compares a six-pair, bipolar, adjective thermal comfort ballot to a 32-item differential attribute ballot. For this multiple item ballot the rater must evaluate each descriptor with a seven-point scale from very accurate to very inaccurate. Two separate rating scales were generated from these two ballots, thermal satisfaction and dissatisfaction. When comparisons between the two were made "the findings suggested that the



DATE ____________ SUBJECT ____________

RUN ____________ GARMENT ____________

DURING THE RUN YOU WILL BE ASKED TO FILL IN THIS CHART UNDER AN APPROPRIATE TIME PERIOD.
PLEASE RATE THE INTENSITY OF EACH COMFORT DESCRIPTOR. (YOU HAVE TO FILL OUT ALL OF BLANKS EACH PERIOD.)
PLEASE 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 NEXT PAGE AND THE TIME PERIOD IN WHICH THEY WERE NOTICED.

USE THIS INTENSITY SCALE: 0 (NOT AT ALL)
1 (PARTIALLY)
2 (MILDLY)
3 (DEFINITELY)
4 (TOTALLY)

COMFORT DESCRIPTOR	RATING PERIOD 1	2	3	4	5
ABSORBENT					
NONABSORBENT					
AIRY					
ATTACHED					
UNATTACHED					
BINDING					
BREATHES					
DOES NOT BREATHE					
CLAMMY					
CLINGY					
COMFORTABLE					
CONFINING					
CONSTRICTING					
COOL					
DAMP					
DRY					
FLEXIBLE					
NONFLEXIBLE					
FUZZY					
FEELS GOOD					
HOT					
IMPERMEABLE					
ITCHY					
LIGHT					
MEDIUM WEIGHT					
HEAVY					
LOOSE					
ALLOWS MOVEMENT					
DOES NOT ALLOW MOVEMENT					
KNOBBY					
PICKY					
ROUGH					
SCRATCHY					
SHINY					
SILKY					
SLICK					
SLIPPERY					
SMOOTH					
SNUG					
SOFT					
STRETCHES					
STICKY					
STIFF					
THICK					
TIGHT					
WARM					
WET					
WRINKLES					
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 5. Comfort Descriptor Rating Sheet. From "Skin Sensations Perceived in Apparel Wear, Part I: Development of a New Perceptual Language" by S. O. Hyun, N. R. S. Hollies, and S. M. Spivak, Journal of the Textile Institute, 82(3), p. 392-393.

satisfaction and dissatisfaction scales did not measure the subjective response in the same way as the traditional comfort ballot" (Lavinia & Rohles, 1987, p. 1069). The differences in comfort ratings may have possibly been due to the fact that comfort sensations are affected by many factors other than just thermal considerations, as has been addressed.

Most of the previously mentioned psychological scales measured either general/overall comfort or thermal comfort only. Other studies combined these general comfort or thermal sensations together on the same ballot with sensations of wetness and/or tactile (Hollies, 1965; Hyun et al., 1991; Brandt & Otten, 1991).

Still other studies have focused on only wetness and/or tactile sensations. The determination of moisture in clothing has been limited in the past to mostly subjective scales. Hollies (1977) used a four-point scale with the terms dry, slightly damp, moderately damp, and wet to assess wetness perceptions of subjects wearing shirts that were treated with a fluorocarbon finish to change their drying rates. Later Hollies et al. (1979) used a four-point intensity scale to rate descriptive sensations experienced such as clammy, damp, clingy, and sticky.

Morris et al. (1985) and Markee et al. (1990), in addition to using general and thermal comfort scales, used a wetness sensation scale that ranged from 1 "dry" to 7 "very wet" and a contact sensation scale using nine descriptors that were rated using an intensity scale of 0 "no contact sensation" to 5 "extreme" (Figure 5).

Psychophysics

Recently, an innovative methodological technique was developed by Sweeney and Branson (1990a) to assess moisture sensation and proved successful. This technique, which was based on psychophysics, was carried further by Mord (1990) and Branson et al. (unpublished). Psychophysics is the scientific study of the relationship between stimulus and sensation (Gescheider, 1976). Stated another way, it is how the magnitude or intensity of a psychological sensation or experience is related to a variable physical stimulus (D'Amato, 1970).

Gustov Fechner, in the early 1800's, developed what are now called the classical psychophysical methods to show the relationship of mind to matter and suggested that an increase in the physical intensity of a stimulus corresponded to an increase in mental intensity. He proceeded to develop methods of empirically measuring psychological responses to physical stimuli and treated the results mathematically. Fechner's methods of classical threshold theory deal with detection and discrimination of stimuli which can be measured by the absolute and difference thresholds. "The complete sequence of events in any psychophysical determination is: "Stimulus ---> Sensation ---> Judgmental Response" (D'Amato, 1970, p. 120). The benefits over psychological scaling include the measurement of a single sensation in relation to its initiating physical stimulus of a known intensity.

Psychophysical Methods

There are three popular psychophysical methods that were developed by Fechner to explore the laws relating sensory experience to traits of the initiating stimulus: the method of limits, the method of constant stimuli, and the method of adjustment. The method of constant stimuli is regarded by Guilford (1936) as the most accurate and widely used psychophysical method and requires that a constant or fixed set of stimuli be presented in random order repeatedly to each observer (Coren, Porac, & Ward, 1978). This method of psychophysics was the one used by Sweeney and Branson (1990a), Mord (1990), and Branson et al. (unpublished).

Absolute Threshold. The absolute threshold (abbreviated AL) or *limen* (its Latin denotation) is the smallest amount of stimulus energy necessary for an observer to detect a stimulus and is one value that can be found using psychophysical methods (Goldstein, 1980). A common definition of the AL is "the stimulus value that evokes a sensation 50% of the time" (D'Amato, 1970, p. 119). This statistical value may vary from one psychophysical method to another because it is not a fixed quantity but rather one that varies over time and is ever-changing. Another psychophysical study by Sweeney and Branson (1990b) used the method of magnitude estimation to assess the intensities of moisture stimuli. Magnitude estimation is a direct psychophysical scaling technique where the subject makes direct numerical estimates of the sensory magnitudes produced by the random presentation of defined physical stimuli in relation to a standard stimulus (Sweeney & Branson, 1990b). Elder, Fisher, Armstrong, and Hutchison (1984a), Elder, Fisher, Armstrong, and Hutchison (1984b), and Elder, Fisher, Hutchison, and Beattie (1985) also successfully used psychophysical methods, but these studies assessed fabric stiffness, handle, and flexion.

Clothing and Fabric

The human body strives to maintain a constant body temperature which is critical to normal bodily functions. Heat production must be equal to heat loss for a person to be in heat balance (Guyton, 1986). If an imbalance occurs, the body's thermoregulatory mechanisms may be initiated to produce or dissipate heat by one or a combination of the physiological methods of heat exchange including conduction, convection, evaporation, radiation, sweating, and shivering, and/or behavioral type actions such as increased exercise or crossing the arms or legs.

Clothing plays a part in many of these methods of heat exchange because the exchange must occur through the clothing ensemble itself, thus interacting with the thermoregulatory system of the body (Mecheels & Umbach, 1977). One purpose of clothing is to sustain a constant body temperature which has been shown to be a vital factor in deciding comfort (DeMartino et al., 1984). A mean skin temperature of about 33-35^0 C and core temperature of 37^0 C is considered a thermally comfortable state when temperature regulation is totally vasomotor controlled (Hardy, 1968). "The best clothing system enables the body's thermoregulation under subjectively felt comfort conditions to control the broadest range of different climatic conditions and different work loads. This is termed the psychometric range of a clothing system" (Mecheels & Umbach, 1977, p. 134).

It is generally agreed that the major physical factors that influence clothing comfort are the movement of heat, moisture, and air through fabric (Slater, 1977; Mehta & Narrasimham, 1987). The capability of clothing to handle moisture at the skin interface and the nature of that contact can greatly influence clothing comfort sensations (Hollies, 1965; Barker et al., 1990).

Hollies (1977) showed that as water content increased the wearers were accurately able to perceive the increase. A study conducted with vests of cotton and polypropylene worn in four combinations in a cold environment with periods of intensive walking (to promote sweating), produced similar results as did another study with wool and nylon garments (Vocak, Kopke, & Keul, 1976; Holmer, 1985).

Contact sensation may be escalated when sweaty moist skin is interfaced with fabric, even when a very small amount of moisture is involved, causing discomfort (Hollies, 1965; 1971). Results indicated a strong relationship between the water content of the clothing due to sweating, the relative humidity, and the subjective comfort rating assigned to the garment worn. As fabric/clothing and environmental moisture increased, the comfort rating of that garment decreased (Hollies, 1971). A similar study by Scheurell et al. (1985) indicated discomfort sensations were directly influenced by the amount of moisture at the clothing/skin interface, which resulted in lower comfort ratings of knit shirts after exercising in a hot environment with varying humidity.

Studies on the tactile perception of clothing, or the actual interface sensation between fabric and skin have exposed subjects to exercise and/or changing environmental conditions. Hollies, Custer, Morin, and Howard (1979) used cotton and Nomex shirts and cotton and polyester/cotton blend jeans and found a comfort preference for the cotton garments. Women subjects exposed to exercise and a hot-dry then hot-humid environment found cotton leotards were preferred over various other fiber contents (Hyun et al., 1991). DeMartino et al. (1984) used long sleeved cowl neck tops of untreated polyester, cotton, and polyester/cotton blends and found that the cotton was considered most comfortable and was preferred over the other fabrics. In a second part of this same study, polyester was modified through engineering, cross-section variation, and pressure jet treatments and showed improved perceived comfort that was equal to or exceeded polyester/cotton blends and all cotton from part one of the study. Under normal wearing conditions when the body's heat balance was held constant and there was no active sweating, the perception of tactile differences was not present except when the fabric was highly textured (Hollies et al., 1984).

Markee et al. (1990) found that various perceived sensations to three garments worn by exercising female subjects in a hot-humid environment differed only for perceived overall comfort. There was no difference between fabrics (cotton and two different polyesters) for wetness or thermal sensations which was attributed to the extremely small differences in physical characteristics of the fabrics. However, contact descriptors related to wetness (clammy, sticky, nonabsorbent, breathable) were significantly different for the three knit fabrics. The soft polyester received more positive comment ratings than the cotton and the stiffer polyester. In addition, contact descriptors relating to tactile sensations also differed by fabric. The stiff polyester was considered scratchiest, stiffer, and rougher.

In the psychophysical studies done by Sweeney and Branson (1990a), Mord (1990), and Branson et al. (unpublished), the absolute thresholds (ALs) were determined by presenting subjects with stimuli (one at a time) and having them respond "yes" or "no" as to whether they detected moisture or not. Sweeney and Branson (1990a) used one knit fabric, a 50/50 polyester cotton blend, while Mord (1990) used that same fabric (C/P) plus an all cotton (C), all polyester (specially engineered for comfort) (P), and a double sided nylon/cotton (N/C). More recent, yet unpublished, psychophysical research used four more knit fabrics: 94% cotton/6% spandex blend (C/SP), 90% polyester (specially engineered)/10% spandex blend (P/SP), 90% polypropylene/10% spandex blend (PP/SP), and an 80% nylon/20% spandex blend (N/SP).

The ALs of these fabrics, as well as their physical characteristics can be found in Table 1. An AOV of AL values yielded a significant difference at $p < .03$. An LSD multiple comparison test indicated no significant differences between fabrics PP/SP and P/SP, and between C/P, N/C, N/SP, and C (Table 2). Fabrics P, P/SP, and PP/SP had the lowest ALs, meaning that moisture was detected at very small amounts, and contain polyester or polypropylene as their major fiber contents. In contrast, fabrics C and C/SP had the highest Als, meaning that moisture was detected only at substantially higher amounts, and both contain cotton as their major fiber content. In other words, there were significant differences by fiber content.

Moisture Transport in Fabric

"Comfort acceptance of garments next to the skin is in some way related to the ability of these garments to remove sweat from the skin-garment interface" (Hollies, 1977, p. 119). The ability of fabric to transport moisture is very important and has been studied in depth in research laboratories. The restriction of water passage by diffusion can be sensed subjectively (Fourt & Hollies, 1970).

There are several physical properties relating to moisture transport such as wettability, wicking, moisture regain, moisture content, vapor permeability, and drying rate that can be classified into two major groups, liquid and moisture vapor transport (Latta, 1977; Slater, 1977). Liquid and moisture vapor transport are "critical in determining the degree to which fabric reduces the heat dissipation process for a clothed body" (Hatch, Woo, Barker, Radhakrishnaiah, Markee, & Maibach, 1990, p. 407).

Liquid Moisture Transport

Liquid moisture transport refers to water transport through capillary interstices in yarns and/or to the migration of water along the fiber surfaces of fabrics. Wettability is the behavior or rate of sorption of liquid moisture when applied to a fabric surface (Latta, 1977). The wetting process is very complex because it deals with the interaction of such things as interfacial tension, the condition of the fiber surface, and capillary action (Mehta & Narrasimham, 1987; Clark & Miller, 1978). Improving the wettability properties of fabric may be done through caustic treatments that may pit the fabric surface.

A form of mass water movement which occurs through the capillaries formed by the individual fibers of the fabric is known as wicking. The rate of liquid moisture travel by wicking depends somewhat on fiber arrangement which controls capillary size and continuity (Hollies, Kaessinger, Watson, & Bogaty, 1957). Liquid moisture transport is enhanced by other fiber/fabric characteristics. The higher the surface energy of a fiber, the greater its wicking ability (Hatch et al., 1990).

Some believe that there exists a critical moisture value before the capillary action of wicking can occur (Adler & Walsch, 1984). The capillaries must be completely full so that the moisture can diffuse in and out of fibers. At moisture contents below this critical value there is not enough external pressure to move the liquid and only vapor transport occurs. Ideally, wicking promotes quick drying and faster cooling in hot environments or when sweat is present on the skin's surface. Wicking is not important in cooler environments or when there is no accumulation of liquid sweat on the skin.

In a study by Hatch et al. (1990), a cotton knit had high wicking rates and a polyester knit had much lower wicking rates. Wicking was affected by hydrophylicity of the fibers involved. When cotton and polyester were studied for their wicking abilities, by Adler and Walsch (1984), they were shown to have the same tendency to increase transport for low initial moisture contents and decrease transport for contents that were greater than their absorptive capacities. A finish did increase wicking in polyester shirts, but did not affect transient moisture transport between layers and did not improve comfort ratings. The extent or rate to which applied moisture wicks was found to be a function of the hydrophilic treatment to the polyester fabric. However, in knitted fabrics, wicking between layers did not transpire well as others have found, probably due to the large air spaces that increase capillary volume and decrease interfabric contact (Adler & Walsch, 1984; Latta, 1984; Hong, 1985; Farnworth & Dolhan, 1985).

Farnworth and Dolhan (1985) tested cotton (known for poor wicking) and polypropylene (known for very good wicking) on a sweating hot plate in combinations with a cotton/nylon blend shirt fabric. At high sweat rates, drying (the rate of evaporation from wet fabric) occurred differently for the two fabrics which was attributed to their different wicking abilities. The polypropylene indicated that wicking had transpired within the fabric, but it was not certain whether water was being transferred to the other fabric layer of shirting. Further experimentation showed that heat loss, during heavy sweating, between the two fabrics was about the same.

Liquid moisture transport between fabric layers can only occur when moisture content is very high or if a wet and dry fabric layer are held together under very high pressure (Adler & Walsch, 1984). But in actual wear, wicking rarely occurs because garments usually don't get completely wet, except in the case of extreme exercise and very active sweating (Hong et al., 1988). More commonly, certain regions such as the arm pit may hold higher moisture concentrations while the rest of the garment remains fairly dry (Latta, 1984). Laboratory wicking tests only measure the rate of vertical wetting which is not an indication of a fabric's ability to transport moisture, especially in actual wear (Wallenberger, Franz, Dullaghan, & Schrof, 1980).

Moisture Vapor Transmission

Moisture vapor transmission/permeability is the second grouping of moisture transport methods and it can be defined as the rate or passage of water vapor through fabric (Latta, 1977). Vapor permeability is the major way moisture is transported through a fabric layer or clothing system (Hollies, 1971). Whether the moisture occurs on the skin as sweat and passes outward as a vapor, or occurs in the environment as rain and passes inward to the microclimate depends on the direction of the concentration gradient (Vocak, Kopke, & Keul, 1972).

There are three ways for moisture vapor to travel through fabric: through fiber interiors, along the fiber surfaces, and through air spaces between fibers (Wehner, Miller, & Rebenfeld, 1988; Hatch et al., 1990). The dominant method of travel is through the air spaces of the fabric which can be varied by fiber structure, because a water molecule is much more likely to diffuse through air than fabric (Mehta & Narrasimham, 1987; Wehner et al., 1988). Woodcock (1962a, b) developed an apparatus to find the moisture permeability index for fabric and fabric systems. Results from his test show the permeability index falls with decreasing wind and rises with increasing wind, as would be expected. Experiments looking at moisture vapor permeability have shown cotton, rayon, and a 50/50 cotton/polyester blend to be most favored over modified polyester and polypropylene (DeMartino et al., 1984; Hollies et al., 1984). In Hatch et al. (1990), the finer diameter polyester fibers had the highest water vapor transmission rate. In addition, diffusion rates of the three knit fabrics (cotton and two polyesters) at 22^0 C were influenced by the difference in the vapor pressure between the water surface and ambient air in the lower temperature. In the warmer environment of 32^0 C, the water vapor transfer rate is influenced again by the vapor pressure difference and also by the temperature difference between ambient air at 22^0 C and the water surface at 32^0 C.

Dynamic moisture changes. Because the humidity of the environment is ever-changing, it is believed that moisture levels of fabric are dynamic also. A clothing hygrometer was developed by Hollies and Penoyer (1970) to measure the moisture content of fabric surfaces next to the skin. Results of this testing device have indicated that the relative humidity around the wearer influenced the amount of moisture that condensed on the fabric surface.

A dynamic experience termed "after exercise chill" may occur when moisture accumulates in the form of condensation inside clothing as a result of unevaporated sweat (Figure 6). This moisture will eventually evaporate after active sweating stops, cooling the body when it no longer needs to be, thus causing the chill (Farnworth & Dolhan, 1985; Tsuchida, Harada, & Uchiyama, 1982).

Condensation (the change from moisture vapor to liquid) can also occur when local vapor pressure rises to the saturation level at the local temperature due to the diffusional resistance of one layer of fabric or to the larger vapor pressure gradient close to the skin causing inward traveling diffusion (Farnworth, 1986a).

Hygroscopic absorption of water vapor is similar to condensation because it can become trapped in clothing also, liberating its heat of vaporization and raising the temperature in the microclimate. However, absorption can occur at all vapor pressures, not just at the saturation level like condensation, and the quantity of water absorbed is limited (Farnworth, 1986a).

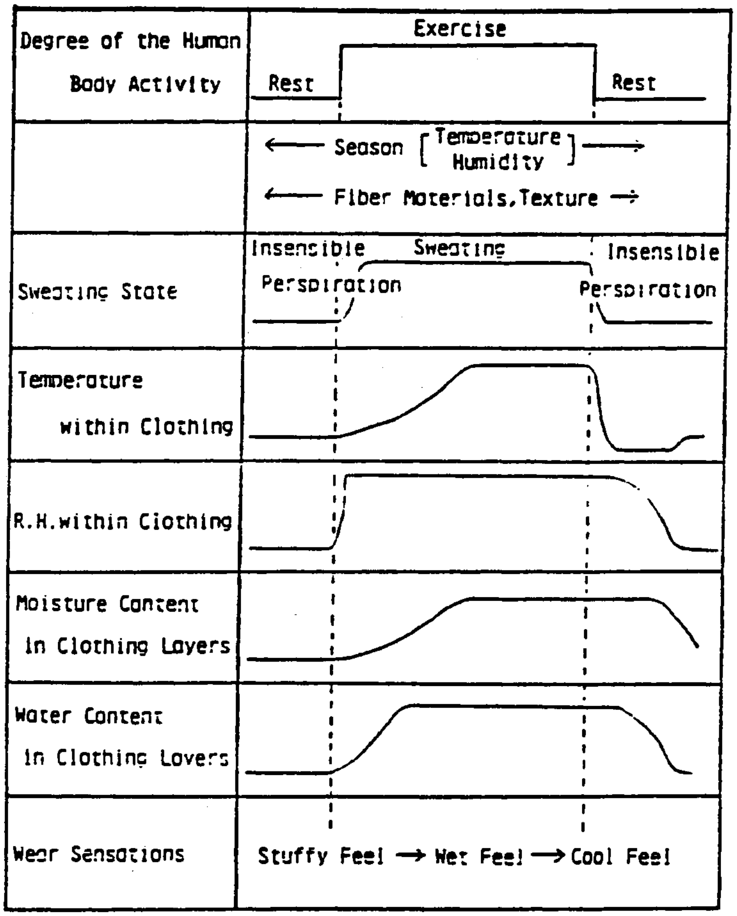


Figure 6. Model Diagram Showing Relationship Between the Degree of the Human Body Activity, the Microclimate within Clothing, and Wear Sensations. From "Fabric Properties Influencing Moisture and Heat Transport Through Fabrics" (p. 423) by K. Tsuchida, T. Harada, and S. Uchiyama, 1982. In S. Kawabata, R. Postle, & M. Niwa (Eds.), Objective Specification of Fabric Quality, Mechanical Properties and Performance, Osaka, Japan: The Textile Machinery Society of Japan.

Scheurell et al. (1985) designed the first study to observe dynamic moisture changes by applying cobaltous chloride to undyed fabric to detect moisture levels. A device to study this movement of moisture at the fabric surface was developed with a wetted chamois heated by a sweating hot plate to a skin temperature of 34° C to simulate sweating skin. Knitted cotton and polyester (with and without finishes) were held in a hoop away from the chamois to duplicate the dynamic water distillation process that can occur in clothing wear. This part of the experiment was done to see if fabrics of similar surface hairiness would pick up the same amount of moisture independent of fiber type. While the fabrics did gain the same amounts of moisture, subjects did not perceive them similarly in terms of comfort.

In the second part of the experiment by Scheurell et al. (1985), woven cotton, polyester, and a 50/50 cotton/polyester blend were padded with cobaltous chloride, dried in hoops, and exposed to the chamois device. The purpose of using cobaltous chloride is that it forms hydrates with water that take on a range of colors from blue to pink, depending on the quantity of moisture at the fabric surface at a given time. Subjects rated these treated samples on a color index of one to ten, matching Munsell hues, which were plotted as a function of time on the device. Results indicated effects by fiber only.

It is believed that mobile water films can form on cotton's internal surface, but not on polyester's, providing mobility for condensed water at low moisture levels. These films occur in fibers that have a certain range of internal micropore sizes that when present cause water to move freely from one fabric surface to another (Scheurell et al., 1985). This traveling action can decrease the concentration of moisture next to the skin.

Other researchers have used the wetted chamois and sweating hot plate to study the fabric surfaces of cotton, polyester, and a 50/50 cotton/polyester blend fabrics (Hong et al., 1988). Results indicated that polyester has a steeper time curve and higher overall moisture vapor pressure than cotton, with the blend falling in the middle, for both inner and outer surfaces (Figures 7 and 8). Cotton's slow and gradual moisture buildup over time may cause people to feel dryer because vapor pressure is low and the body is not shocked physiologically by a rapid

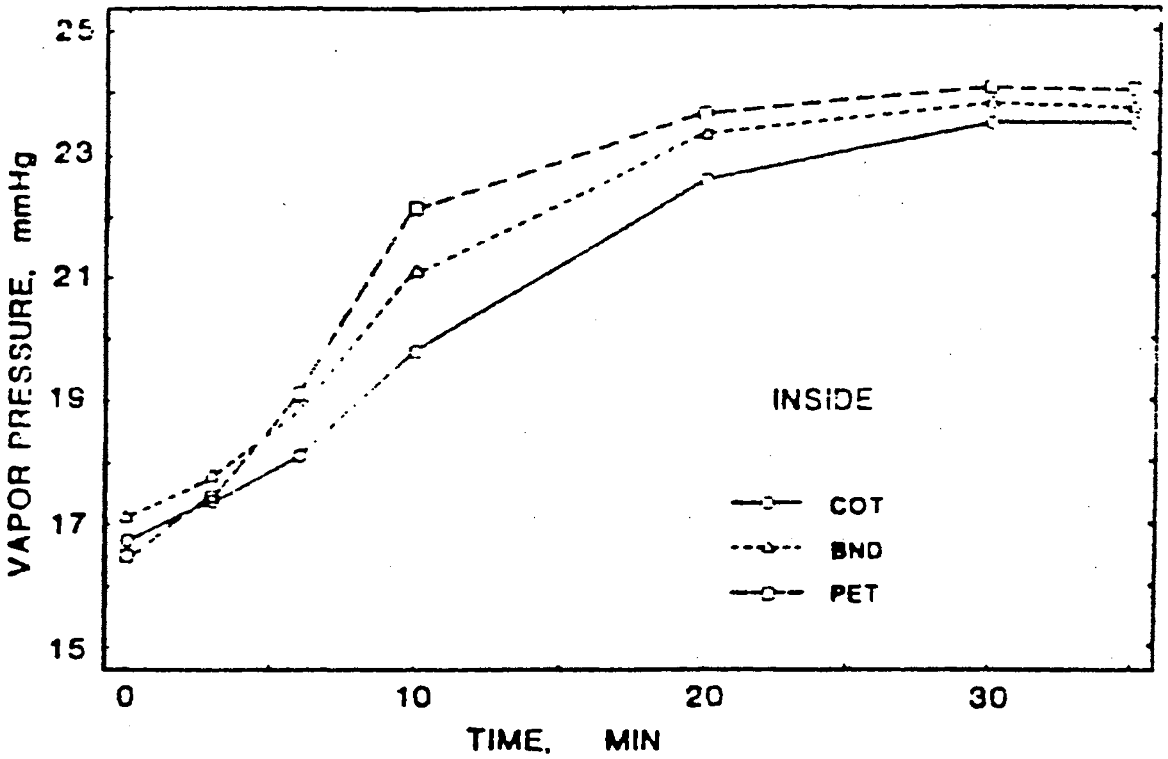


Figure 7. Dynamic Moisture Vapor Transfer at the Inner Fabric Surface. From "Dynamic Moisture Vapor Transfer Through Textiles" by K. Hong, N. R. S. Hollies, and S. M. Spivak, 1988, Textile Research Journal, 58, p. 702.

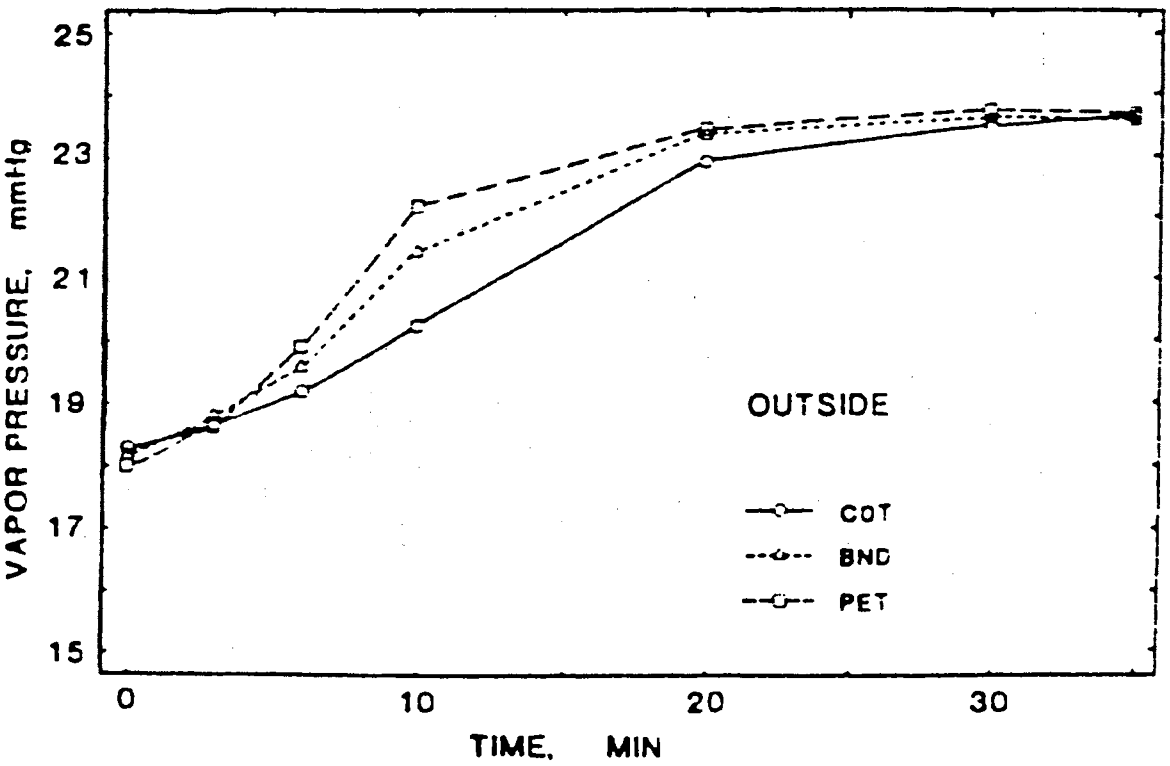


Figure 8. Dynamic Moisture Vapor Transfer at the Outer Fabric Surface. From "Dynamic Moisture Vapor Transfer Through Textiles" by K. Hong, N. R. S. Hollies, and S. M. Spivak, 1988, <u>Textile Research Journal</u>, <u>58</u>, p. 702.

moisture increase leading to discomfort sensations (Hong et al., 1988).

Recently, Kim and Spivak (1994) focused on measurements of temperature and moisture concentration at the inner fabric surface as comfort variables. Discomfort sensations are associated with the amount of moisture present on the inner fabric surface and microclimate during transient conditions. "A simulated sweating skin system was used to measure how fiber type influences fabric surface vapor pressure and temperature changes" (Kim & Spivak, 1994, p. 119). Fiber differences were found for these variables at the inner fabric surface during dynamic moisture transfer. Temperature changes were also found between the simulated skin and first layer of fabric in Yasuda, Miyama, and Yasuda (1992).

The cotton/cotton had a slower rate of inner vapor pressure buildup due to its fast and higher sorbing power during dynamic conditions (Figure 9). In addition, the temperature at the cotton/cotton inner surface rose at the same time (Figure 10). These two variables indicate continuing sorption and evaporation of cotton fabric. The higher rate of sorption and evaporation leads to slower vapor pressure changes at the inner surface. The polyester/polyester showed rapid build-up of moisture at the inner surface and microclimate due to weak and small sorption capacity. However, gradual temperature changes suggest that the polyester/polyester transported moisture by direct condensation of vapor on the fabric surface in the form of a film that must be redistributed. The cotton/cotton fabrics would result in a drier, warmer feeling at the onset of sweating, whereas the polyester/polyester fabric would result in a cooler, wetter feeling (Kim & Spivak, 1994).

The transient period in a fabric after exposure to a humidity gradient is a result of moisture sorption and flux, both of which are measurable by a device developed by Wehner et al. (1988). The amount of moisture sorption can be calculated from the original moisture content of a sample and the moisture regain value. Results of Wehner's et al. (1988) tests, while not generalizable to fiber type, showed there was competition between moisture absorption of fabric and the moisture flux across it. Absorption of these fabrics tested increased very fast then leveled out linearly. The slope of this function is known as the rate of moisture flux. As the rate

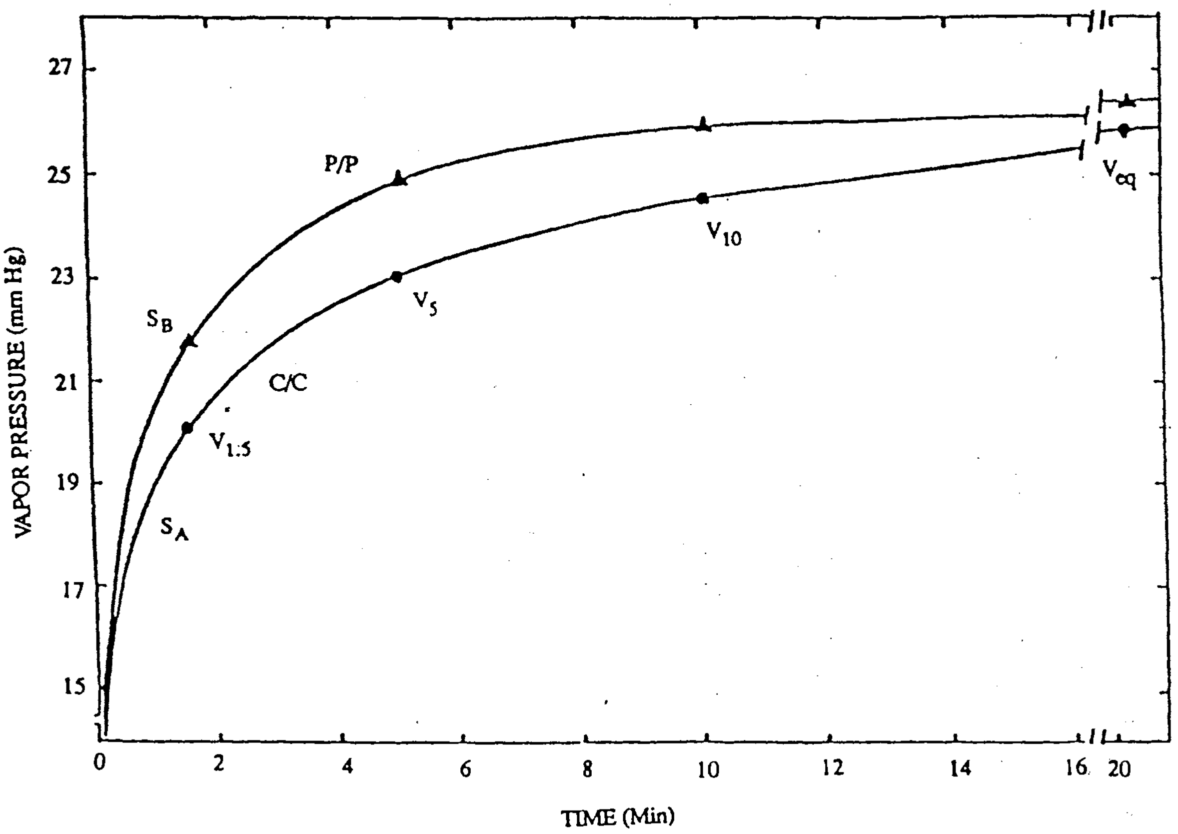


Figure 9. Dynamic Surface Vapor Pressure Changes, as a Function of Time, Measured at the Inner Fabric Surface Facing the Sweating Skin. From "Dynamic Moisture Vapor Transfer Through Textiles. Part II: Techniques for Microclimate Moisture and Temperature Measurement" by J. O. Kim and S. M. Spivak, 1994, Textile Research Journal, 64(2), p. 116.

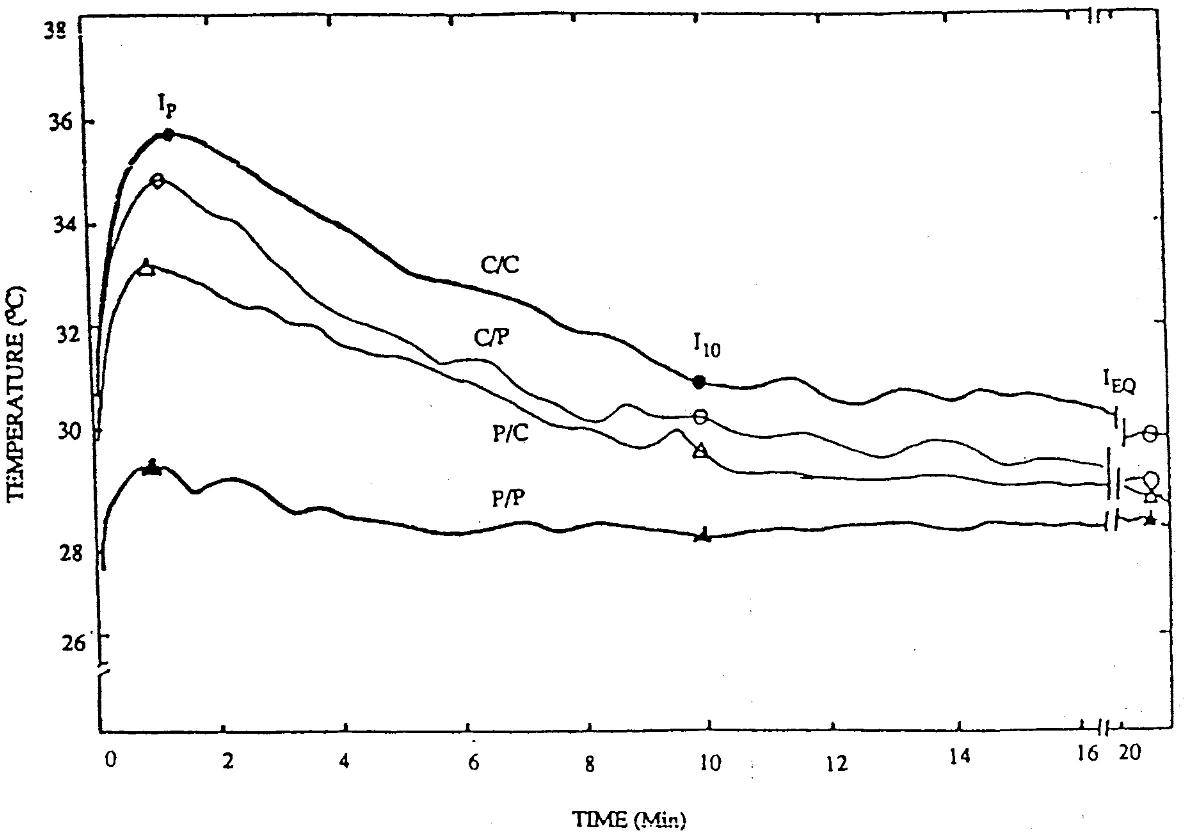


Figure 10. Dynamic Surface Temperature Changes with Time, Measured at the Inner Fabric Surface. From " Moisture Vapor Transfer Through Textiles. Part II: Techniques for Microclimate Moisture and Temperature Measurement" by J. O. Kim and S. M. Spivak, 1994, Textile Research Journal, 64(2), p. 118.

of moisture sorption reaches zero the rate of moisture flux approaches a steady value (Wehner et al., 1988).

Farnworth (1986b) created a numerical model to measure the combined diffusion of heat and water vapor through multiple clothing layers taking diffusional characteristics of condensation, evaporation, and sorption into account. Calculations performed in a time-dependent mode were compared to experiments with a sweating hot plate. The numerical model was found to be somewhat useful in understanding the interactions between condensation, evaporation, and sorption. A layer of fabric can be represented by a few numbers and its desirability can be determined from its influence on overall heat and moisture transport.

A cross section of the skin-microclimate-fabric-environment system (the triad) has been characterized recently by Hong (1985), Hong et al. (1988) (Figure 11), and Kim and Spivak (1994) (Figure 12). The model assumes that Cs, the moisture concentration of the ambient air, is fully saturated and that the fabric surfaces (Ci and Co) include surface fibers, the entrapped air between those fibers, and the still air layer just above the fibers.

Vapor diffusion through clothing goes through phase changes (vapor and liquid) at the fabric surface. The small moisture flux along the fibers (qf) is mainly the complex process of distillation and is believed to be extremely important to clothing comfort (Hong et al., 1988). The moisture distillation process entails condensation of water vapor from the microclimate (Cm) onto the inner fabric surface (Ci), transferring a liquid film along qf to the outer fabric surface (Co) where re-evaporation and diffusion into the environment can take place (assuming it's dry).

The problem with moisture in fabric is that it is dynamic, and steady-state type test methods measure moisture after time (te) has passed, thereby excluding the dynamic region OAB (Figure 13). Wear tests usually occur over time, taking the transient area into consideration. Dynamic surface wetness methods deal with moisture transfer prior to the time it takes to reach equilibrium, between points B and A. Hong (1985) and Hong et al. (1988) studied the contribution of fabric surfaces (Ci and Co) in relation to the area OAB to determine whether it varies by fiber or finish and how it effects moisture concentrations in the microclimate at Ci, Co,

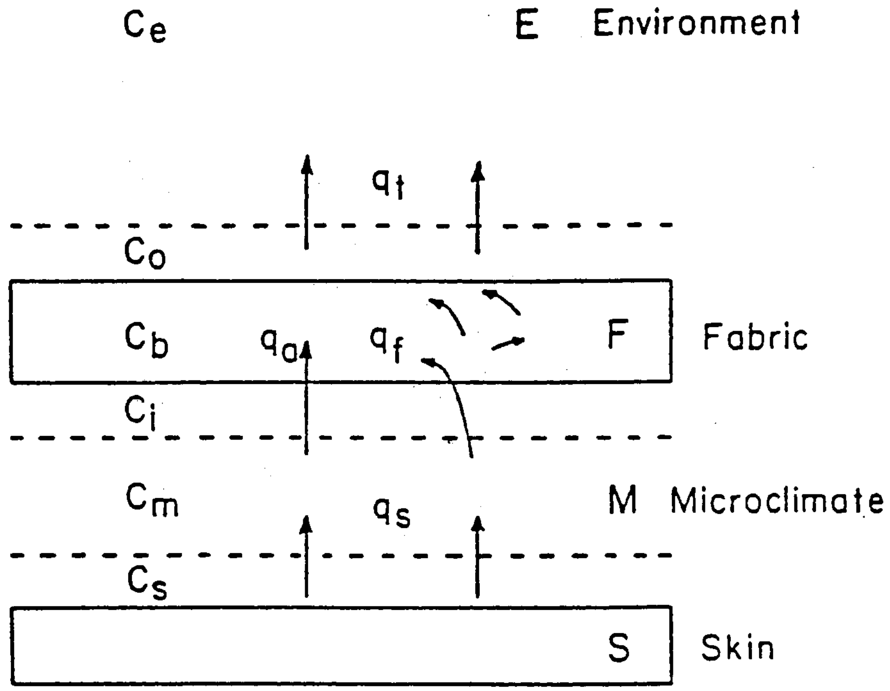


Figure 11. Cross Section of the Skin-Microclimate-Fabric-Environment System. From "Dynamic Moisture Vapor Transfer Through Textiles" by K. Hong, N. R. S. Hollies, and S. M. Spivak, 1988. Textile Research Journal, 58, p. 698.

C_s = moisture concentration at the skin surface, g/cm^3
C_m = moisture concentration in the microclimate between the skin and inner fabric surface, g/cm^3
C_i = moisture concentration at the inner fabric surface, g/cm^3
C_b = moisture concentration in the bulk fabric, g/cm^3
C_o = moisture concentration at the outer fabric surface, g/cm^3
C_e = moisture concentration in the environment, g/cm^3
q_s = moisture flux from the skin, g/cm^2 sec
q_a = moisture flux through the open air spaces in the fabric, g/cm^2 sec
q_f = moisture flux passing along internal pore surfaces in fibers, g/cm^2 sec
q_t = moisture flux passing through the fabric, g/cm^2 sec

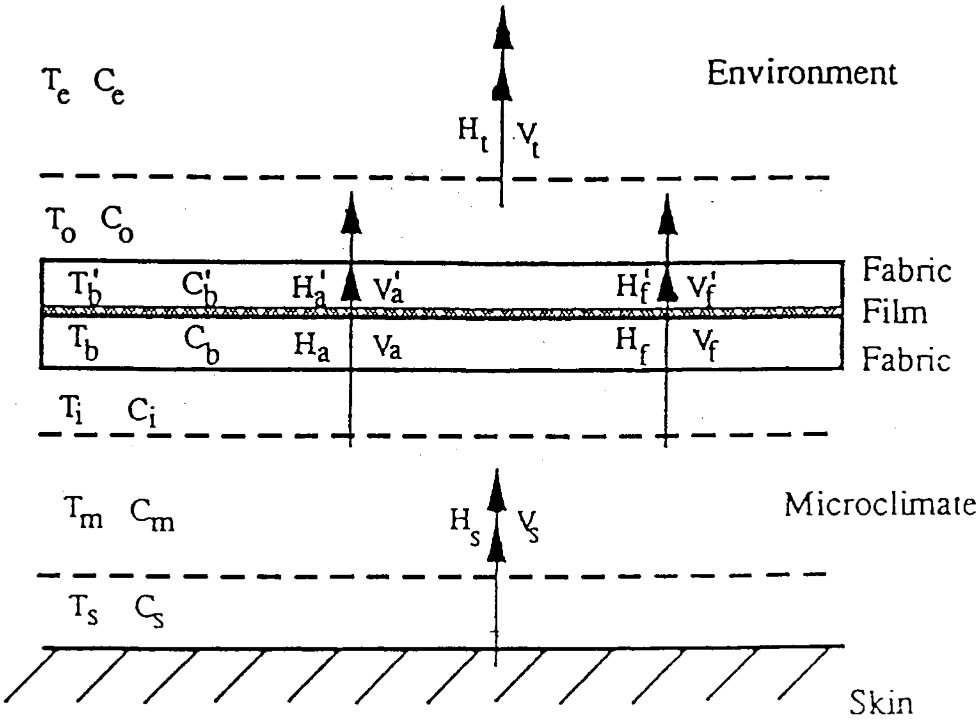


Figure 12. A Conceptual Framework for Fabric Surface Temperature and Moisture Vapor Transfer Effects, in Cross-Sectional View. From " Moisture Vapor Transfer Through Textiles. Part II: Techniques for Microclimate Moisture and Temperature Measurement" by J. O. Kim and S. M. Spivak, 1994, Textile Research Journal, 64(2), p. 113.

H = heat flux
V = moisture vapor flux

T = temperature
C = moisture concentration

s = skin surface
m = microclimate
i = inner fabric surface
o = outer fabric surface

a = flux through air space of inner fabric layer
a' = flux through air space of outer fabric layer
b = moisture absorbed by inner fabric layer, (T_b = bulk thermal capacitance)
b' = moisture absorbed by outer fabric layer
f = flux through fibers in inner fabric layer
f" = flux through fibers in outer fabric layer
e = environment
t = flux to outer environment

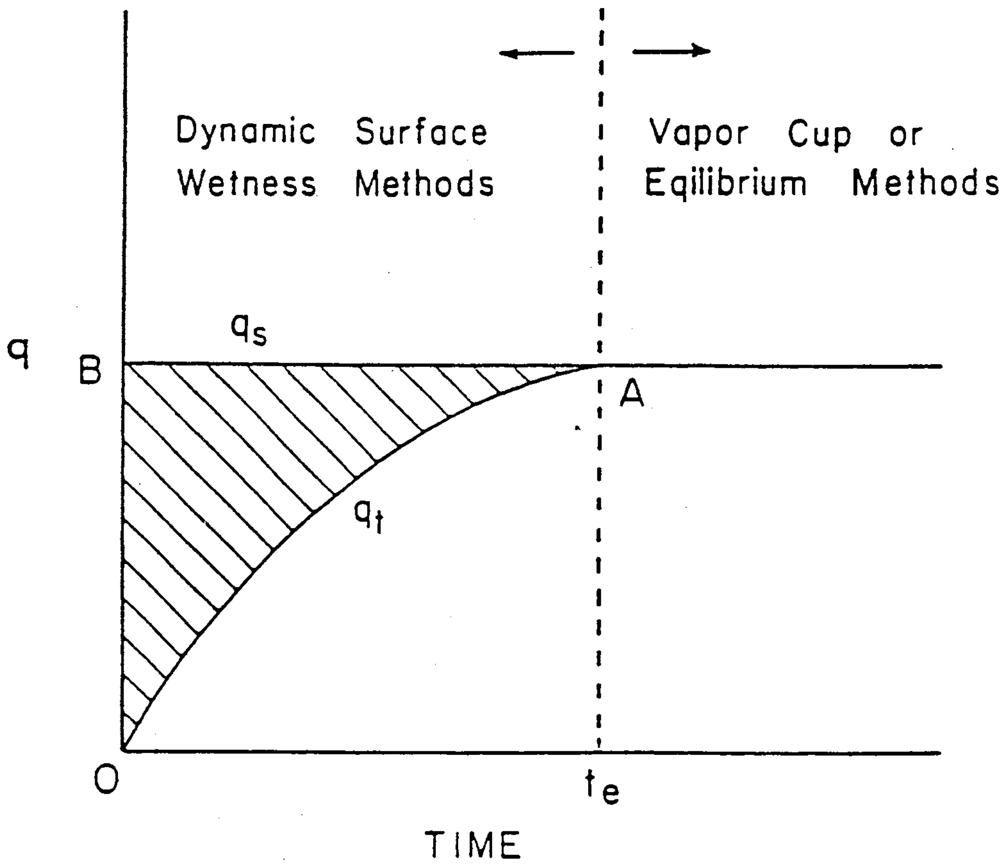


Figure 13. A Generalized Determination of Moisture Transfer Variables. From "Dynamic Moisture Vapor Transfer Through Textiles" by K. Hong, N. R. S. Hollies, and S. M. Spivak, 1988. <u>Textile Research Journal</u>, <u>58</u>, p. 699.

Area OAB = area between q_s and q_t, equals the amount of moisture held near skin, microclimate, inner fabric surface, bulk fabric, and outer fabric surface

t_e = time to reach equilibrium for moisture buildup in the microclimate M

Cb, and Cm. Results reported earlier indicated that there were differences by fiber type.

Fabric Surface Characteristics and Mechanical Properties

The nature of the fabric surface is extremely important to clothing comfort as mentioned previously. The number and type of contact points varies by fabric and is not homogenous (Barker et al., 1990). "Ridges are formed by interlaced or looped yarns" (Barker et al., p. 491, 1990). A spun yarn will tend to be fuzzier due to the large number of short fiber ends protruding from the fabric surface. The degree of fuzziness depends on fiber type, length, and spinning method used. The fabric surface affects warm/cool sensations (thermal) in that a larger surface area of contact between fabric and skin causes a greater flow of heat from the skin, making the fabric feel cooler (Barker et al., 1990). Fabrics of filament fiber yarns will tend to be cooler feeling due to the lack of fuzziness which allows greater fabric/skin contact. Therefore, "minimizing body contact could be and important determinant of comfort, especially in activewear clothing where the skin is wet with sweat" (Barker et al., 1990, p. 493). However, this idea may conflict with garment design of activewear. The stiffness of a fiber and/or drape of a fabric is also important in how fabric rests against the skin (Barker et al., 1990).

Gwosdow et al. (1986) conducted research to see if skin wettedness influenced perception of fabric texture and pleasantness. Subjects were exposed to different environmental conditions: neutral, hot-dry, hot-humid, and back to neutral, and had six fabrics varying in texture pulled across their inner forearm. Interestingly, all fabrics were reported as most textured in the hot-humid stage of testing in Gwosdow et al. (1986). It is very common, when the environmental conditions are hot-dry or hot-humid and or when the subjects are made to exercise to induce sweating, for all the sensation types (general comfort, thermal, wetness, contact) to become more negative in intensity.

In a wear study involving an exercise protocol, both hot and cold environments, and eight fabrics by Li, Keighley, McIntyre, & Hampton (1991), subjective wearing preference votes from both environments were closely related to fabric roughness and fullness, fabric perpendicular deformability, and moisture transport properties of fabric wettability and permeability. A second correlation suggested that handling preference votes were mainly related to fabric stiffness, perpendicular deformability, yarn stiffness, and fabric wettability. In general, objective laboratory measurements of physical properties of fabrics showed good ability to predict subjective preferences for clothing.

Subjects in the Yamakawa and Isaji (1987) study touched cotton broadcloth fabric samples that had moisture contents of dry (1-6%), moist (7-100%), or wet (80-640%) and temperatures of warm, medium, or cold. Subjects were asked to classify clamminess into five rankings. Results showed that reports of clamminess were dependent on moisture content, the temperature of the fabric sample, and the texture of the fabric sample. When the moisture content of the sample was high and the temperature low, heat was drawn (conducted) from the skin to the sample causing an increase in the latent heat of vaporization. Since water is a better conductor of heat than air, very moist fabric samples conducted heat better than dry samples (Yamakawa & Isaji, 1987).

In Hatch et al. (1990), cotton knit had higher thermal conductivity and conductance than either of the polyester knits, probably due to its hydrophilic nature. "Thermal conductivity is useful for analyzing the effect of the material properties on heat transfer" (Hatch et al., 1990, p. 409). The main form of heat transfer for these fabrics was conduction through the air entrapped in the fabric. The polyester knits had lower thermal conductivity due to their higher porosity and coarseness of the fibers.

In this same study the energy dissipation rate increased when moisture, in the form of sweat, was present. This result was due to evaporation energy in the transfer of heat through the fabric. Energy dissipation can also be increased with increased air velocity.

Dry heat transfer is related to fabric thickness, bulk density, volume fraction, and thermal conductance. Evaporative heat transfer is related to fabric porosity and air permeability. In addition, Hatch et al. (1990) found that both dry and evaporative energy transfer are influenced more by the knit fabric thickness and bulk density rather than by fiber type.

Skin

Evaporation of sweat from the skin's surface is an excellent and efficient means of heat dissipation when the body is trying to lose heat. The conversion of liquid sweat to a vapor state depends on the vapor concentration gradient between the body and ambient air (Jensen, 1980). If the environment is saturated with moisture (humidity or rain) sweat will not evaporate from the skin's surface. This dilemma is further complicated by clothing and the degree to which a particular fabric acts as a vapor barrier to evaporating sweat.

Sweat glands are the physiological mechanisms controlled by the sympathetic nervous system, that produce sweat when stimulated. The volume of sweat secreted is proportional to the number of nerve impulses received from the brain. If the body is in heat balance, sweat in excess will not be produced, although insensible perspiration occurs continuously in various body parts. A study by Tokura and Midorikawa-Tsuratani (1985) using untreated and hygroscopically treated polyester and cotton found that sweat produced by the body varied by fabric in a warm environment. Sweat rate was measured at the frontal chest level with thermocouples and hygrometer after one hour. In addition, sweat drops were wiped off the skin's surface with a dry towel that was weighed along with the garment ensemble worn.

The region of the skin that touches fabric is the stratum corneum (SC) made up of 12 to 15 layers of dead cells forming the epidermis. The purpose of the SC is to serve as an environmental barrier for the body and "helps to maintain an optimal hydration state for internal organs by controlling the passage of water" (Hatch et al., 1987, p. 584). A change in the SC water content can be accomplished by occlusive materials and some hand lotions by causing the surface to become more hydrated thereby increasing evaporation. A change in the SC water content can also be initiated by sweating due to exercise. The SC increases the amount of unbound water and controls the rate of loss of water to the environment which is influenced by environmental conditions (Blank, 1952; Markee, Hatch, French, Maibach, & Wester, 1991). The amount of relative humidity in the air can change the SC's hydration and evaporative capabilities--as environmental humidity increases evaporation from the skin decreases (Hatch, et al., 1987). Air movement can also alter the hydration of the SC by increasing the rate of evaporation by forced convection, altering the water flux through the skin (Blank, 1952). More recently, fabric moisture content has been found to influence SC hydration (Hatch, Markee, Prato, Zerconian, Maibach, Kuehl, & Axelson, 1992).

Transepidermal diffusion varies greatly over the body despite fairly uniform skin thickness, except for the palms and soles of the feet (Rushmer, Buettner, Short, & Odland, 1966). The palm's SC layer is 40 times thicker than the back of the hand and sweats continuously and invisibly even in a cool environment, as do the soles of the feet (Baker & Kligman, 1967; Kuno, 1959).

In a study done by Hatch, et al. (1987), two different fabrics (some covered with plastic film) were placed on subjects' skin for various time periods. Results showed a statistical difference in SC hydration and evaporation in occluded samples due to fabric type, but no statistical difference in unoccluded samples due to fabric type. The nondifference in unoccluded samples is possibly attributed to the body's ability to evaporate moisture from the fabrics at conditions of 22^0 C and 55% relative humidity, thus achieving a steady state. If moisture from the body could not evaporate right away for some reason, the fabric would absorb the moisture from the microclimate and eventually release it from the outer fabric surface to the environment, thus also achieving a steady state.

Though there are skin receptors to detect thermal sensations, there are no known humidity/moisture skin receptors. Yet, wetness in fabric can be detected by individuals in the moisture regain amount of 4% above standard textile testing conditions (Markee et al., 1991; Yamakawa & Isaji, 1987; Holmer, 1985; Morooka & Niwa, 1979; Vocak et al., 1976; DeMartino et al., 1984). Vocak et al. (1976) suggests that since there are no specific humidity receptors, these wetness/moisture sensations must be derived from the thermal and tactile receptors in the skin.

Skin wettedness or moisture on the skin's surface is defined as "the fraction of skin covered with sweat necessary to account for the observed evaporative heat transfer" (Berglund, Oohori, Cunningham, & Gagge, 1985, p. 3). Humidity within the microclimate can be measured with miniature dew-point sensors placed on the skin surface (Berglund, Cunningham, & Stolwijk, 1983; Berglund et al., 1985; Graichen, Rascati, & Gonzalez, 1982).

Skin wettedness is dependent on the rate of sweat secretion and evaporation, which in turn is dependent on the vapor pressure gradient between the skin and environment and the vapor resistance of the clothing and microclimate. "People seldom judge themselves to be comfortable when their skin wettedness is above about 25% of their whole body surface, but such a level may be still acceptable" (Berglund et al., 1985, p. 3).

When skin wettedness levels were compared for a range of warm weather clothing at various body locations in a hot environment with no exercise, they were found to be higher on the trunk than the extremities, possibly suggestive of the trunk's increased sweat gland activity and density (Berglund et al., 1985). However, a study conducted by Vocak et al. (1972) found that the amount of moisture in the peripheral body parts of a ski ensemble worn in a cold environment with exercise, was higher than for the central body area. The authors suggested that more attention be paid to the limbs when measuring sweat and thermal comfort. This moisture was measured by weighing each item of clothing before and after the experiment to find the amount of trapped sweat.

Gwosdow et al. (1986) showed that skin temperature increased or decreased with the ambient temperature in the chamber and that as skin temperature, skin hydration, and skin wettedness increased, perceived texture increased and fabric pleasantness ratings decreased.

In Markee et al. (1991), female subjects wore pants and long-sleeved t-shirts of three knit fabrics (cotton and two different polyesters) and performed a wear protocol consisting of exercise and rest in hot-humid and hot-dry environments. The t-shirt was designed so that the skin of the upper back was accessible at various intervals throughout the trial for physiological measurements to be taken. Those measurements taken included: capillary blood flow, evaporative water loss, skin temperature, and water content of the SC. The results indicated the SC water content and blood flow were higher in the hot-humid environment than in the hot-dry environment.

Other results from Markee et al. (1991) showed that the rate of water evaporation and mean skin temperature was higher in the hot-dry environment than in the hot-humid. Overall, the physiological measurements only differed by environment not fabric. There were no significantly differences by fabric. This major finding was attributed to two things: the fabrics were very similar in physical characteristics and the prototype garment did not fit the body snugly enough to touch the skin's surface at the test site thereby preventing them from absorbing different amounts of sweat (Markee et al., 1991). If the fabric/skin contact had been greater, perhaps fiber differences would have affected the degree of skin hydration, thus the physiological measurements taken. It was expected that the cotton fabric would hydrate the skin more because of that fiber's superior absorption characteristics over that of polyester.

In Part V of the Hatch, et al. (1992) series of papers, the same fabrics were used but were held in direct contact with wet (80% hydrated) and dry skin surfaces of inactive subjects on their volar forearm in a comfortable environment. After removal of occluded fabric samples, SC hydration was assessed by measuring the rate of evaporative water loss from the skin. Moisture levels in fabric samples were at regain, at saturation, and a common total moisture content (regain + content). Results showed that fabric moisture content does influence SC hydration. "SC hydration was greater under cotton and polyester fabrics at saturation than at regain because fabrics at regain were more able to accumulate transepidermal water than at saturation" (Hatch et al., 1992, p. 644). Results also indicated that the polyester fabric at saturation wicked moisture whereas the cotton did not. " Generally, evaporative water loss rates increased as moisture content of fabric increases" (Hatch et al., 1992, p. 647).

In another study by the same authors SC water content, evaporative water loss, and blood flow significantly increased while skin temperature decreased slightly during the exercise protocol on the treadmill (Hatch et al., 1990). Major changes occurred again during the resting phase, the SC water content, evaporative water loss, and blood flow all decreased, and skin temperature increased. The fewest differences occurred when there was no activity.

CHAPTER 3

METHODOLOGY

Subjects

Eight female volunteers, ages 18 to 28, were recruited at local gyms and health clubs (Appendix A). Only those subjects who had regularly performed aerobic exercise, for at least the last four months, were allowed to participate because subjects had to be in excellent cardiovascular and physical condition. During recruitment subjects were asked about the level and extent of their cardiovascular and physical activity and their overall physical health. The nature of the experiment was explained to the potential subjects so that they understood what the study required of them. If they agreed to participate in the research project they signed and were given a copy of an informed consent form that provided addresses and phone numbers for contacting the principle investigator, the major advisor, and individuals at University Research Services (Appendix B). Approval for all experimental procedures was obtained from Oklahoma State University Institutional Review Board (IRB) prior to the experiment (Appendix C).

Experimental Design

The experimental design for this study was a 3 X 4 factorial arrangement of treatments in a randomized block design with repeated measures. The **independent variables** included environment, fabric, and time. There were three levels of **environment** including comfortable (denoted as)C, hot-dry (H-D), and hot-humid (H-H). There were four levels of **fabric** treatment. The four different fabrics were constructed into a top and bottom garment ensemble that were worn together. **Time** effects were observed during the 40 minute duration of the wear trial protocol.

The **dependent variables** included **perceived tactile, wetness, thermal comfort, and overall clothing comfort sensations**, **skin temperature** in six body locations, and **pre- and post-weights of the garments** (tops and bottoms).

Independent Variables

Test Facility and Environmental Conditions

Testing was performed in an environmentally controlled chamber in the College of Human Environmental Sciences at Oklahoma State University in Summer, 1993. Three different environmental conditions were used. One environment was considered thermally comfortable for clothed subjects at 23° C (73.4° F) and 50% RH. A second environment was considered hot-dry (H-D) at 32.2° C (90° F) and 50% RH. A third environment was considered hot-humid (H-H) at 32.2° C (90° F) and 70% RH. All conditions were ± 1° C and ± 5% RH.

Test Fabrics and Garments

A total of four different test fabrics, all of which were suitable to be worn next to the skin as exercise-wear, were used in this study. These fabrics were chosen based on results of two previous studies that determined absolute thresholds for moisture sensation for a total of eight different fabrics (Mord, 1990; Branson et al., unpublished). The absolute threshold (denoted AL) is the minimum value of a physical stimulus that will evoke a sensation fifty percent of the time (D'Amato, 1970). The ALs for the eight fabrics ranged from -.012 to .044 ml of moisture (Table 1). An AOV of AL values yielded a significant difference between the eight fabrics ($p < .03$). An LSD multiple comparison test which indicated no significant differences between fabrics PP/SP and P/SP, and between C/P, N/C, N/SP, and C. All other fabric combinations were significantly different (Table 2). Fabrics P, P/SP, and PP/SP had the lowest ALs, meaning that moisture was detected at very small amounts, and contain polyester and polypropylene as their major fiber contents. In contrast, fabrics C and C/SP had the highest ALs, meaning that moisture was detected only at substantially higher amounts, and both contain cotton as their major fiber content. Fabric P yielded a negative AL which can only be explained by an idealized outcome with a sharp step-like function between .000 and .005 ml of moisture (for more information about fabric P, see Mord, 1990).

Fabrics P, P/SP, C, and C/SP were the four fabrics chosen for this research project. These four fabrics were obtained in white. The garment treatment ensemble consisted of two separate garments that were worn by the subjects at the same time during the testing procedures. At all times the two garments were of the same test fabric. One of the garments was a waist-length style top that was sleeveless and crew neck. All side and shoulder seams were serged as were the armhole, neck, and bottom edges to finishing purposes. The second garment worn by subjects was bicycle-type shorts. Again, seams (u-shaped crotch) were serged as were the lower-leg edges for finishing purposes. Elastic (3/4 inch) was applied at the waistline of the shorts for better fit. Subjects were not be allowed to wear any undergarments under the test garments. Subjects did wear their own socks and athletic shoes.

Each subject had their own set of test garments made from each of the four test fabrics. All test garments were laundered in cold water on the delicate cycle and line dried after each session

Time

Data were collected, inside the environmental chamber, at eight different times (every five minutes) per fabric treatment during the 40 minute duration of the wear trial protocol.

Dependent Variables

Perceived Sensation Ballot

A perceived sensation ballot, previously used by Markee et al. (1990) and by Morris et al. (1985), was utilized for this research project. The perceived sensation ballot included scales relating to overall clothing comfort, thermal sensations, wetness sensations, and contact sensations. The contact sensation scale used by Markee et al. (1990) was changed slightly by deleting the descriptor "picky", adding the descriptors "smooth", "soft", and "thick", and changing the descriptor "non-absorbent" to "absorbent" for ease of subject comprehension. The perceived sensation scales may be seen in Appendix D.

Physiological Measurements

Skin temperature was monitored and recorded by the investigator using surface skin thermistors. Six thermistors were secured on subjects' skin with athletic tape at these locations: upper chest, stomach, groin, thigh, back scapular region, and lower back (see Appendix E). In addition, one thermistor monitored the ambient air temperature in the environmental chamber. The temperature data were recorded by the investigator (Appendix F).

Testing Protocol

The testing protocol consisted of four phases: preparation, acclimation, exercise, and recovery/rest. The first visit by each subject included an introductory session to explain the study and protocol. The investigator reviewed all perception ballots and descriptors with the subjects to familiarize them. The informed consent form was reviewed and signed.

The first phase of preparation lasted ten minutes. During this phase the garments constructed from one of the test fabrics was weighed in plastic, re-sealable bags on a top-loading digital readout balance to the nearest hundredth gram. The subject donned the garments and were then weighed on a human scale to the nearest 1/4 pound. In addition, a glass of water was weighed (127.99 g, 125 ml of water) in case the subjects needed a drink between sessions. All pre-weights were recorded on subject information data sheets (Appendix G).

Immediately upon entering the chamber, phase two, the acclimation phase, began. This phase of the protocol lasted ten minutes, during which time the subjects were mostly seated and at rest. Six surface skin thermistors were applied to subjects at various body locations and adhered to the skin with medical tape. A large poster was mounted on a chamber wall with a front and back view of a person to indicate the proper thermistor placement (Appendix E). It was necessary at some times for the subjects to stand up for thermistor placement.

Phase three, exercise, lasted 15 minutes during which time the subjects exercised on a stepper at 80-90 steps per minute and at a constant resistance. A metronome was used to aid in keeping time. This physical activity was enough to induce sweating. Phase four, recovery/rest lasted 15 minutes. The subjects remained seated at rest in the environmental chamber during this period of time.

At eight times (every 5 minutes) during the phases in the environmental chamber (phases two, three, and four) the investigator prompted the subjects to subjectively evaluate the garment ensemble being worn by rating the intensity of each descriptor using the appropriate scale on the wall . The intensity scales were enlarged to poster-size and were placed on the wall directly in front of the subjects (Appendix D). Scoring of the perceived sensation ballot data sheet was completed by the investigator (Appendix H).

At the end of the recovery/rest phase, all thermistors were removed and subjects and the investigator left the environmental chamber. Post-weights of subjects were taken immediately and recorded on the subject information data sheets (Appendix G). Upon removal of the garments they were placed in individual plastic, resealable bags and weighed. The subjects were allowed to towel off, drink some water (125 ml) if they chose, and use the restroom if they so desired. After which time phase one (preparation) began again. The next unidentified garment treatment set was weighed in their bags and given to the subjects to put on. The subjects were then weighed and directed into the environmental chamber for phase two and so on.

Subjects completed four of the above protocol sessions or repetitions during each visit in order that each of the four garment treatment sets could be worn all in the same day and in the same environmental condition. No more than 10 minutes elapsed between the protocol sessions or repetitions for each fabric. A randomized block design for fabrics was used to alleviate a fabric affect. Subjects did not know which fabrics they were wearing at any time.

Subjects came to be tested on three separate occasions, one for each of the three different environmental conditions. To minimize fatigue resulting from the experiment, at least 48 hours always elapsed between individual subject's sessions. An $80 gift certificate to a local retail clothing store was given to subjects after completion of the entire testing regime. In addition, a can of Gatorade was offered to subjects after each completed session.

CHAPTER IV

MANUSCRIPT I

INFLUENCE OF FABRIC AND ENVIRONMENT ON PERCEIVED SENSATIONS OF EXERCISING SUBJECTS

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ABSTRACT

Clothing acts as a barrier to the human body's thermoregulatory process. Of particular importance is moisture at the skin/fabric interface and its affects clothing comfort and related sensations. Eight female volunteers wore garment treatment ensembles composed of four different fabrics in three different environments during a protocol of acclimation, exercise, and recovery/rest. The four fabrics were all suitable for activewear and were composed of 100% cotton, 96% cotton and 4% spandex, 100% polyester (specially engineered for coolness), and 90% polyester (specially engineered for coolness) and 10% spandex. The three environments were comfortable (23° C, 50% RH), hot-dry (32.2° C, 50% RH, and hot-humid (32.2° C, 70% RH). Perceived sensations relating to tactile, wetness, thermal, and overall clothing comfort, as well as skin temperature at six different body sites and garment pre- and post-weights were assessed over time.

An ANOVA found significant differences by environmental condition for the tactile descriptors -- clammy, clingy, absorbent, sticky, wetness sensation, thermal sensation, all skin temperature locations, and pre- and post- weights of garment tops and bottoms. In all cases, the highest means occurred in the hot-humid environment, followed by hot-dry and comfortable environments. Dependent variables significant by fabric were tactile descriptors -- rough, smooth, soft, and stiff, overall clothing comfort, and pre- and post-weights of garment tops and bottoms. Fabric C was rated as softest and smoothest, while fabric P was rated roughest and stiffest. Fabric C was rated the most comfortable followed by P, C/SP, and P/SP. Mean weight differences for both garment tops and bottoms were highest for fabric C, followed by P, P/SP, and C/SP. The first order interaction between environment and time was significant for the skin temperature sites T2, T5, T6, and T7, and wetness sensation.

While exercising, the body is constantly trying to maintain a constant body temperature or heat balance for critical bodily functions. This is accomplished by dissipating excess heat by one or a combination of methods of heat exchange including sweating, evaporation, conduction, convection, and/or radiation. The clothing that we wear interacts with the thermoregulatory system of the human body, both in cold and hot weather, and can contribute to sensations of comfort or discomfort for various reasons. It is well known that the major physical factors that influence clothing comfort are the movement of heat, moisture, and air through fabric [24, 20].

The capability of fabric to handle moisture at the skin interface and the nature of the fabric to skin contact has been of tremendous interest to researchers because of its importance and impact on our daily lives. The research has generally found that moisture at the skin/fabric interface can influence clothing comfort and related sensations.

The region of the skin that touches fabric is the stratum corneum (SC) and is composed of dead cells forming the epidermis. The purpose of the SC is to act as an environmental barrier for the body and to help "maintain an optimal hydration state for internal organs by controlling the passage of water" [8, p. 584]. The SC controls the rate of water loss to the environment. Sweating and/or environmental relative humidity can cause a change in the state of the SC water content and/or evaporative capabilities [8]. As environmental humidity increases, SC water content and blood flow increase, and evaporation from the skin decreases [8, 19].

Fabric moisture content has also been found to influence SC hydration [7]. SC hydration was greater under cotton and polyester fabrics when saturated than at regain because the fabrics at regain were better able to accumulate transepidermal water. In other words, evaporative water loss rates increased as moisture content of fabric increased.

In still another related study by the same group of authors, SC water content, evaporation, and blood flow significantly increased while skin temperature decreased slightly during an exercise protocol on a treadmill [6]. During the resting phase---the SC water content, evaporation, and blood flow all decreased while skin temperature increased.

Several researchers have shown that as water content increased in fabric, subjects were accurately able to perceive this increase [11, 26, 14]. Scheurell, Spivak, and Hollies [23], Hollies [9, 10] all found that discomfort sensations were directly influenced by the amount of moisture at the clothing/skin interface due to sweaty skin.

It is believed that other sensations are involved in the total perception of comfort--mainly tactile, thermal, and wetness sensations having to do with fabric characteristics. Hollies, DeMartino, Yoon, Buckley, Becker, and Jackson [13] found that under normal wearing conditions when the body's temperature is held constant and there is no active sweating, the perception of tactile differences was not present except when the fabric was highly textured.

Markee, Hatch, Maibach, Barker, Radhakrishnaiah, and Woo [18] found that overall comfort differed for exercising subjects wearing cotton and two different polyester garment ensembles in a hot-humid environment, but thermal and wetness sensations did not. These results were attributed to the extremely small differences in physical characteristics of the fabrics. However, contact descriptors related to wetness (clammy, sticky, nonabsorbent, breathable) were significantly different for the three fabrics.

Psychophysical studies done by Sweeney and Branson [25], Mord [21], and Branson, Mord, & Gatros [2], determined that absolute thresholds of moisture sensation could be found when subjects were presented fabric stimuli. The absolute threshold is the smallest amount of stimulus energy necessary for an observer to detect a stimulus [5]. Even extremely small amounts of moisture (.05 ml) could be sensed by subjects [21]. Table 1 shows fiber content and characteristics of the eight fabrics used in the Mord [21] and Branson et al. [2] studies.

Table 1 about here

An AOV of the absolute threshold values yielded significant differences at $p < .03$. An LSD multiple comparison test showed no significant differences between fabrics P/SP and PP/SP, and fabrics C/P, N/C, N/SP, and C (Table 2).

Table 2 about here

All other fabric combinations were significantly different. Fabrics P, P/SP, and PP/SP had the lowest ALs, meaning that moisture was detected at very small amounts. In contrast, C and C/SP had the highest ALs, meaning that moisture was detected at only substantially higher amounts.

The nature of a fabric's surface is believed to be extremely important to clothing comfort as well. The number and type of contact points varies by fabric [1]. The stiffness of a fiber and/or the drape of a fabric is also important in how fabric rests against the skin [1]. A greater surface area of contact between skin and fabric causes greater flow of heat from the skin making the fabric feel cooler [1]. In addition, fabrics of filament fibers and yarns will tend to feel cooler due to the lack of fuzziness which allows greater fabric/skin contact [1]. Greater fabric/skin contact can encourage absorbency of sweat from the skin, however, the passage of moisture in the form of liquid and/or vapor through the fabric and the sweat's evaporation from the fabric are also factors.

Yamakawa and Isaji [27] reported that clamminess was dependent on moisture content and temperature of fabric. When the moisture content of cotton fabric samples was high and temperature low the samples were rated as clammier, probably due to efficient heat conduction since water is a better conductor of heat than air. Hatch, Markee, Maibach, Barker, Woo, & Radhakrishnaiah [6] also found cotton to have higher thermal conductivity than polyester and the energy dissipation rate increased when moisture (sweat) was present due to evaporation.

The purpose of this study was to assess the influence of fabric and environment on female subjects' perceived sensations of overall clothing comfort, thermal sensations, wetness sensations, and contact/tactile sensations, as well as skin temperature at various body locations and pre- and post-weights of the test garments.

Methods and Procedures

SUBJECTS

Eight female volunteers, ages 18-28, were recruited from local gyms and health clubs where they regularly taught aerobic exercise as certified aerobics instructors. This high level of activity ensured their cardiovascular and physical conditioning for participation in the study. Subjects were given an $80 gift certificate for their participation (see Appendix A, B, and C).

TEST FACILITY AND ENVIRONMENTAL CONDITIONS

Testing was performed in an environmentally controlled chamber in three different environmental conditions. The comfortable environment was considered thermally comfortable for clothed subjects at 23^0 C and 50% RH. The hot-dry (H-D) environment was 32.2^0 C and 50% RH and the hot-humid (H-H) environment was 32.2^0 C and 70% RH. All conditions were $\pm$ 1^0 C and $\pm$ 5% RH.

TEST FABRICS AND GARMENTS

Fabrics were chosen based on results of two previous studies that determined the absolute thresholds of moisture sensation for a total of eight fabrics [21, 2] and for their suitability to be worn next to the skin as exercise-wear (Table 1). The absolute threshold is the minimum value of a physical stimulus that will evoke a sensation fifty percent of the time [3]. An AOV of the absolute threshold values yielded a significant difference between the eight fabrics ($p < .03$). An LSD multiple comparison test (Table 2) indicated that three fabrics composed of all synthetic fibers (P, PP/SP, and P/SP) had the lowest absolute thresholds. This meant that moisture was detected at extremely small levels (.05 ml). Fabrics containing all or mostly all natural fibers (C/SP and C) had higher absolute thresholds, meaning moisture was detected only at higher levels. Fabrics P, P/SP, C, and C/SP were chosen for this research because they occurred at opposite ends of the spectrum in terms of moisture sensation. Color was controlled as all fabrics were obtained in white.

The garment treatment ensembles were all of white knit fabric and consisted of a crew-necked, sleeveless, waist-length style top and bicycle-type shorts with elasticized waist. The test garments fit very snugly against the skin. Subjects wore their own socks and shoes and no undergarments beneath the test garments.

PERCEIVED SENSATION BALLOT

A ballot, previously used by Markee, Hatch, Maibach, Barker, Radhadrishnaiah, and Woo [18] and by Morris, Prato, Chadwick, and Bernauer [22], was modified slightly and used for this research (Figure 14).

Figure 14 about here

The ballot included intensity scales relating to contact sensations, wetness sensation, thermal sensation, and overall clothing comfort. Modifications in the contact sensation scale by Markee et al. [18], included deleting the descriptor "picky", adding the descriptors "smooth", "soft", and "thick", and changing "non-absorbent" to "absorbent" for ease of understanding (see Appendix D)

TESTING PROTOCOL

The testing protocol consisted of preparation, acclimation, exercise, and recovery/rest. On the first visit subjects had an introductory session to explain the protocol and procedures of the study. Preparation, consisted of weighing the test garments separately before the subject donned the garments, weighing the subject, and entering the test chamber (see Appendix G). Entrance into the chamber started the ten-minute acclimation phase during which the subjects were mostly seated and at rest so that skin thermistors could be applied to various body locations (Figure 15).

Figure 15 about here

The exercise phase lasted 15 minutes and entailed the subjects exercising on a stepper at a constant resistance at 80-90 steps per minute. This physical activity was rigorous enough to increase heart rate and induce sweating in volunteer practice subjects. The recovery/rest phase required the subject to be seated at rest for 15 minutes.

Every 5 minutes during the acclimation, exercise, and rest/recovery phases of the protocol, subjects were asked to subjectively evaluate the garment ensemble by rating the intensity of eleven tactile descriptors, wetness sensation, thermal comfort, and overall clothing comfort when prompted by the investigator (Figure 1). All of the descriptors and their intensity scales were posted on the wall directly in front of the subjects. Skin temperatures were also recorded by the investigator at these times (see Appendix F).

At the conclusion of the rest/recovery phase, the thermistors were removed and both subject and investigator exited the environmental chamber. The subject was immediately weighed and removed the garment ensemble for weighing. The subject was then allowed to towel off, drink some water, and use the restroom as needed. After this brief time (about 10 minutes), the protocol began again with a different garment treatment set. Four of the protocol repetitions were completed on a visit so that the four fabric/garment treatment sets could be worn all in the same day. Fabric order was randomized using a latin square technique. Subjects did not know which fabric they were wearing. Environment order was also randomized using a latin square technique. Subjects came three separate times for participation in all three environmental conditions.

Results and Discussion

The experimental design for this study was a 3 x 4 factorial arrangement of treatments in a randomized block design with repeated measures over time. The independent variables were environment, fabric, and time. Dependent variables were perceived tactile, wetness, thermal, and overall clothing comfort sensations, skin temperature at seven body locations, and pre- and post-weights of the garments. The results were analyzed using a Type III ANOVA (see Appendix I).

ENVIRONMENT

Many of the dependent variables were significantly different by environmental condition (Table 3) (see Appendix I).

Table 3 about here

Duncan's Multiple Range tests indicated that in all cases the highest means occurred in the H-H environment followed by the H-D and lastly, the C environment (see Appendix J). The tactile sensation variables that were significantly different by environment were clammy, clingy, absorbent, and sticky. The intensity scale for these variables ranged from 0-no contact sensation to 5-extreme contact sensation. The means for clammy were 2.035 in H-H compared to 1.234 in H-D and 0.570 in the C environment. The means for clingy were 2.063, 1.563, and 0.965 in the environments, while the means for absorbent ranged from 1.922 and 1.812 to 1.043. The means for sticky were 1.887, 1.211, and 0.445. In other words, the tactile sensation variables ranged from slightly-moderate to no contact sensation in all of the different environments.

The variables wetness sensation and thermal sensation were also significantly different by environments, again with the highest ratings given in the H-H environment and the lowest ratings given in the C environment (see Appendix I and J). The means for wetness sensation were 2.957, 2.453, and 1.555 on an intensity scale ranging from 1-dry to 7-very wet. These means ranged from slightly wet to almost dry. The means for thermal sensation were 5.832, 5.766, and 5.023 on an intensity scale ranging from 1-very cold to 5-neutral to 9-very hot. These means were all between slightly warm to neutral.

All of the skin temperature locations had significant differences among the three environments (see Appendix I, and J). Like the perceived sensations, the temperatures were highest in the H-H environment followed by the H-D and C environments. In all three environments, skin temperature at all of the body sites mostly increased during acclimation. During exercise in the C and H-D environments, skin temperature at all sites decreased, while in the H-H environment they stayed the same. During recovery/rest all skin temperatures in the C environment gradually increased. In the H-D environment, skin temperature decreased at three locations. In H-H, four out of six decreased (Tables 4, 5, and 6).

Tables 4, 5, and 6 about here

Differences in the pre- and post-weights of both the tops and bottoms of the garment ensembles were significantly different by the three environments, again in order of the H-H, H-D, and C environments (see Appendix I and J). The mean weight differences for the tops were 15.117 g in H-H, 12.347 g in H-D, and 1.950 g in C. The mean weight differences for the bottoms were 12.720 g in H-H, 6.046 g in H-D, and 0.929 g in C.

Interestingly, these variables all have to do with moisture and heat/temperature and their influence on the human skin, supporting what is already known about environmental conditions and the body's thermoregulatory system. In the H-H environment , skin temperatures leveled during exercise then declined during recovery/rest and sweating occurred in an effort to dissipate excess heat. Since clothing was involved, the heat loss had to occur through the fabric.

In the H-H environment compared to the C environment, maximum sweating likely occurred thereby eliciting decreased skin temperatures and thermal responses, extreme tactile sensations having to do with moisture and wetness, and increased weights of both the top and bottom garments as a result of trapped sweat. These results agree with findings from other studies that showed strong relationships between water content of clothing due to sweating, the relative humidity, and ratings given to the garments worn [9, 10, 23].

FABRIC

The dependent variables smooth, soft, rough, stiff, overall clothing comfort, and pre- and post-weights of garment tops and bottoms were significant by fabric (Table 7)(see Appendix I).

Table 7 about here

It is interesting to note that the four significant tactile descriptors (rough, stiff, soft, and smooth) all have to do with surface texture characteristics of fabric. The intensity scale for these variables ranged from 0-no contact sensation to 5-extreme contact sensation. The spandex blend fabrics were rated as rougher and stiffer, but the mean differences were quite small ranging from 3-moderate to 0-no contact sensation (Table 8) (see Appendix K).

Table 8 about here

The 100% fibers were evaluated as smoother and softer with mean differences ranging from 3-moderate to 1-slight contact sensation.

The variable overall clothing comfort was significantly different by fabric (see Appendix I). The intensity scale for overall clothing comfort ranged from 1-comfortable to 7-very uncomfortable. Fabric P/SP had the highest mean at 2.9, followed by C/SP at 1.927, P at 1.818, and fabric C at 1.4. These means ranged from slightly uncomfortable to almost comfortable (see Appendix K).

Many other researchers [12, 16, 4] have found that 100% cotton is rated the most comfortable by subjects compared to other fiber contents. More specifically, Markee et al. [18] found differences between fabrics (cotton and polyester) in a hot-humid environment for overall clothing comfort and wetness-related contact descriptors (clammy, sticky, nonabsorbent, breathable), but not for thermal or wetness sensations.

Differences in the pre- and post-weights of both the tops and bottoms of the garment ensembles were significantly different by fabric (see Appendix I). The mean weight differences for the tops were 12.260 g for fabric C, followed by 11.614 g for P, 8.250 g for P/SP, and 7.675 g for fabric C/SP (see Appendix K). The mean weight differences for the bottoms were 8.962 g for fabric C, followed by 7.448 g for P, 4.964 g for C/SP, and 4.886 g for P/SP. Natural fibers are generally known for their excellent absorbency as compared to synthetics. So the uncomfortable sensations elicited by the polyester and spandex blend fabrics and the lower weight increase (pre- and post-) of both the tops and bottoms would seem to be partially due to their lack of absorbency of subjects' sweat.

ENVIRONMENT * TIME

The first order interaction between environment and time was significantly different for skin temperature locations T2, T5, T6, and T7 (see Appendix I and L). Over the duration of the protocol, skin temperature at sites T2, T5, T6, and T7 did not follow the same pattern of increasing and/or decreasing in the three different environments when the data points were graphed (see Appendix M and N). The most pronounced differences occurred during the recovery/rest phase in that skin temperatures increased in the C environment and decreased in the H-H environment.

The variable wetness sensation was also significantly different for the interaction between environment and time (see Appendix I and L). Over the duration of the protocol, wetness sensation intensity was more pronounced in the H-D and H-H environments compared to the C environment, even though when graphed the lines generally follow the same pattern (Figure 16)(see Appendix M and N).

Figure 16 about here

Summary and Conclusions

This research supports the popular belief that the excellent absorbency of cotton makes it more comfortable to wear than polyester, even when the polyester is specially engineered for coolness. It appeared that sweating, caused by exercise and environmental conditions, may change the hydration state of the SC and increase skin temperature. The sweat on the skin's surface was absorbed by the garment treatment ensembles which in turn probably influenced the SC hydration [6]. The SC hydration was probably greater for fabric C (a natural fiber) fabric than for the other fabrics (synthetics) because it had a larger weight increase, attributed to sweat, than the other fabrics after wearing. In other words, as sweat was absorbed, evaporative water loss increased for subjects wearing fabric C causing more sweat to be absorbed and even more evaporation to occur. This process allowed the body to dissipate excess heat to maintain heat balance.

In addition to the physical and physiological responses, there were psychological responses to this phenomena as well. Fabric C was rated as more comfortable than fabrics P, P/SP, and C/SP, even when P and P/SP were specifically designed for coolness.

The fabric surface texture characteristics also varied by fabric with P/SP, C/SP, and P rated as rougher and stiffer than fabric C. In turn, fabric C was rated as softer and smoother than the other fabrics. The differences between means were not great, perhaps because of the similarities between the physical characteristics of the fabrics. Further physical tests should be performed on the fabrics so that firmer conclusions can be drawn.

Statistical differences were found between the three different environmental conditions for many variables. In all instances, the H-H environment had the highest mean followed by environments H-D and C. All of the skin temperatures (T2-T7) were higher in the H-H environment which was expected. In addition, the mean differences in the weights of the garment tops and bottoms were higher for the H-H environment as would also be expected due to increased sweating by the subjects and to absorbency by the fabrics.

Four of the tactile contact sensations, all having to do with moisture in fabric, were significantly different by environment. The tactile sensations -- clammy, clingy, absorbent and sticky -- were rated by subjects in the moderate to slight contact range, again subjects reported more intense sensations in the H-H environment. Wetness and thermal comfort sensations were also significantly different, and their differences followed a similar pattern to the tactile sensations. Clearly, the heavy sweating achieved in H-H was a factor in all of these differences. As the temperature and relative humidity increased, moisture-related sensations became more pronounced.

This work built on three psychophysical studies that used the method of constant stimuli to determine absolute thresholds of moisture sensation for selected fabrics [2, 21, 25]. The four fabrics chosen for this study had significantly different absolute thresholds. Fabrics P and P/SP had very low absolute thresholds of moisture sensation which meant that subjects sensed very small amounts of moisture in the fabrics. Fabrics C and C/SP, on the other hand had higher absolute thresholds. While psychophysics proved to be a good way to quantify the relationship between moisture stimuli and the resulting sensation, the greatest limitation was that the testing took place under static conditions with the moisture pre-applied to the fabrics [25, 21, 2]. This is different than actually wearing a fabric under dynamic conditions.

It was anticipated that these fabrics might "feel" differently to human subjects when used in a wear trial that induced sweating by both exercise and manipulation of environmental conditions. Thus, the four extreme fabrics were used in this wear trial in order to simulate more realistic dynamic wearing conditions. Researchers have documented that cotton has a slower inner vapor pressure buildup than polyester due to its higher sorbing and evaporative power [15, 17]. This gradual change for cotton, compared to polyester's rapid one, might result in a drier, warmer feeling at the onset of sweating compared to a cooler, wetter feeling [17]. "Humans feel drier and more comfortable when vapor pressure at the inner fabric/clothing surface is low" [15, p. 704). A slow rate of increase in moisture vapor pressure does not trigger uncomfortable sensations as strongly as does an abrupt change and it also allows more time for the subject to physiologically adjust to the new exposure [15]. It is believed that fabric C was rated as more comfortable than the fabrics P, P/SP, and C/SP because moisture was sensed in the cotton very gradually, allowing the body more time to adjust physiologically to the changes.

Fabrics P/SP and C/SP seemed to be greatly affected by the spandex, even though it was 10% or less of the total fiber content. The differences between fabrics C and P were not as great as was expected. Perhaps the special engineering of fabric P makes it "feel" somewhat more similar to cotton than if it had not been modified at all. Further testing with an unmodified polyester is warranted and might indeed clarify this issue.

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TABLE 1

FABRIC CHARACTERISTICS

Fabric	Fiber Content	Yarn Count (cm)	Thickness (mm)	Construction	Yarn Type and Twist	Fiber Type	AL (ml)
C/P	50/50 cotton, polyester	Wales 16 Courses 14	.2337	plain	single Z twist	staple	.018
C	100% cotton	Wales 17 Courses 13	.3848	plain	single Z twist	staple	.025
P*	100% polyester	Wales 19 Courses 17	.0889	plain	single Z twist	staple	-.012
N/C**	100% nylon 100% cotton	Wales 19 Courses 17	.3696	double-knit	multifilament 0 twist single Z twist	filament staple	.021

*Fabric P had a special four channel fiber engineered to promote wicking.
**Fabric N/C was a double-sided fabric with 100% nylon on the back side and 100% cotton on the front.

TABLE 1 (Continued)

FABRIC CHARACTERISTICS

Fabric	Fiber Content	Yarn Count (cm)	Thickness (mm)	Construction	Yarn Type and Twist	Fiber Type	AL (ml)
C/SP	94/6 cotton, spandex	Wales 25 Courses 14	.0145	plain	single S twist	staple	.044
P/SP*	90/10 polyester, spandex	Wales 21 Courses 16	.0130	plain	multifilament Z twist	filament	.009
PP/SP	90/10 polypropylene, spandex	Wales 30 Courses 17	.0078	plain	multifilament S twist	filament	.009
N/SP	80/20 nylon, spandex	Wales 26 Courses 17	.0100	plain	multifilament	filament	.021

*Fabric P/SP polyester had a special four channel fiber engineered to promote wicking.

TABLE 2

LSD COMPARISON TEST
FOR FABRIC AL VALUES

	Fabrics P	PP/SP	P/SP	C/P	N/C	N/SP	C	C/SP
	-.012	.0085	.009	.018	.0206	.021	.025	.044
AL Values		———	———					
				———	———	———	———	

*Fabrics connected by a line were not significantly different.
**$p < .05$, DF = 56

DATA SHEET

SUBJECT________

DATE________

TIME_______

SESSION 1 2 3

ENV: C H-D H-H

FABRIC: B C E F

RATING PERIODS

CONTACT DESCRIPTORS	1	2	3	4	5	6	7	8
BREATHABLE								
CLAMMY								
CLINGY								
ITCHY								
NON-ABSORBENT								
ROUGH								
SCRATCHY								
SMOOTH								
SOFT								
STICKY								
STIFF								

CONTACT SENSATION SCALE

0. No Contact Sensation
1. Slight
2. ______
3. Moderate
4. ______
5. Extreme

RATING PERIODS

▨	1	2	3	4	5	6	7	8
WETNESS SENSATION								
THERMAL SENSATION								
CLOTHING COMFORT								

WETNESS SENSATION SCALE

1. Dry
2. ______
3. Slightly Wet
4. ______
5. Moderatly Wet
6. ______
7. Very Wet

THERMAL SENSATION

1. Very Cold
2. Cold
3. Cool
4. Slightly Cool
5. Neutral
6. Slightly Warm
7. Warm
8. Hot
9. Very Hot

OVERALL CLOTHING COMFORT SENSATION

1. Comfortable
2. ______
3. Slightly Uncomfortable
4. ______
5. Moderatly Uncomfortable
6. ______
7. Very Uncomfortable

Figure 14. Perceived Sensation Ballot.

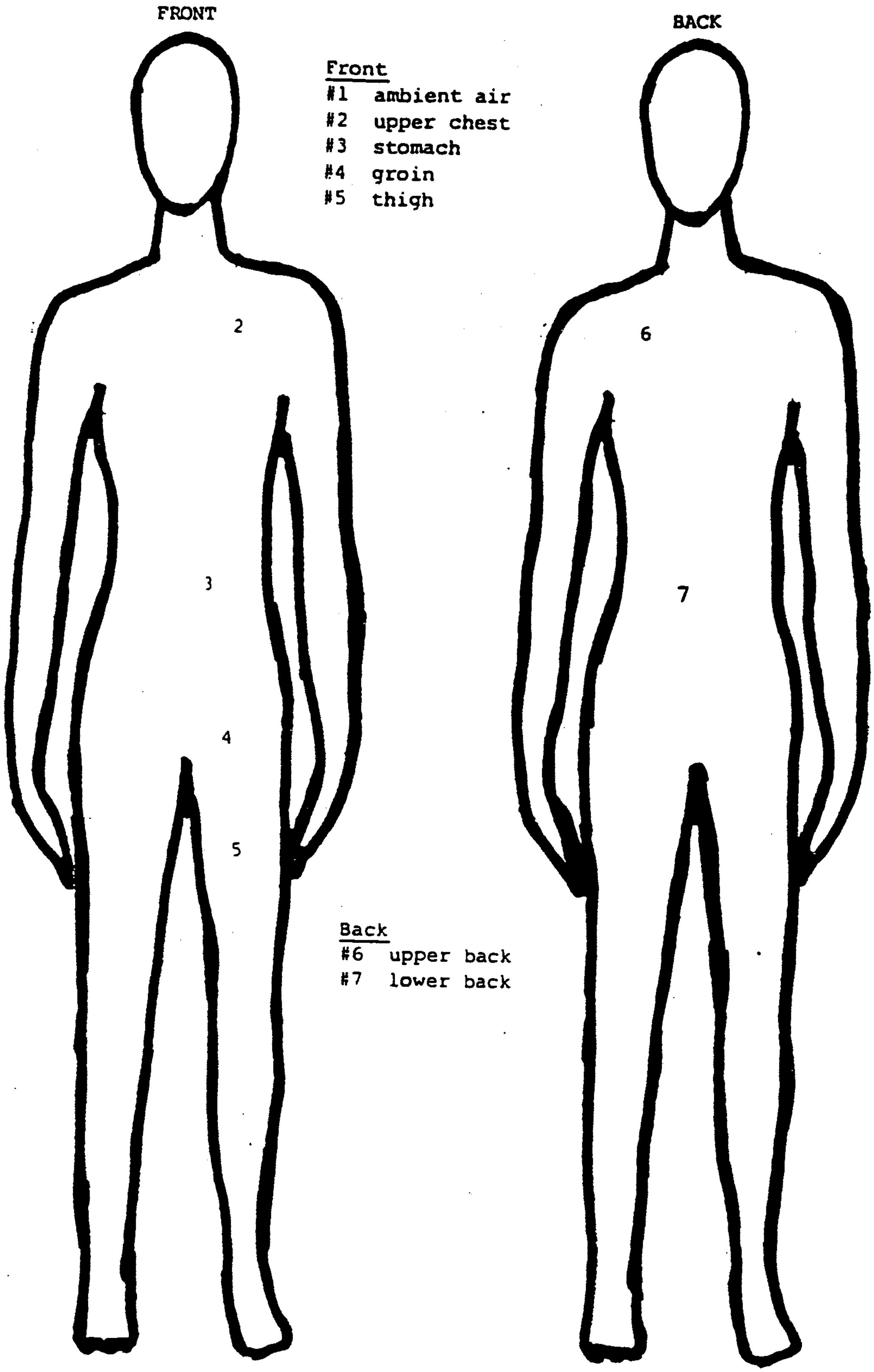

Figure 15. Skin Temperature Sites.

TABLE 3

ANALYSIS OF VARIANCE FOR SOURCE -- ENVIRONMENT

Variable	Sum of Squares	Mean Square	F-Value	Prob. > F
clammy	259.210	129.605	16.14	0.0001
clingy	137.584	68.792	10.60	0.0006
absorbent	101.893	50.947	8.00	0.0025
sticky	251.550	125.775	11.00	0.0005
wetness sensation	252.286	126.143	58.79	0.0001
thermal comfort	107.189	53.594	31.79	0.0001
T2* (upper chest)	851.654	425.827	31.22	0.0001
T3* (stomach)	1505.560	752.780	98.48	0.0001
T4* (groin)	1373.302	686.651	161.69	0.0001
T5* (thigh)	3606.488	1803.244	198.80	0.0001
T6* (upper back)	1269.797	634.899	65.52	0.0001
T7* (lower back)	1384.895	692.447	216.76	0.0001
pre-/post-weight of top	5050.166	2525.083	74.12	0.0001
pre-/post-weight of bottom	2232.734	1116.367	110.16	0.0001

*T2-T7 refer to skin temperature at the given locations
**DF = 2, 22

TABLE 4

SKIN TEMPERATURE (°F) BY BODY SITE FOR ENVIRONMENT -- COMFORTABLE

	ACCLIMATION		**EXERCISE**			**RECOVERY/REST**		
TIME (MIN.)/ BODY SITE	**05**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
T2 (chest)	92.2	92.8	93.1	92.7	91.8	90.7	90.7	91.5
T3 (stomach)	90.4	91.0	90.8	90.1	89.0	88.6	89.0	89.5
T4 (groin)	90.7	91.1	91.1	90.5	89.5	89.3	90.0	90.2
T5 (thigh)	87.3	88.6	87.8	87.4	86.8	87.9	88.9	89.6
T6 (upper back)	91.6	91.8	92.3	92.3	91.2	88.6	88.8	89.6
T7 (lower back)	89.5	89.8	90.2	90.1	89.4	88.4	88.7	89.1

TABLE 5

SKIN TEMPERATURE (°F) BY BODY SITE FOR ENVIRONMENT -- HOT-DRY

	ACCLIMATION		**EXERCISE**			**RECOVERY/REST**		
TIME (MIN.)/ BODY SITE	**05**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
T2 (chest)	94.4	94.9	94.7	93.8	93.1	92.2	91.3	91.1
T3 (stomach)	93.7	94.3	93.5	92.6	91.2	91.4	91.2	91.7
T4 (groin)	93.8	94.5	93.9	93.0	92.0	91.7	92.0	92.6
T5 (thigh)	92.2	93.3	92.6	92.3	92.0	91.8	92.3	92.8
T6 (upper back)	94.2	94.8	95.0	94.0	93.4	91.7	90.3	89.1
T7 (lower back)	92.6	93.2	93.2	93.0	92.1	90.5	89.3	89.7

TABLE 6

SKIN TEMPERATURE (^{o}F) BY BODY SITE FOR ENVIRONMENT -- HOT-HUMID

	ACCLIMATION		**EXERCISE**			**RECOVERY/REST**		
TIME (MIN.)/ BODY SITE	**05**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
T2 (chest)	94.8	95.3	95.3	95.1	95.2	94.2	93.3	93.1
T3 (stomach)	93.8	94.6	94.2	93.4	92.8	92.6	91.9	91.8
T4 (groin)	94.1	94.9	94.5	93.6	92.6	92.3	92.3	92.4
T5 (thigh)	92.3	93.7	93.3	93.5	93.2	93.0	92.2	92.5
T6 (upper back)	94.4	94.9	95.1	95.0	95.3	93.5	92.2	91.7
T7 (lower back)	92.8	93.7	93.9	93.7	93.8	92.2	90.7	90.1

TABLE 7

ANALYSIS OF VARIANCE FOR SOURCE -- FABRIC

Variable	Sum of Squares	Mean Square	F-Value	Prob. > F
rough	75.854	25.285	2.97	0.0540
smooth	167.797	55.932	5.77	0.0045
soft	295.478	98.493	9.69	0.0003
stiff	175.211	58.404	10.34	0.0002
overall clothing comfort	222.562	74.187	12.14	0.0001
T7* (lower back)	36.017	12.006	3.76	0.0256
pre-/post-weight of top	369.911	123.304	3.62	0.0181
pre-/post-weight of bottom	289.377	96.459	9.52	0.0001

*T7 refers to skin temperature at the given location
*DF = 3, 22

TABLE 8

DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATIONS -- ROUGH, STIFF, SOFT, AND SMOOTH

ROUGH Fabric	P/SP	C/SP	P	C
Mean	1.172	1.016	0.537	0.333
	———	———		
		———	———	———
STIFF Fabric	P/SP	C/SP	P	C
Mean	1.630	0.510	0.495	0.359
		———	———	———
SOFT Fabric	C	P	C/SP	P/SP
Mean	3.224	12.453	2.245	1.401
		———	———	
SMOOTH Fabric	C	P	C/SP	P/SP
Mean	3.063	2.604	2.188	1.719
	———	———		
		———	———	
			———	———

*All fabrics had the same n = 192

**Fabrics connected by a line were not significantly different

***$p < .05$, DF = 22, MSE (rough) = 8.511, MSE (stiff) = 5.650, MSE (soft) = 10.162, MSE (smooth) = 9.689

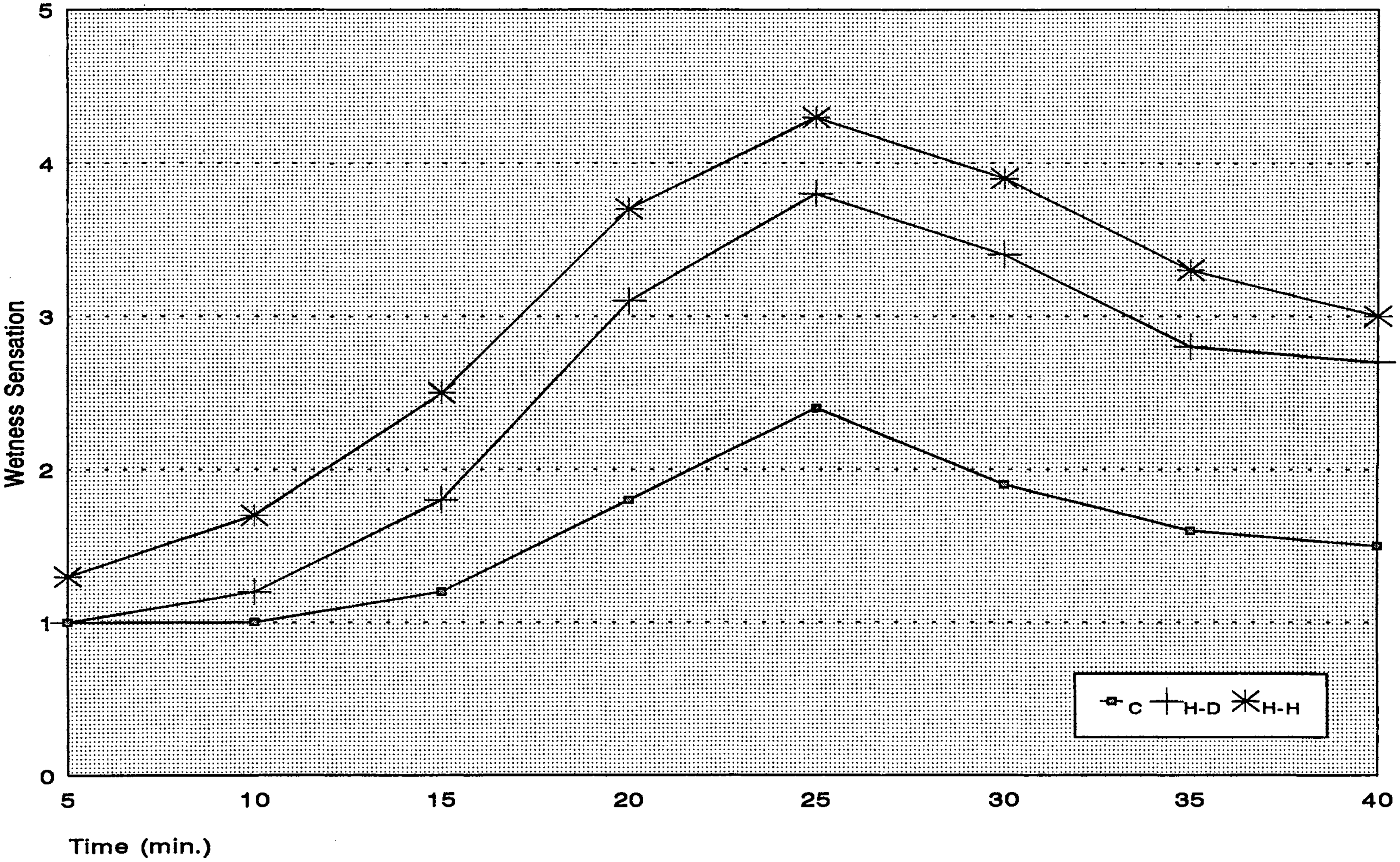

Figure 16. Wetness Sensation by Environment Over Time

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

Exercise has become very commonplace in our society as a result of its contribution to a longer and healthier life. Business has responded to the increased demand for appropriate exercise-wear, by providing a marketplace full of specialized apparel to accommodate almost every form of activity. In addition to specialized design and styling of the garments, specially engineered fabrics have been developed and are promoted to consumers. Much of this promotional advertising declares that these special fabrics will "facilitate" a person in their quest of becoming more physically fit by keeping them more comfortable during exercise.

While exercising, the body is constantly trying to maintain a constant body temperature or heat balance for critical bodily functions. This is accomplished by dissipating excess heat by one or a combination of heat exchange methods of heat exchange including sweating, evaporation, conduction, convection, radiation, or behavioral type actions such as removing clothing to expose more surface area of the skin. Clothing acts as a barrier to this thermoregulatory process so that the heat exchange must occur through it.

It is well known that the major physical factors that influence clothing comfort are the movement of heat, moisture, and air through fabric (Slater, 1977; Mehta & Narrasimham, 1987). Of particular interest is moisture at the skin/fabric interface, its affect on clothing comfort and related sensations such as thermal, wetness, and tactile. Fabric moisture has been found to influence stratum corneum hydration, which in turn has the potential to increase the water content of a fabric worn next to the skin. Studies have shown that as water content in fabrics increased, subjects were able to perceive the increase and that discomfort sensations were directly influenced by the amount of moisture at the clothing/skin interface due to sweaty skin (Hollies, 1977; Vocak et al., 1976; Holmer, 1985; Scheurell et al., 1985; Hollies, 1965; 1971).

Psychophysical studies to assess moisture sensation in fabrics have been done by Sweeney and Branson (1990a), Mord (1990), and Branson et al., (unpublished). These studies determined that absolute thresholds of moisture sensation could be determined when subjects were presented with known amounts of wetted fabric stimuli. The absolute threshold is the smallest amount of stimulus energy necessary for an observer to detect a stimulus (Goldstein, 1980). Even extremely small amounts of moisture (.05 ml) could be sensed in a specially engineered polyester fabric (Mord, 1990). An AOV of the absolute threshold values for eight fabrics found differences between the fabrics, mainly between the synthetic and natural fibers. Moisture could be sensed at small amounts in the synthetic fabrics but not in cotton (a natural fiber) (see Tables 1 and 2).

Other sensations believed to be involved in the total perception of clothing comfort are wetness , thermal, and tactile sensations, but research has found the relationship among these sensations to be inconclusive. Markee et al., (1990) found differences in overall comfort for exercising subjects wearing cotton and two different polyester fabrics in a hot-humid environment, but not in thermal or wetness sensations. This was attributed to the fabrics being extremely similar in physical characteristics.

The nature of a fabric's surface is also believed to be extremely important to the assessment of clothing comfort. The number and type of contact points varies by fabric and can affect how a fabric rests against the skin's surface. Fiber and fabric characteristics like stiffness, fuzziness, roughness, scratchiness, and stickiness probably influence the tactile sensations elicited by a fabric. Markee et al. (1990) found that contact descriptors relating to wetness (clammy, sticky, nonabsorbent, breathable) were significantly different for the three fabrics.

The purpose of this study was to determine the influence of fabric and environment on female subjects' perceived sensations of overall clothing comfort, thermal, wetness, and tactile/contact sensations, as well as skin temperature at various body sites, and differences in pre- and post-weights of the tops and bottoms of the garment treatment ensemble.

Objectives

This research was guided by four objectives. The first was to explore how fabric differences affected perceived clothing comfort, thermal comfort, wetness and contact/tactile sensations, and skin temperature. Four different fabrics were used. The second was to explore how three different environmental conditions affected perceived clothing comfort, thermal comfort, wetness and contact/tactile sensations, and skin temperature. Three different environments were used: comfortable, hot-dry, and hot-humid. The third objective was to explore how time affected perceived clothing comfort, thermal comfort, wetness and contact/tactile sensations, and skin temperature during the study's protocol which included exercise. The final objective was to attempt to relate this perceived sensation data to the moisture sensation data obtained by Mord (1990) and Branson et al., (unpublished) in an effort to better understand the nature of the dynamics of humans' perceptions of clothing comfort and related sensations.

Subjects

Eight female volunteers, ages 18-28, were recruited form local gyms where they regularly taught aerobic exercise as certified aerobics instructors. This high level of activity ensured their high level of cardiovascular and physical conditioning for participation in the study.

Test Facility and Environmental Conditions

Testing was done in an environmentally controlled chamber in three different environments. The comfortable environment was 23^0 C and 50% RH, the hot-dry (H-D) environment was 32.2^0 C and 50% RH, and the hot-humid environment (H-H) was 32.2^0 C and 70% RH. All conditions were $\pm$ 1^0 C and $\pm$ 5% RH.

Test Fabrics and Garments

Four fabrics were chosen based on the results of two studies that determined the absolute thresholds of moisture sensation for a total of eight fabrics (Mord, 1990; Branson et al., unpublished) and for their suitability to be worn next to the skin. An AOV found differences between the fabrics' absolute thresholds. Post hoc testing placed the specially engineered polyester fabrics and the cotton fabrics at opposite ends of the moisture sensation spectrum. As a result, the four fabrics chosen were P, P/SP, C, and C/SP (see Tables 1 and 2).

The four fabrics were all obtained in white. The garment treatment ensembles were composed of a crew-neck, sleeveless, waist-length style top and elasticized-waist bicycle-type shorts. All garments fit very snugly. Subjects wore their own socks and shoes and no undergarments.

Dependent Variables

A perceived sensation ballot including intensity scales relating to contact/tactile sensations, wetness sensation, thermal comfort, and overall clothing comfort was used to record data. The descriptors and their intensity scales were posted directly in front of the subjects during testing. In addition, skin temperature data were collected for seven different body sites and pre- and post-weights of the garment tops and bottoms were recorded.

Testing Protocol

The testing protocol consisted of preparation, acclimation, exercise, and recovery/rest. Preparation consisted of weighing the test garments before the subject donned them, weighing the subject, and entering the test chamber. Entrance into the chamber started the 10 minute acclimation phase during which time the subjects were mostly seated and at rest so that skin thermistors could be applied to various body sites.

The exercise phase lasted 15 minutes and entailed the subjects exercising on a stepper at a constant resistance at 80-90 steps per minute. It had been determined beforehand that this physical activity was rigorous enough to induce sweating. The recovery/ rest phase required the subject to be seated at rest for 15 minutes.

Every five minutes during the acclimation, exercise, and recovery/rest phases of the protocol, subjects were asked to subjectively evaluate the garment ensemble they were wearing by rating the intensity of 11 tactile descriptors, wetness sensation, thermal comfort, and overall clothing comfort when prompted by the investigator. Skin temperatures were also recorded at these times.

At the conclusion of the rest/recovery phase, the thermistors were removed and both subject and investigator exited the environmental chamber. The subject was immediately weighed and removed the garment ensemble for weighing. The subject was then allowed to towel off, drink some water, and use the restroom as needed. After this brief time (about 10 minutes), the protocol began again with a different garment treatment set. Four of the protocol repetitions were completed on a visit so that the four fabric/garment treatment sets could be worn all in the same day. Fabric order was randomized using a latin square technique. Subjects did not know which fabric they were wearing. Environment order was also randomized using a latin square technique. Subjects came three separate times for participation in all three environmental conditions.

Results

The experimental design for this study was a 3 X 4 factorial arrangement of treatments in a randomized block design with repeated measures. A Type III ANOVA was used to analyze the data.

Environment. In all cases the highest means for the significant variables occurred in the H-H environment, followed by the H-D and C environments. The tactile descriptors that were significantly different by environment were: clammy, clingy, absorbent, and sticky (Appendix I). The intensity scale for these variables ranged from 0-no contact sensation to 5-extreme contact sensation. The means for clammy were 2.035, 1.234, and 0.507 in the H-H, H-D, and C environments. The means for clingy were 2.063, 1.563, and 0.965, while the means for absorbent ranged from 1.922 and 1.812 to 1.043. The means for sticky were 1.887, 1.211, and 0.445 (Appendix J). In other words, the tactile sensation variables ranged from slightly-moderate to no contact sensation in all the different environments.

Both wetness and thermal comfort sensations were also significantly different, again with the highest ratings given in the H-H environment and the lowest ratings given in the C environment (Appendix I and J). The means for wetness sensation were 2.957, 2.453, and 1.555 on an intensity scale ranging from 1-dry to 7-very wet, so these means ranged from slightly wet to almost dry. The means for thermal sensation were 5.832, 5.766, and 5.023, not very much different. The intensity scale for thermal sensation ranged from 1-very cold to 5-neutral to 9-very hot, so these means were all between slightly warm to neutral.

All of the skin temperature locations were significantly different by environment (Appendix I). Like the perceived sensations, the skin temperatures were highest in the H-H environment followed by the H-D and C environments (Appendix J). In all three environments, skin temperature at all of the body sites mostly increased during acclimation. During exercise in environments C and H-D environments, skin temperature at all sites decreased, while in the H-H environment they generally stayed the same. During recovery/rest all skin temperatures in the C environment gradually increased. In the H-D environment, skin tempertature decreased at three locations. In H-H, four out of six locations had decreased skin temperature.

Differences in the pre- and post-weights of both the tops and bottoms of the garment ensemble were significantly different by the three environments, again in order of the H-H, H-D, and C environments (Appendix I and J). The mean weight differences for the tops were 15.117 g in the H-H environment, 12.347 g in the H-D, and 1.950 g in the C environment. The mean weight differences for the bottoms were 12.720 g in the H-H environment, 6.046 in the H-D, and 0.929 g in the C environment.

Fabric. The tactile descriptors that were significantly different by fabric were: rough, smooth, soft, and stiff (Appendix I). The intensity scale for these variables ranged from 0-no contact sensation to 5-extreme contact sensation. Fabric C was rated as the softest (3.224) and smoothest (3.063), followed by fabrics P (2.453, 2.604), C/SP (2.245, 2.188) and P/SP (1.401, 1.719)(Appendix K). In contrast, fabric P/SP was rated as the roughest (1.172) and stiffest (1.630), followed by fabrcis C/SP(1.016, 0.510), P (0.537, 0.495), and C (0.333, 0.359).

Overall clothing comfort was also significantly different by fabric (Appendix I). The intensity scale for overall clothing comfort ranged from 1-comfortable to 7-very uncomfortable. Fabric C was rated as almost comfortable (1.4), followed by fabric P (1.818), C/SP (1.927) and P/SP (2.9) as slightly uncomfortable (Appendix K).

Differences in the pre- and post-weights of both the tops and bottoms of the garment ensemble were significantly different by fabric (Appendix I). The mean weight differences for the tops were 12.26 g for fabric C, followed by 11.614 g for P, 8.250 g for P/SP, and 7.675 g for fabric C/SP (Appendix K). Mean weight differences for the bottoms were 8.962 for fabric C, followed by 7.448 g for P, 4.964 g for C/SP, and 4.886 g for fabric P/SP.

Environment * Time. The first order interaction between environment and time was significant for the skin temperature variables T2, T5, T6, T7 (Appendix I and L). Over the duration of the protocol, the skin temperature at these sites did not follow the same pattern of increasing and/or decreasing in the three different environemtns when the data points were graphed (Appendix M and N). The most pronounced differences occurred during the recovery/rest phase in that skin temperatures increased in the C environment and decreased in the H-H environment.

The variable wetness sensation was also significantly different for the interaction between environment and time (Appendix I and L). Over the duration of the protocol, wetness sensation intensity was more pronounced in the H-D and H-H environemtns compared to the C environment, even though when graphed the lines generally follow the same pattern (Appendix M and N).

Implications

This research resulted in part from three psychophysical studies that used the method of constant stimuli to determine absolute thresholds of moisture sensation for selected fabrics (Sweeney & Branson, 1990a; Mord, 1990; and Branson et al, unpublished). The results from these studies based on a total of eight fabrics led to the fabric selection of four for this study. These four fabrics had significantly different absolute thresholds of moisture sensation. The polyester fabric had very low absolute thresholds which meant subjects could sense very small amounts of moisture. The mostly cotton fabrics had higher absolute thresholds which meant that moisture levels had to be greater for subjects to sense its presence.

It was anticipated that these fabrics might feel differently to human subjects when tested in the dynamic conditions of a wear trial that induced sweating by both exercise and manipulation of environmental conditions. It appears that they did, at least for some perceived sensations.

It appears that sweat on the skin's surface, induced by exercise and environmental condition, was absorbed by the garment treatment ensembles and may have changed the SC hydration state. The SC hydration was probably greater for fabric C, being a natural fiber, than for fabrics P, P/SP, or C/SP, being mostly or all synthetics, because it had a larger weight increase. This weight increase, the difference in pre- and post-weights of the tops and bottoms of the garment treatment ensembles, is attributed to greater absorption of subjects' sweat. As sweat was absorbed, evaporative water loss increased for fabric C causing more sweat to be absorbed and even more evaporation to occur. This process generates much heat but would allow the body to dissipate its excess heat to maintain heat balance.

Fabric C was rated as more comfortable than fabrics P, P/SP, and C/SP, even when the polyester fabric utilized (in both P and P/SP) was one specifically designed for coolness, having a special four channel fiber shape. Tactile sensations, all having to do with fabric surface/texture characteristics, also varied by fabric. Fabrics P/SP, C/SP, and P were rated as rougher and stiffer than fabric C. In contrast, fabric C was rated as softer and smoother than the other fabrics. The differences between the means was not great, perhaps because of the similarities between the physical characteristics of the fabrics. Further physical tests should be performed on the fabrics so that firmer conclusions can be drawn.

Some perceived sensations do appear to be different for fabrics P, P/SP, and C/SP compared to C. It is not clearly understood why some perceived sensations were different by fabric whereas others were not, such as wetness and other moisture related tactile and thermal sensations. Researchers have documented that cotton has a slower inner vapor pressure buildup than polyester due to its higher sorbing and evaporative power (Hong et al., 1988; Kim & Spivak, 1994). "Humans feel drier and more comfortable when vapor pressure at the inner fabric/clothing surface is low" (Hong et al., 1988, p. 704). A slow rate of increase in moisture vapor pressure does not trigger uncomfortable sensations as strongly as does an abrupt change and it also allows more time for the subject to physiologically adjust to the new exposure (Hong et al., 1988). It also may result in a drier, warmer feeling at the onset of sweating and less friction between fabric and skin, compared to a cooler, wetter feeling and greater friction (Kim & Spivak, 1994). Further research is required so that this is more clearly understood.

Fabrics P/SP an C/SP seemed to be greatly affected by the spandex, even though it was 10% or less of the total fiber content. The differences between fabrics C and P were not as great as was expected. Perhaps the special engineering of fabric P makes it "feel" somewhat more similar to cotton than if it had not been modified at all. Further testing with an unmodified polyester is warranted and might clarify this issue.

Statistical differences were found between the three different environments for many of the dependent variables. Skin temperature at all of the body sites (T2-T7) were highest in the H-H environment which was expected. In addition, the mean differences in pre- and post-weights of the garment tops and bottoms were highest for the H-H environment due to increased sweating by the subjects and absorbency by the fabrics.

Four of the tactile contact sensations, all having to do with moisture, were significantly different by environment. These sensations -- clammy, clingy, absorbent, and sticky, were rated by subjects in the moderate to slight contact range, again subjects reported more intense sensations in the H-H environment. Wetness and thermal comfort sensations were also significantly different and their differences followed a similar pattern to the tactile sensations.

It makes sense that the highest mean ratings and skin temperatures would occur in the most extreme environment and the lowest in the more acceptable environment. It is interesting to note that all of the variables significant by environment had to do with moisture and heat/temperature and their influence on the human skin, supporting what is already known about environmental conditions and the body's thermoregulatory system. As the temperature and relative humidity increased and exercise was performed, sweating occurred in an effort to dissipate excess heat. Since clothing was involved, the heat loss had to occur through the fabric.

In the H-H environment, compared to the C environment, maximum sweating likely occurred thereby eliciting more intense thermal and wetness sensations, as well as tactile sensations having to do with moisture. In addition, the trapped sweat resulted in increased weight differences of both the garment tops and bottoms. These results agree with findings from other studies that showed strong relationships between water content of clothing due to sweating, the relative humidity, and ratings given to the garments worn (Hollies, 1965; 1971;

Scheurell, Spivak, & Hollies, 1985).

Recommendations

1. It is recommended that an unmodified polyester fabric and an unmodified polyester/spandex blend fabric be tested in a wear trial exactly the same as this study.

2. It is recommended that further fabric testing be done so that it is more fully understood how fabric differences influence perceived sensations and skin temperature.

3. It is recommended that human sweat rate be studied in relation to perceived sensations and skin temperatures as well as fabric and environmental differences.

4. It is recommended that psychophysical testing be done in different environmental conditions and perhaps involving exercise so that better linkages can be made between psychophysics and perceived sensations.

5. It is recommended that subjects be trained in sensory evaluation of fabrics before participation in a similar study so that they can more accurately evaluate perceived sensations of fabrics.

Limitations

1. Female subjects were recruited and paid $80 in the form of a gift certificate for their participation. For their participation, subjects had to give approximately 12-14 hours of their time. The method of sample acquisition, monetary payment, and time commitment may have influenced subjects' responses. Limitations of gender, age, and both cardiovascular and physical fitness do not allow the results to be generalized to other populations.

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APPENDICES

APPENDIX A

SUBJECT ADVERTISEMENT

SUBJECTS NEEDED FOR RESEARCH PROJECT

You must be a female, age 18-26, in excellent physical condition and have done some form of aerobic exercise, regularly for the last four (4) months. Your participation will require three (3) sessions of 4 to 5 hours each. Exercise involved.

PAYS $80 ! ! !

You must attend all sessions to get paid.
Project will start approximately MAY 10, 1993 ! ! !

If interested call Sharon at 744-5035

APPENDIX B

INFORMED CONSENT FORM

INFORMED CONSENT

I, ________________________________, voluntarily agree to participate in this study entitled: Influence of Fabric, Environment, and Body Site on Perceived Clothing Comfort and Related Sensations of Exercising Subjects which is sponsored by Human Environmental Sciences Research through the Department of Design, Housing & Merchandising, Oklahoma State University.

I understand that the purpose of this study is to assess perceived overall comfort, thermal sensations, wetness sensations, and tactile/contact sensations for four different fabrics. The assessments will take place during and exercise protocol in three different environmental conditions.

I understand that the procedure for assessing these comfort and related sensations will require my participation in the following ways:

1. Preparation: (10 minutes approximately) Two garments, a top/bodice and handbands, will be weighed individually in plastic, re-sealable bags on a top-loading digital readout balance. Subjects will already have on their own shorts, underwear, socks, and shoes, and will be asked to remove their top and bra and put on the test garments. The test garments consist of a sleeveless top and handbands. The subject will be weighed on a human scale to the nearest 1/4 pound. Approximately six to eight surface skin thermistors will be placed on the subject in the following areas: dorsal/top region of each hand, back scapular region, front upper chest above bustline, front upper chest in middle of bustline, and front chest below bustline. Sensors will be secured to subject's skin with surgical tape. The subject and investigator will enter the environmental chamber.

2. Acclimation: (10 minutes) Immediately upon entering the chamber acclimation will begin. During this time the subject will be seated at a table and at rest.

3. Exercise: (15 minutes) Subjects will exercise on an exercise bicycle at a constant rate of 20 km/hr and a constant resistance.

4. Recovery/Rest: (15 minutes) Subjects will get off the exercise bicycle and will remain in the chamber seated at a table and at rest.

At the end of phase four, subjects will leave the chamber and be weighed before removing the garment treatment. Upon removal, the two garments will be place in their bags and weighed. At this time, subjects will be allowed to towel off and drink some water. After this time (about five minutes), phase one (preparation) begins again. Subjects will complete four of the above protocol sessions or repetitions during each visit. Subjects will come to be tested on three separate occasions, one for each of the three environmental conditions. The environmental conditions are: "comfortable" at 23^0 C (73.4^0 F) $\pm$ 1^0 and 50% RH $\pm$ 5%, "hot-dry" at 32.2^0 C (90^0 F) and 50% RH $\pm$ 5%, and "hot humid" at 32.2^0 C (90^0 F) and 70% RH $\pm$ 5%.
The first visit by each subject will include an introductory session of approximately ten minutes during which time this informed consent form will be read and, if necessary, the experiment explained in greater detail.

Three times (every five minutes) during the acclimation, exercise, recover/rest phases the investigator will ask subjects to report their clothing comfort and related sensations by rating the each sensation using the appropriate intensity scale. The score sheet/ballot will be completed by the investigator. The four scales will be enlarged and placed on the wall directly in front of the subjects. Additionally, skin temperature will be monitored by the investigator every four minutes during phases two, three, and four.

I understand that participating in this study may present discomforts to me in the form of a physiological increase in body temperature and the inducement of sweating due to the temperature, relative humidity, and exercise involved.

I understand that participating in this study presents the following possible benefits to me:

1. knowledge of, and experience in, sensory and wear trial testing,
2. and payment of $80.00 in the form of a gift certificate from a local clothing store for completion of all three sessions.

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

I have read this informed consent document and understand its contents. I am a female, age 18-26. I have regularly performed aerobic exercise for the last four months and am in excellent physical condition. I freely consent to participate in this study under the conditions described here. I understand that I will receive a copy of this signed consent form.

__________ ____________________________________

Date/Time Signature of the Research Subject

I have personally explained all elements of this form and the experiment to the subject before requesting the subject to sign it.

__________ ____________________________________

Date/Time Signature of the Principal Investigator

I may contact the principle investigator, **Sharon Mord,** at **(405) 377-4534** should I have any questions or wish further information regarding this research. I also may contact **Dr. Donna Branson** (the advisor of the principle investigator) at telephone number **(405) 744-5035**. Additionally, I may also contact **LeAnn Prater** or **Beth Mctereman**, University Research Services, 001 Life Sciences East, Oklahoma State University, Stillwater, OK 74078, telephone number **(405) 744-5700**.

APPENDIX C

IRB FORM

OKLAHOMA STATE UNIVERSITY
INSTITUTIONAL REVIEW BOARD
HUMAN SUBJECTS REVIEW

Date: 08-07-95 **IRB#:** HE-93-001A

Proposal Title: INFLUENCE OF FABRIC, ENVIRONMENT, AND BODY SITE ON PERCEIVED CLOTHING COMFORT AND RELATED SENSATIONS OF EXERCISING SUBJECTS

Principal Investigator(s): Donna Branson, Sharon Mord

Reviewed and Processed as: Continuation

Approval Status Recommended by Reviewer(s): Approved

ALL APPROVALS MAY BE SUBJECT TO REVIEW BY FULL INSTITUTIONAL REVIEW BOARD AT NEXT MEETING.
APPROVAL STATUS PERIOD VALID FOR ONE CALENDAR YEAR AFTER WHICH A CONTINUATION OR RENEWAL REQUEST IS REQUIRED TO BE SUBMITTED FOR BOARD APPROVAL.
ANY MODIFICATIONS TO APPROVED PROJECT MUST ALSO BE SUBMITTED FOR APPROVAL.

Comments, Modifications/Conditions for Approval or Reasons for Deferral or Disapproval are as follows:

Signature: Date: August 10, 1995

Chair of Institutional Review Board

APPENDIX D

PERCEIVED SENSATION SCALES

BREATHABLE

CLAMMY

CLINGY

ITCHY

ABSORBENT

ROUGH

SCRATCHY

SMOOTH

SOFT

STICKY

STIFF

CONTACT DESCRIPTOR DEFINITIONS

BREATHABLE: allowing air to pass through

CLAMMY: being damp

CLINGY: adhering to skin

ITCHY: irritating to skin

ABSORBENT: able to absorb moisture

ROUGH: course, uneven surface

SCRATCHY: prickly, irritating to skin

SMOOTH: a continuous even surface

SOFT: pleasing to touch

STICKY: adhering to skin

STIFF: rigid, not easily bent, unyielding

CONTACT SENSATION SCALE

0. **No Contact Sensation**

1. **Slight**

2. **..............**

3. **Moderate**

4. **..............**

5. **Extreme**

WETNESS SENSATION SCALE

1. **Dry**
2. **..............**
3. **Slightly Wet**
4. **..............**
5. **Moderately Wet**
6. **..............**
7. **Very Wet**

THERMAL SENSATION SCALE

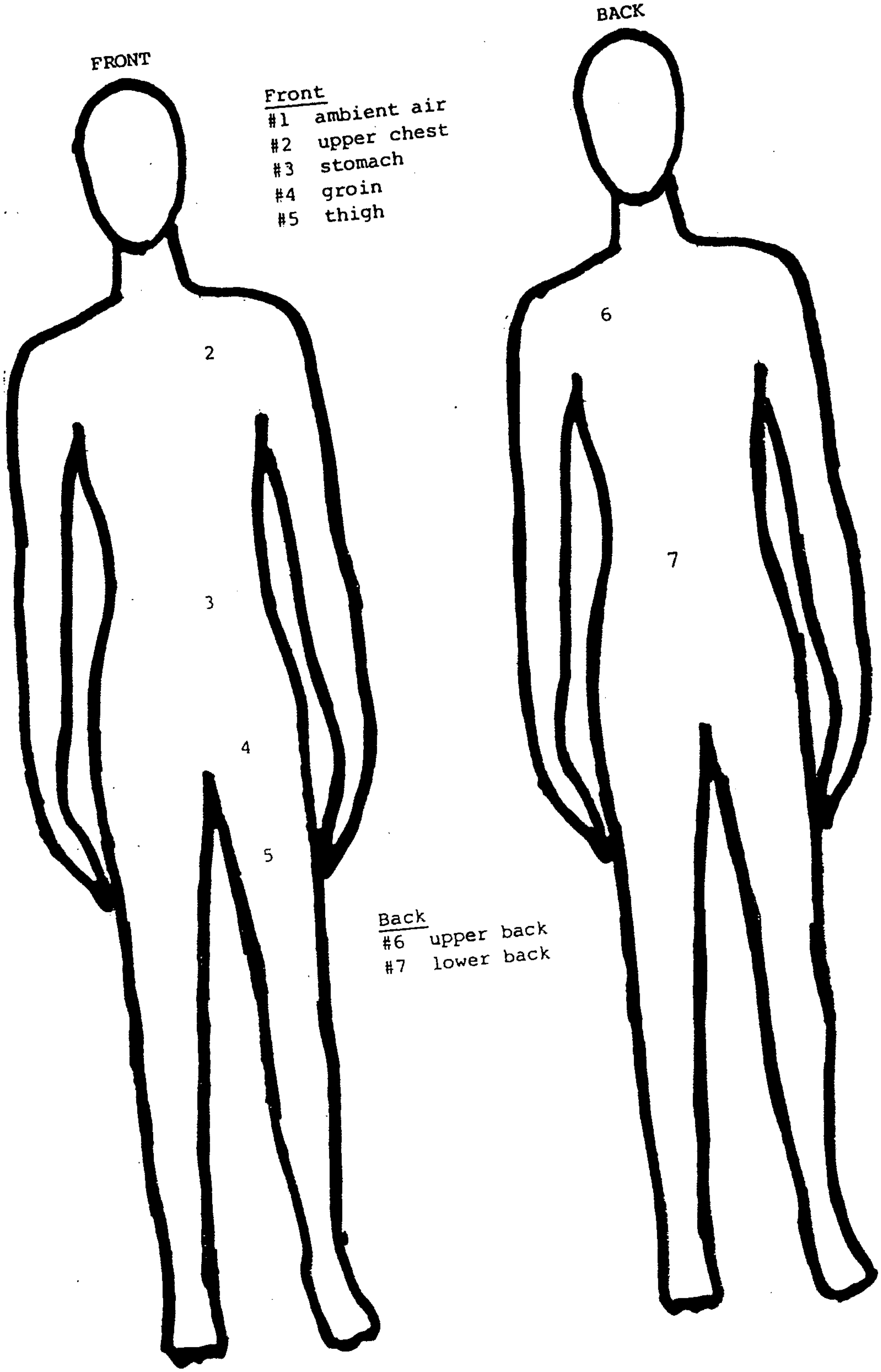
1. Very Cold
2. Cold
3. Cool
4. Slightly Cool
5. Neutral
6. Slightly Warm
7. Warm
8. Hot
9. Very Hot

OVERALL CLOTHING COMFORT SENSATION SCALE

1. **Comfortable**
2. **..............**
3. **Slightly Uncomfortable**
4. **..............**
5. **Moderately Uncomfortable**
6. **..............**
7. **Very Uncomfortable**

APPENDIX E

SKIN TEMPERATURE BODY SITES



Front
#1 ambient air
#2 upper chest
#3 stomach
#4 groin
#5 thigh

Back
#6 upper back
#7 lower back

APPENDIX F

SKIN TEMPERATURE DATA SHEET

TEMPERATURE DATA

SUBJECT_________
DATE___________
TIME___________

SESSION 1 2 3
ENV: C H-D H-H
FABRIC: B C E F

TIME	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	SITE 7
T = 05							
T = 10							
T = 15							
T = 20							
T = 25							
T = 30							
T = 35							
T = 40							

APPENDIX G

SUBJECT INFORMATION DATA SHEET

SUBJECT INFORMATION SHEET

SUBJECT_________
DATE_____________
TIME_____________

ENVIRONMENTAL CONDITION: C H-D H-H

FABRIC: B C E F

PRE:	**POST:**
ENSEMBLE WT:	**ENSEMBLE WT:**
TOP_____________	**TOP_____________**
SHORTS_________	**SHORTS_________**
SUBJECT WT__________	**SUBJECT WT__________**

APPENDIX H

PERCEIVED SENSATION BALLOT SHEET

DATA SHEET

SUBJECT_______
DATE_________
TIME________

SESSION 1 2 3
ENV: C H-D H-H
FABRIC: B C E F

RATING PERIODS

CONTACT DESCRIPTORS	1^{05} (05)	2^{10} (10)	3^{05} (15)	4^{10} (20)	5^{15} (25)	6^{05} (30)	7^{10} (35)	8^{15} (40)
BREATHABLE								
CLAMMY								
CLINGY								
ITCHY								
ABSORBENT								
ROUGH								
SCRATCHY								
SMOOTH								
SOFT								
STICKY								
STIFF								

CONTACT SENSATION
0. No Contact Sensation
1. Slight
2. ....
3. Moderate
4. ....
5. Extreme

RATING PERIODS

▨	1^{05} (05)	2^{10} (10)	3^{05} (15)	4^{10} (20)	5^{15} (25)	6^{05} (30)	7^{10} (35)	8^{15} (40)
WETNESS SENSATION								
THERMAL SENSATION								
CLOTHING COMFORT								

WETNESS SENSATION
1. Dry
2. ....
3. Slightly Wet
4. ....
5. Moderately Wet
6. ....
7. Very Wet

THERMAL SENSATION
1. Very Cold
2. Cold
3. Cool
4. Slightly Cool
5. Neutral
6. Slightly Warm
7. Warm
8. Hot
9. Very Hot

OVERALL CLOTHING COMFORT SENSATION
1. Comfortable
2. ....
3. Slightly Uncomfortable
4. ....
5. Moderately Uncomfortable
6. ....
7. Very Uncomfortable

APPENDIX I

AOV STATISTICAL TABLES

TABLE 9. ANALYSIS OF VARIANCE FOR TACTILE SENSATION--BREATHABLE

Source	Numerator DF	Sum of Squares	Mean Square	F-Value	Prob. > F
Env. Cond.	2	4.478	2.239	0.21	0.8142
Fabric	3	39.760	13.253	1.23	0.3233
Env. Cond. * Fabric	6	12.442	2.074	0.19	0.9758
Session	2	0.681	0.340	0.36	0.6983
Experimental Error (Session * Env. Cond. * Fabric)	22	237.485	10.795		
Time	{7}* 1	14.224	2.032	2.15	0.1460
Env. Cond. * Time	{14} 2	3.385	0.242	0.26	0.7716
Fabric * Time	{21} 3	2.995	0.143	0.15	0.9295
Env. Cond. * Fabric * Time	{42} 6	9.021	0.215	0.23	0.9659
Repeated Measure Error	{648} 92	613.667	0.947		

*Numerator DF in {} were divided by 7 due to being repeated measures over time

TABLE 10. ANALYSIS OF VARIANCE FOR TACTILE SENSATION--CLAMMY

Source	Numerator DF	Sum of Squares	Mean Square	F-Value	Prob. > F
Env. Cond.	2	259.210	129.605	16.14	0.0001
Fabric	3	13.990	4.663	0.58	0.6339
Env. Cond. * Fabric	6	6.848	1.141	0.14	0.9888
Session	2	20.763	10.382	14.23	0.0001
Experimental Error (Session * Env. Cond. * Fabric)	22	176.683	8.031		
Time	{7}* 1	179.301	25.614	35.11	0.0000
Env. Cond. * Time	{14} 2	12.773	0.912	1.25	0.2913
Fabric * Time	{21} 3	5.475	0.261	0.36	0.7820
Env. Cond. * Fabric * Time	{42} 6	14.529	0.346	0.47	0.8290
Repeated Measure Error	{648} 92	472.797	0.730		

*Numerator DF in {} were divided by 7 due to being repeated measures over time

TABLE 11. ANALYSIS OF VARIANCE FOR TACTILE SENSATION--CLINGY

Source	Numerator DF	Sum of Squares	Mean Square	F-Value	Prob. > F
Env. Cond.	2	137.584	68.792	10.60	0.0006
Fabric	3	37.009	12.336	1.90	0.1589
Env. Cond. * Fabric	6	17.597	2.933	0.45	0.8357
Session	2	43.149	21.575	30.60	0.0001
Experimental Error (Session * Env. Cond. * Fabric)	22	142.722	6.487		
Time	{7}* 1	108.530	15.504	21.99	0.0000
Env. Cond. * Time	{14} 2	16.935	1.210	1.72	0.1848
Fabric * Time	{21} 3	10.725	0.511	0.72	0.5426
Env. Cond. * Fabric * Time	{42} 6	19.701	0.469	0.67	0.6741
Repeated Measure Error	{648} 92	456.818	0.705		

*Numerator DF in {} were divided by 7 due to being repeated measures over time

TABLE 12. ANALYSIS OF VARIANCE FOR TACTILE SENSATION--ITCHY

Source	Numerator DF	Sum of Squares	Mean Square	F-Value	Prob. > F
Env. Cond.	2	4.071	2.036	0.18	0.8357
Fabric	3	82.374	27.458	2.44	0.0913
Env. Cond. * Fabric	6	19.044	3.174	0.28	0.9393
Session	2	20.304	10.152	9.24	0.0001
Experimental Error (Session * Env. Cond. * Fabric)	22	247.500	11.250		
Time	{7}* 1	10.114	1.445	1.31	0.2554
Env. Cond. * Time	{14} 2	2.117	0.151	0.14	0.8695
Fabric * Time	{21} 3	9.913	0.472	0.43	0.7320
Env. Cond. * Fabric * Time	{42} 6	12.622	0.301	0.27	0.9496
Repeated Measure Error	{648} 92	712.089	1.099		

*Numerator DF in {} were divided by 7 due to being repeated measures over time

TABLE 13. ANALYSIS OF VARIANCE FOR TACTILE SENSATION--ABSORBENT

Source	Numerator DF	Sum of Squares	Mean Square	F-Value	Prob. > F
Env. Cond.	2	101.893	50.947	8.00	0.0025
Fabric	3	24.699	8.233	1.29	0.3019
Env. Cond. * Fabric	6	4.851	0.808	0.13	0.9917
Session	2	7.191	3.595	3.56	0.0289
Experimental Error (Session * Env. Cond. * Fabric)	22	140.161	6.371		
Time	{7}* 1	264.438	37.777	37.43	0.0000
Env. Cond. * Time	{14} 2	20.398	1.457	1.44	0.2422
Fabric * Time	{21} 3	12.448	0.593	0.59	0.6231
Env. Cond. * Fabric * Time	{42} 6	8.372	0.199	0.20	0.9760
Repeated Measure Error	{648} 92	653.990	1.009		

*Numerator DF in {} were divided by 7 due to being repeated measures over time

TABLE 14. ANALYSIS OF VARIANCE FOR TACTILE SENSATION--ROUGH

Source	Numerator DF	Sum of Squares	Mean Square	F-Value	Prob. > F
Env. Cond.	2	0.484	0.242	0.03	0.9720
Fabric	3	75.854	25.285	2.97	0.0540
Env. Cond. * Fabric	6	12.272	2.045	0.24	0.9582
Session	2	17.883	8.941	9.20	0.0001
Experimental Error (Session * Env. Cond. * Fabric)	22	187.252	8.511		
Time	{7}* 1	4.832	0.690	0.71	0.4016
Env. Cond. * Time	{14} 2	3.344	0.239	0.25	0.7793
Fabric * Time	{21} 3	10.319	0.491	0.51	0.6764
Env. Cond. * Fabric * Time	{42} 6	6.802	0.162	0.17	0.9842
Repeated Measure Error	{648} 92	629.516	0.971		

*Numerator DF in {} were divided by 7 due to being repeated measures over time

TABLE 15. ANALYSIS OF VARIANCE FOR TACTILE SENSATION--SCRATCHY

Source	Numerator DF	Sum of Squares	Mean Square	F-Value	Prob. > F
Env. Cond.	2	5.441	2.720	0.27	0.7686
Fabric	3	88.692	29.564	2.89	0.0581
Env. Cond. * Fabric	6	14.625	2.437	0.24	0.9589
Session	2	20.676	10.338	9.00	0.0001
Experimental Error (Session * Env. Cond. * Fabric)	22	224.696	10.213		
Time	{7}* 1	6.745	0.964	0.84	0.3618
Env. Cond. * Time	{14} 2	1.747	0.125	0.11	0.8960
Fabric * Time	{21} 3	8.974	0.427	0.37	0.7748
Env. Cond. * Fabric * Time	{42} 6	7.846	0.187	0.16	0.9865
Repeated Measure Error	{648} 92	744.438	1.149		

*Numerator DF in {} were divided by 7 due to being repeated measures over time

TABLE 16. ANALYSIS OF VARIANCE FOR TACTILE SENSATION--SMOOTH

Source	Numerator DF	Sum of Squares	Mean Square	F-Value	Prob. > F
Env. Cond.	2	4.751	2.376	0.25	0.7847
Fabric	3	167.797	55.932	5.77	0.0045
Env. Cond. * Fabric	6	6.663	1.111	0.11	0.9937
Session	2	13.397	6.700	3.20	0.0415
Experimental Error (Session * Env. Cond. * Fabric)	22	213.161	9.689		
Time	{7}* 1	1.432	0.205	0.10	0.7526
Env. Cond. * Time	{14} 2	1.669	0.119	0.06	0.9418
Fabric * Time	{21} 3	6.630	0.316	0.15	0.9295
Env. Cond. * Fabric * Time	{42} 6	12.237	0.291	0.14	0.9905
Repeated Measure Error	{648} 92	1356.990	2.094		

*Numerator DF in {} were divided by 7 due to being repeated measures over time

TABLE 17. ANALYSIS OF VARIANCE FOR TACTILE SENSATION--SOFT

Source	Numerator DF	Sum of Squares	Mean Square	F-Value	Prob. > F
Env. Cond.	2	7.167	3.583	0.35	0.7067
Fabric	3	295.478	98.493	9.69	0.0003
Env. Cond. * Fabric	6	23.653	3.942	0.39	0.8788
Session	2	13.089	6.545	2.95	0.0530
Experimental Error (Session * Env. Cond. * Fabric)	22	223.559	10.162		
Time	{7}* 1	4.245	0.606	0.27	0.6046
Env. Cond. * Time	{14} 2	2.521	0.180	0.08	0.9232
Fabric * Time	{21} 3	6.818	0.325	0.15	0.9295
Env. Cond. * Fabric * Time	{42} 6	7.823	0.186	0.08	0.9980
Repeated Measure Error	{648} 92	1437.010	2.218		

*Numerator DF in {} were divided by 7 due to being repeated measures over time

TABLE 18. ANALYSIS OF VARIANCE FOR TACTILE SENSATION--STICKY

Source	Numerator DF	Sum of Squares	Mean Square	F-Value	Prob. > F
Env. Cond.	2	251.550	125.775	11.00	0.0005
Fabric	3	16.430	5.477	0.48	0.7001
Env. Cond. * Fabric	6	3.157	0.526	0.05	0.9995
Session	2	42.312	21.156	33.04	0.0001
Experimental Error (Session * Env. Cond. * Fabric)	22	251.448	11.429		
Time	{7}* 1	123.978	17.711	27.66	0.0000
Env. Cond. * Time	{14} 2	13.924	0.995	1.55	0.2177
Fabric * Time	{21} 3	6.663	0.317	0.50	0.6832
Env. Cond. * Fabric * Time	{42} 6	9.357	0.223	0.35	0.9082
Repeated Measure Error	{648} 92	414.911	0.640		

*Numerator DF in {} were divided by 7 due to being repeated measures over time

TABLE 19. ANALYSIS OF VARIANCE FOR TACTILE SENSATION--STIFF

Source	Numerator DF	Sum of Squares	Mean Square	F-Value	Prob. > F
Env. Cond.	2	6.003	3.002	0.53	0.5952
Fabric	3	175.211	58.404	10.34	0.0002
Env. Cond. * Fabric	6	9.824	1.637	0.29	0.9355
Session	2	0.462	0.231	0.30	0.7396
Experimental Error (Session * Env. Cond. * Fabric)	22	124.300	5.650		
Time	{7}* 1	2.426	0.347	0.45	0.5040
Env. Cond. * Time	{14} 2	0.727	0.052	0.07	0.9324
Fabric * Time	{21} 3	4.454	0.212	0.28	0.8397
Env. Cond. * Fabric * Time	{42} 6	5.878	0.140	0.18	0.9817
Repeated Measure Error	{648} 92	495.828	0.765		

*Numerator DF in {} were divided by 7 due to being repeated measures over time

TABLE 20. ANALYSIS OF VARIANCE FOR WETNESS SENSATION

Source	Numerator DF	Sum of Squares	Mean Square	F-Value	Prob. > F
Env. Cond.	2	252.286	126.143	58.79	0.0001
Fabric	3	2.217	0.739	0.34	0.7935
Env. Cond. * Fabric	6	2.921	0.487	0.23	0.9636
Session	2	37.756	18.878	28.83	0.0001
Experimental Error (Session * Env. Cond. * Fabric)	22	47.207	2.146		
Time	{7}* 1	489.947	69.992	106.89	0.0000
Env. Cond. * Time	{14} 2	51.221	3.659	5.59	0.0051
Fabric * Time	{21} 3	4.507	0.215	0.33	0.8037
Env. Cond. * Fabric * Time	{42} 6	9.060	0.216	0.33	0.9196
Repeated Measure Error	{648} 92	424.328	0.655		

*Numerator DF in {} were divided by 7 due to being repeated measures over time

TABLE 21. ANALYSIS OF VARIANCE FOR THERMAL COMFORT

Source	Numerator DF	Sum of Squares	Mean Square	F-Value	Prob. > F
Env. Cond.	2	107.189	53.594	31.79	0.0001
Fabric	3	1.722	0.574	0.34	0.7962
Env. Cond. * Fabric	6	5.226	0.871	0.52	0.7894
Session	2	9.180	4.590	6.37	0.0018
Experimental Error (Session * Env. Cond. * Fabric)	22	37.088	1.686		
Time	{7}* 1	172.384	24.626	34.16	0.0000
Env. Cond. * Time	{14} 2	7.659	0.547	0.76	0.4706
Fabric * Time	{21} 3	5.882	0.280	0.39	0.7605
Env. Cond. * Fabric * Time	{42} 6	9.310	0.222	0.31	0.9303
Repeated Measure Error	{648} 92	467.182	0.721		

*Numerator DF in {} were divided by 7 due to being repeated measures over time

TABLE 22. ANALYSIS OF VARIANCE FOR OVERALL CLOTHING COMFORT

Source	Numerator DF	Sum of Squares	Mean Square	F-Value	Prob. > F
Env. Cond.	2	18.858	9.429	1.54	0.2359
Fabric	3	222.562	74.187	12.14	0.0001
Env. Cond. * Fabric	6	7.231	1.205	0.20	0.9741
Session	2	39.364	19.682	16.66	0.0001
Experimental Error (Session * Env. Cond. * Fabric)	22	134.415	6.110		
Time	{7}* 1	11.697	1.671	1.41	0.2381
Env. Cond. * Time	{14} 2	2.612	0.187	0.16	0.8524
Fabric * Time	{21} 3	6.569	0.313	0.26	0.8540
Env. Cond. * Fabric * Time	{42} 6	7.982	0.190	0.16	0.9865
Repeated Measure Error	{648} 92	765.599	1.181		

*Numerator DF in {} were divided by 7 due to being repeated measures over time

TABLE 23. ANALYSIS OF VARIANCE FOR SKIN TEMPERATURE SITE T2 (UPPER CHEST)

Source	Numerator DF	Sum of Squares	Mean Square	F-Value	Prob. > F
Env. Cond.	2	851.654	425.827	31.22	0.0001
Fabric	3	2.294	0.765	0.06	0.9821
Env. Cond. * Fabric	6	32.708	5.45	0.40	0.8712
Session	2	95.501	47.750	23.56	0.0001
Experimental Error (Session * Env. Cond. * Fabric)	22	300.109	13.641		
Time	{7}* 1	764.468	109.210	53.88	0.0000
Env. Cond. * Time	{14} 2	122.977	8.784	4.33	0.0160
Fabric * Time	{21} 3	10.328	0.492	0.24	0.8682
Env. Cond. * Fabric * Time	{42} 6	15.217	0.362	0.18	0.9817
Repeated Measure Error	{647} 92	1311.308	2.027		

*Numerator DF in { } were divided by 7 due to being repeated measures over time
**Skin Temperature in °F

TABLE 24. ANALYSIS OF VARIANCE FOR SKIN TEMPERATURE SITE T3 (STOMACH)

Source	Numerator DF	Sum of Squares	Mean Square	F-Value	Prob. > F
Env. Cond.	2	1505.560	752.780	98.48	0.0001
Fabric	3	51.251	17.084	2.23	0.1126
Env. Cond. * Fabric	6	90.518	15.086	1.97	0.1133
Session	2	110.997	55.499	16.99	0.0001
Experimental Error (Session * Env. Cond. * Fabric)	22	168.168	7.644		
Time	{7}* 1	711.737	101.677	31.12	0.0000
Env. Cond. * Time	{14} 2	57.733	4.124	1.26	0.2885
Fabric * Time	{21} 3	11.260	0.536	0.16	0.9230
Env. Cond. * Fabric * Time	{42} 6	55.083	1.312	0.40	0.8773
Repeated Measure Error	{647} 92	2113.753	3.267		

*Numerator DF in {} were divided by 7 due to being repeated measures over time
**Skin Temperature in ^{0}F

TABLE 25. ANALYSIS OF VARIANCE FOR SKIN TEMPERATURE SITE T4 (GROIN)

Source	Numerator DF	Sum of Squares	Mean Square	F-Value	Prob. > F
Env. Cond.	2	1373.302	686.651	161.69	0.0001
Fabric	3	20.915	6.972	1.64	0.2086
Env. Cond. * Fabric	6	11.846	1.974	0.46	0.8267
Session	2	77.052	38.526	19.82	0.0001
Experimental Error (Session * Env. Cond. * Fabric)	22	93.428	4.247		
Time	{7}* 1	560.513	80.073	41.19	0.0000
Env. Cond. * Time	{14} 2	44.202	3.157	1.62	0.2035
Fabric * Time	{21} 3	9.404	0.448	0.23	0.8753
Env. Cond. * Fabric * Time	{42} 6	50.703	1.207	0.62	0.7138
Repeated Measure Error	{644} 92	1251.797	1.944		

*Numerator DF in {} were divided by 7 due to being repeated measures over time

**Skin Temperature in ^{0}F

TABLE 26. ANALYSIS OF VARIANCE FOR SKIN TEMPERATURE SITE T5 (THIGH)

Source	Numerator DF	Sum of Squares	Mean Square	F-Value	Prob. > F
Env. Cond.	2	3606.488	1803.244	198.80	0.0001
Fabric	3	10.422	3.474	0.38	0.7662
Env. Cond. * Fabric	6	36.212	6.035	0.67	0.6783
Session	2	42.560	21.280	9.11	0.0001
Experimental Error (Session * Env. Cond. * Fabric)	22	199.552	9.071		
Time	{7}* 1	134.294	19.185	8.21	0.0052
Env. Cond. * Time	{14} 2	176.291	12.592	5.39	0.0061
Fabric * Time	{21} 3	42.558	2.027	0.87	0.4597
Env. Cond. * Fabric * Time	{42} 6	34.386	0.819	0.35	0.9082
Repeated Measure Error	{648} 92	1514.025	2.336		

*Numerator DF in { } were divided by 7 due to being repeated measures over time
**Skin Temperature in ^{0}F

TABLE 27. ANALYSIS OF VARIANCE FOR SKIN TEMPERATURE SITE T6 (UPPER BACK)

Source	Numerator DF	Sum of Squares	Mean Square	F-Value	Prob. > F
Env. Cond.	2	1269.797	634.899	65.52	0.0001
Fabric	3	31.833	10.611	1.10	0.3721
Env. Cond. * Fabric	6	19.724	3.287	0.34	0.9086
Session	2	118.135	59.067	23.76	0.0001
Experimental Error (Session * Env. Cond. * Fabric)	22	213.174	9.690		
Time	{7}* 1	1752.623	250.375	100.73	0.0000
Env. Cond. * Time	{14} 2	227.608	16.258	6.54	0.0022
Fabric * Time	{21} 3	17.303	0.824	0.33	0.8037
Env. Cond. * Fabric * Time	{42} 6	42.414	1.010	0.41	0.8707
Repeated Measure Error	{641} 92	1593.298	2.486		

*Numerator DF in { } were divided by 7 due to being repeated measures over time

**Skin Temperature in ^{0}F

TABLE 28. ANALYSIS OF VARIANCE FOR SKIN TEMPERATURE SITE T7 (LOWER BACK)

Source	Numerator DF	Sum of Squares	Mean Square	F-Value	Prob. > F
Env. Cond.	2	1384.895	692.447	216.76	0.0001
Fabric	3	36.017	12.006	3.76	0.0256
Env. Cond. * Fabric	6	5.394	0.899	0.28	0.9396
Session	2	170.010	85.005	50.62	0.0001
Experimental Error (Session * Env. Cond. * Fabric)	22	70.281	3.195		
Time	{7}* 1	974.647	139.235	82.92	0.0000
Env. Cond. * Time	{14} 2	222.474	15.891	9.46	0.0002
Fabric * Time	{21} 3	19.995	0.952	0.57	0.6362
Env. Cond. * Fabric * Time	{42} 6	18.283	0.435	0.26	0.9540
Repeated Measure Error	{648} 92	1088.125	1.679		

*Numerator DF in {} were divided by 7 due to being repeated measures over time
**Skin Temperature in ^{0}F

TABLE 29. ANALYSIS OF VARIANCE FOR DIFFERENCE IN PRE- AND POST-WEIGHT OF TOP GARMENT

Source	Numerator DF	Sum of Squares	Mean Square	F-Value	Prob. > F
Env. Cond.	2	5050.166	2525.083	74.12	0.0001
Fabric	3	369.911	123.304	3.62	0.0181
Env. Cond. * Fabric	6	160.943	26.824	0.79	0.5833
Session	2	67.438	33.719	0.99	0.3777
Experimental Error (Session * Env. Cond. * Fabric)	22	754.498	34.295		

TABLE 30. ANALYSIS OF VARIANCE FOR DIFFERENCE IN PRE- AND POST-WEIGHT OF BOTTOM GARMENT

Source	Numerator DF	Sum of Squares	Mean Square	F-Value	Prob. > F
Env. Cond.	2	2232.734	1116.367	110.16	0.0001
Fabric	3	289.377	96.459	9.52	0.0001
Env. Cond. * Fabric	6	121.514	20.252	2.00	0.0799
Session	2	10.127	5.063	0.50	0.6093
Experimental Error (Session * Env. Cond. * Fabric)	22	581.748	26.443		

APPENDIX J

POST HOC STATISTICAL TABLES

(ENVIRONMENT)

TABLE 31. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--BREATHABLE

Env. Cond.	H-H	H-D	C
Mean	1.891	1.891	1.695

*All environments had the same n=256
** Environmental conditions connected by a line were not significantly different
***p < .05, DF = 22, MSE = 10.795

TABLE 32. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--CLAMMY

Env. Cond.	H-H	H-D	C
Mean	2.035	1.234	0.570

*All environments had the same $n=256$
** Environmental conditions connected by a line were not significantly different
***$p < .05$, $DF = 22$, $MSE = 8.031$

TABLE 33. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--CLINGY

Env. Cond.	H-H	H-D	C
Mean	2.063	1.563	0.965

*All environments had the same n=256
** Environmental conditions connected by a line were not significantly different
***$p < .05$, DF = 22, MSE = 6.487

TABLE 34. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--ITCHY

Env. Cond.	H-D	H-H	C
Mean	0.859	0.852	0.668

*All environments had the same n = 256

** Environmental conditions connected by a line were not significantly different

***p < .05, DF = 22, MSE = 11.250

TABLE 35. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--ABSORBENT

Env. Cond.	H-H	H-D	C
Mean	1.922	1.812	1.043
	———	———	

*All environments had the same n=256
** Environmental conditions connected by a line were not significantly different
***$p < .05$, DF = 22, MSE = 6.371

TABLE 36. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--ROUGH

Env. Cond.	H-H	H-D	C
Mean	0.793	0.754	0.746

*All environments had the same n = 256
** Environmental conditions connected by a line were not significantly different
***$p < .05$, DF = 22, MSE = 8.511

TABLE 37. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--SCRATCHY

Env. Cond.	H-H	H-D	C
Mean	0.910	0.813	0.691

*All environments had the same n=256
** Environmental conditions connected by a line were not significantly different
***p < .05, DF = 22, MSE = 10.213

TaBLE 38. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--SMOOTH

Env. Cond.	H-H	C	H-D
Mean	2.449	2.367	2.363

*All environments had the same n=256
** Environmental conditions connected by a line were not significantly different
***p < .05, DF = 22, MSE = 9.689

TABLE 39. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--SOFT

Env. Cond.	H-H	H-D	C
Mean	2.414	2.305	2.273

*All environments had the same n = 256
** Environmental conditions connected by a line were not significantly different
***$p < .05$, DF = 22, MSE = 10.162

TABLE 40. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--STICKY

Env. Cond.	H-H	H-D	C
Mean	1.887	1.211	0.445

*All environments had the same n=256
** Environmental conditions connected by a line were not significantly different
***p < .05, DF = 22, MSE = 11.429

TABLE 41. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--STIFF

Env. Cond.	H-H	H-D	C
Mean	0.828	0.797	0.621

*All environments had the same n=256
** Environmental conditions connected by a line were not significantly different
***$p < .05$, DF = 22, MSE = 5.650

TABLE 42. DUNCAN'S MULTIPLE RANGE TEST FOR WETNESS SENSATION

Env. Cond.	H-H	H-D	C
Mean	2.957	2.453	1.555

*All environments had the same n=256
** Environmental conditions connected by a line were not significantly different
***$p < .05$, DF = 22, MSE = 2.146

TABLE 43. DUNCAN'S MULTIPLE RANGE TEST FOR THERMAL COMFORT SENSATION

Env. Cond.	H-H	H-D	C
Mean	5.832	5.766	5.023

*All environments had the same n=256

** Environmental conditions connected by a line were not significantly different

***$p < .05$, DF = 22, MSE = 1.686

TABLE 44. DUNCAN'S MULTIPLE RANGE TEST FOR OVERALL CLOTHING COMFORT SENSATION

Env. Cond.	H-D	H-H	C
Mean	2.133	2.117	1.809

*All environments had the same $n=256$

** Environmental conditions connected by a line were not significantly different

***$p < .05$, DF = 22, MSE = 6.110

TABLE 45. DUNCAN'S MULTIPLE RANGE TEST FOR SKIN TEMPERATURE SITE T2 (UPPER CHEST)

Env. Cond.	H-H	H-D	C
Mean	94.551	93.193	91.950

*All environments had the same n = 256
** Environmental conditions connected by a line were not significantly different
***$p < .05$, DF = 22, MSE = 13.641
****Skin temperature in °F

TABLE 46. DUNCAN'S MULTIPLE RANGE TEST FOR SKIN TEMPERATURE SITE T3 (STOMACH)

Env. Cond.	H-H	H-D	C
Mean	93.138	92.441	89.808

*All environments had the same n=256
** Environmental conditions connected by a line were not significantly different
***$p < .05$, DF = 22, MSE = 7.644
****Skin temperature in °F

TABLE 47. DUNCAN'S MULTIPLE RANGE TEST FOR SKIN TEMPERATURE SITE T4 (GROIN)

Env. Cond.	H-H	H-D	C
Mean	93.335	92.932	90.300

*All environments had the same n = 256
** Environmental conditions connected by a line were not significantly different
***p < .05, DF = 22, MSE = 4.247
****Skin temperature in ^{0}F

TABLE 48. DUNCAN'S MULTIPLE RANGE TEST FOR SKIN TEMPERATURE SITE T5 (THIGH)

Env. Cond.	H-H	H-D	C
Mean	92.959	92.416	88.034

*All environments had the same n=256
** Environmental conditions connected by a line were not significantly different
***$p < .05$, DF = 22, MSE = 9.071
****Skin temperature in ^{0}F

TABLE 49. DUNCAN'S MULTIPLE RANGE TEST FOR SKIN TEMPERATURE SITE T6 (UPPER BACK)

Env. Cond.	H-H	H-D	C
Mean	94.016	92.819	90.848

*All environments had the same n = 256
** Environmental conditions connected by a line were not significantly different
***p < .05, DF = 22, MSE = 9.690
****Skin temperature in ^{0}F

TABLE 50. DUNCAN'S MULTIPLE RANGE TEST FOR SKIN TEMPERATURE SITE T7 (LOWER BACK)

Env. Cond.	H-H	H-D	C
Mean	92.620	91.704	89.411

*All environments had the same n=256
** Environmental conditions connected by a line were not significantly different
***$p < .05$, DF = 22, MSE = 3.195
****Skin temperature in ^{0}F

TABLE 51. DUNCAN'S MULTIPLE RANGE TEST FOR DIFFERENCE IN PRE- AND POST-WEIGHT OF TOP GARMENT

Env. Cond.	H-H	H-D	C
Mean	15.117	12.374	1.950

* All environments had the same n = 32
**Environmental conditions connected by a line were not significantly different
***p < .05, DF = 22, MSE = 34.295

TABLE 52. DUNCAN'S MULTIPLE RANGE TEST FOR DIFFERENCE IN PRE- AND POST-WEIGHT OF BOTTOM GARMENT

Env. Cond.	H-H	H-D	C
Mean	12.720	6.046	0.929

* All environments had the same n = 32
**Environmental conditions connected by a line were not significantly different
***$p < .05$, DF = 22, MSE = 26.443

APPENDIX K

POST HOC STATISTICAL TABLES

(FABRIC)

TABLE 53. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--BREATHABLE

Fabric	C/SP	C	P	P/SP
Mean	2.066	2.047	1.703	1.490

*All fabrics had the same n = 192
**Fabrics connected by a line were not significantly different
***$p < .05$, DF = 22, MSE = 10.795

TABLE 54. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--CLAMMY

Fabric	P/SP	C/SP	P	C
Mean	1.505	1.287	1.250	1.078

*All fabrics had the same n = 192
**Fabrics connected by a line were not significantly different
***p < .05, DF = 22, MSE = 8.031

TABLE 55. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--CLINGY

Fabric	P/SP	P	C/SP	C
Mean	1.885	1.516	1.474	1.245

*All fabrics had the same n = 192
**Fabrics connected by a line were not significantly different
***p < .05, DF = 22, MSE = 6.487

TABLE 56. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--ITCHY

Fabric	P/SP	C/SP	P	C
Mean	1.214	1.078	0.505	0.375

*All fabrics had the same n = 192
**Fabrics connected by a line were not significantly different
***p < .05, DF = 22, MSE = 11.250

TABLE 57. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--ABSORBENT

Fabric	C	C/SP	P/SP	P
Mean	1.818	1.729	1.443	1.385

*All fabrics had the same $n = 192$
**Fabrics connected by a line were not significantly different
***$p < .05$, DF = 22, MSE = 6.371

TABLE 58. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--ROUGH

Fabric	P/SP	C/SP	P	C
Mean	1.172	1.016	0.537	0.333

*All fabrics had the same n = 192
**Fabrics connected by a line were not significantly different
***$p < .05$, DF = 22, MSE = 8.511

TABLE 59. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--SCRATCHY

Fabric	P/SP	C/SP	P	C
Mean	1.234	1.094	0.542	0.349

*All fabrics had the same n = 192
**Fabrics connected by a line were not significantly different
***p < .05, DF = 22, MSE = 10.213

TABLE 60. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--SMOOTH

Fabric	C	P	C/SP	P/SP
Mean	3.063	2.604	2.188	1.719
	———	———		
		———	———	
			———	———

*All fabrics had the same n = 192
**Fabrics connected by a line were not significantly different
***p < .05, DF = 22, MSE = 9.689

TABLE 61. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--SOFT

Fabric	C	P	C/SP	P/SP
Mean	3.224	2.453	2.245	1.401
		———	———	

*All fabrics had the same n = 192
**Fabrics connected by a line were not significantly different
***p < .05, DF = 22, MSE = 10.162

TABLE 62. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--STICKY

Fabric	P/SP	P	C/SP	C
Mean	1.427	1.167	1.068	1.063

*All fabrics had the same n = 192
**Fabrics connected by a line were not significantly different
***$p < .05$, DF = 22, MSE = 11.429

TABLE 63. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--STIFF

Fabric	P/SP	C/SP	P	C
Mean	1.630	0.510	0.495	0.359

*All fabrics had the same n = 192
**Fabrics connected by a line were not significantly different
***p < .05, DF = 22, MSE = 5.650

TABLE 64. DUNCAN'S MULTIPLE RANGE TEST FOR WETNESS SENSATION

Fabric	P/SP	C/SP	C	P
Mean	2.406	2.313	2.302	2.266

*All fabrics had the same n = 192
**Fabrics connected by a line were not significantly different
***p < .05, DF = 22, MSE = 2.146

TABLE 65. DUNCAN'S MULTIPLE RANGE TEST FOR THERMAL COMFORT SENSATION

Fabric	C	C/SP	P/SP	P
Mean	5.589	5.563	5.531	5.479

*All fabrics had the same n = 192
**Fabrics connected by a line were not significantly different
***$p < .05$, DF = 22, MSE = 1.686

TABLE 66. DUNCAN'S MULTIPLE RANGE TEST FOR OVERALL CLOTHING COMFORT SENSATION

Fabric	P/SP	C/SP	P	C
Mean	2.969	1.927	1.818	1.365
		———	———	
			———	———

*All fabrics had the same n = 192
**Fabrics connected by a line were not significantly different
***p < .05, DF = 22, MSE = 6.110

TABLE 67 . DUNCAN'S MULTIPLE RANGE TEST FOR SKIN TEMPERATURE SITE T2 (UPPER CHEST)

Fabric	P	C/SP	C	P/SP
Mean	93.264	93.260	93.219	93.190

*Fabric P had n = 191, fabrics C/SP, C, and P/SP had n= 192
**Fabrics connected by a line were not significantly different
***$p < .05$, DF = 22, MSE = 13.641
****Skin temperature in ^{0}F

TABLE 68 . DUNCAN'S MULTIPLE RANGE TEST FOR SKIN TEMPERATURE SITE T3 (STOMACH)

Fabric	C	P	C/SP	P/SP
Mean	92.210	91.777	91.773	91.414

*All fabrics had the same n = 192
**Fabrics connected by a line were not significantly different
***$p < .05$, DF = 22, MSE = 7.644
****Skin temperature in ^{0}F

TABLE 69. DUNCAN'S MULTIPLE RANGE TEST FOR SKIN TEMPERATURE SITE T4 (GROIN)

Fabric	C	P	C/SP	P/SP
Mean	92.332	92.291	92.186	91.912

*Fabrics C, P, and C/SP the same n = 192. Fabric P/SP had n = 188
**Fabrics connected by a line were not significantly different
***$p < .05$, DF = 22, MSE = 4.247
****Skin temperature in ^{0}F

TABLE 70 . DUNCAN'S MULTIPLE RANGE TEST FOR SKIN TEMPERATURE SITE T5 (THIGH)

Fabric	C/SP	C	P/SP	P
Mean	91.263	91.245	91.130	90.908

*All fabrics had the same n = 192
**Fabrics connected by a line were not significantly different
***p < .05, DF = 22, MSE = 9.071
****Skin temperature in ^{0}F

TABLE 71 . DUNCAN'S MULTIPLE RANGE TEST FOR SKIN TEMPERATURE SITE T6 (UPPER BACK)

Fabric	C/SP	C	P	P/SP
Mean	92.778	92.752	92.480	92.298
	———	———	———	———

*Fabric C/SP had n = 192, fabric C had n = 188, fabric P had n = 190, and fabric P/SP had n = 191
**Fabrics connected by a line were not significantly different
***$p < .05$, DF = 22, MSE = 9.690
****Skin temperature in ^{0}F

TABLE 72. DUNCAN'S MULTIPLE RANGE TEST FOR SKIN TEMPERATURE SITE T7 (LOWER BACK)

Fabric	P	C	C/SP	P/SP
Mean	91.457	91.392	91.232	90.898

*All fabrics had the same n = 192
**Fabrics connected by a line were not significantly different
***$p < .05$, DF = 22, MSE = 3.195
****Skin temperature in ^{0}F

TABLE 73 . DUNCAN'S MULTIPLE RANGE TEST FOR DIFFERENCE IN PRE- AND POST-WEIGHT OF TOP GARMENT

Fabric	C	P	P/SP	C/SP
Mean	12.260	11.614	8.250	7.675
	————	————		
		————	————	
			————	————

*All fabrics had the same n = 24
**Fabrics connected by a line were not significantly different
***p < .05, DF = 22, MSE = 34.295

TABLE 74 . DUNCAN'S MULTIPLE RANGE TEST FOR DIFFERENCE IN PRE- AND POST-WEIGHT OF BOTTOM GARMENT

Fabric	C	P	C/SP	P/SP
Mean	8.962	7.448	4.964	4.886
	———	———		
		———	———	———

*All fabrics had the same n = 24
**Fabrics connected by a line were not significantly different
***$p < .05$, DF = 22, MSE = 26.443

APPENDIX L

POST HOC STATISTICAL TABLES

(TIME)

TABLE 75. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--BREATHABLE

Time	35	30	40	25	20	10	15	5
Mean	2.010	2.010	1.917	1.802	1.802	1.740	1.729	1.594

*All times had the same n = 96
*Times connected by a line were not significantly different
***$p < .05$, DF = 92, MSE = 0.947

TABLE 76. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--CLAMMY

Time	25	30	20	35	40	15	10	5
Mean	1.896	1.677	1.656	1.521	1.292	1.094	0.688	0.417

*All times had the same n = 96
*Times connected by a line were not significantly different
***$p < .05$, DF = 92, MSE = 0.730

TABLE 77. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--CLINGY

Time	25	30	20	35	40	15	10	5
Mean	2.083	1.885	1.823	1.604	1.521	1.323	1.031	0.969

*All times had the same n = 96
*Times connected by a line were not significantly different
***p < .05, DF = 92, MSE = 0.705

TABLE 78. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--ITCHY

Time	25	20	15	40	30	35	10	5
Mean	0.958	0.875	0.854	0.823	0.813	0.760	0.708	0.552

*All times had the same n = 96
*Times connected by a line were not significantly different
***p < .05, DF = 92, MSE = 1.099

TABLE 79. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--ABSORBENT

Time	25	35	30	20	40	15	10	5
Mean	2.198	2.115	2.094	1.823	1.823	1.333	0.813	0.552

*All times had the same n = 96
*Times connected by a line were not significantly different
***p < .05, DF = 92, MSE = 0.730

TABLE 80. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--ROUGH

Time	25	30	15	30	35	40	10	5
Mean	0.844	0.833	0.823	0.792	0.771	0.750	0.719	1.583

*All times had the same n = 96
*Times connected by a line were not significantly different
***p < .05, DF = 92, MSE = 0.971

TABLE 81. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--SCRATCHY

Time	30	25	20	40	35	15	10	5
Mean	0.896	0.885	0.865	0.833	0.813	0.802	0.760	0.583

*All times had the same n = 96

*Times connected by a line were not significantly different

***p < .05, DF = 92, MSE = 1.149

TABLE 82. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--SMOOTH

Time	15	5	25	35	10	20	30	40
Mean	2.458	2.438	2.417	2.406	2.396	2.354	2.354	2.323

*All times had the same n = 96
*Times connected by a line were not significantly different
***p < .05, DF = 92, MSE = 2.094

TABLE 83. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--SOFT

Time	5	10	15	25	20	30	35	40
Mean	2.469	2.406	2.375	2.333	2.281	2.271	2.260	2.250

*All times had the same n = 96
*Times connected by a line were not significantly different
***p < .05, DF = 92, MSE = 2.218

TABLE 84. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--STICKY

Time	25	30	20	35	40	15	10	5
Mean	1.698	1.521	1.396	1.364	1.302	1.052	0.656	0.458

*All times had the same n = 96
*Times connected by a line were not significantly different
***p < .05, DF = 92, MSE = 0.640

TABLE 85. DUNCAN'S MULTIPLE RANGE TEST FOR TACTILE SENSATION--STIFF

Time	25	20	30	15	35	40	5	10
Mean	0.854	0.792	0.781	0.740	0.740	0.719	0.708	0.656

*All times had the same n = 96
*Times connected by a line were not significantly different
***$p < .05$, DF = 92, MSE = 0.765

TABLE 86. DUNCAN'S MULTIPLE RANGE TEST FOR WETNESS SENSATION

Time	25	30	20	35	40	15	10	5
Mean	3.500	3.063	2.865	2.563	2.385	1.802	1.281	1.115

*All times had the same n = 96

**Times connected by a line were not significantly different

***p < .05, DF = 92, MSE = 0.655

TABLE 87. DUNCAN'S MULTIPLE RANGE TEST FOR THERMAL COMFORT SENSATION

Time	25	20	15	30	10	35	5	40
Mean	6.292	6.188	5.865	5.406	5.344	5.115	5.094	5.021

*All times had the same n = 96
*Times connected by a line were not significantly different
***p < .05, DF = 92, MSE = 0.721

TABLE 88. DUNCAN'S MULTIPLE RANGE TEST FOR OVERALL CLOTHING COMFORT SENSATION

Time	25	20	30	35	15	40	10	5
Mean	2.240	2.167	2.073	1.990	1.979	1.958	1.896	1.854

*All times had the same n = 96

*Times connected by a line were not significantly different

***p < .05, DF = 92, MSE = 1.181

TABLE 89. DUNCAN'S MULTIPLE RANGE TEST FOR SKIN TEMPERATURE SITE T2 (UPPER CHEST)

Time	15	10	20	5	25	30	40	35
Mean	94.393	94.371	93.871	93.781	93.358	92.382	91.907	91.787

*All times except t-40 had the same n = 96, t-40 n = 95
*Times connected by a line were not significantly different
***$p < .05$, DF = 647, MSE = 2.027
****Skin temperature in ^{0}F

TABLE 90. DUNCAN'S MULTIPLE RANGE TEST FOR SKIN TEMPERATURE SITE T3 (STOMACH)

Time	10	15	5	20	40	25	30	35
Mean	93.291	92.838	92.635	92.030	91.019	90.992	90.859	90.699

*All times except t-15 had the same n = 96, t-15 n = 95
*Times connected by a line were not significantly different
***$p < .05$, DF = 647, MSE = 3.267
****Skin temperature in ^{0}F

TABLE 91. DUNCAN'S MULTIPLE RANGE TEST FOR SKIN TEMPERATURE SITE T4 (GROIN)

Time	10	15	5	20	40	35	25	30
Mean	93.500	93.156	92.881	92.376	91.744	91.421	91.361	91.118

*Times 10, 15, 5, and 20 had n = 96, t-40, 35, 25, 30 had n = 95
*Times connected by a line were not significantly different
***$p < .05$, DF = 644, MSE = 1.944
****Skin temperature °F

TABLE 92. DUNCAN'S MULTIPLE RANGE TEST FOR SKIN TEMPERATURE SITE T5 (THIGH)

Time	10	40	15	35	20	30	25	5
Mean	91.889	91.645	91.200	91.141	91.056	90.893	90.654	90.615
	—	—						
			—	—	—	—		
					—	—	—	—

*All times had the same n = 96
*Times connected by a line were not significantly different
***p < .05, DF = 92, MSE = 2.336
****Skin temperature in °F

TABLE 93. DUNCAN'S MULTIPLE RANGE TEST FOR SKIN TEMPERATURE SITE T6 (UPPER BACK)

Time	15	10	20	5	25	30	35	40
Mean	94.156	93.820	93.758	93.417	93.291	91.369	90.497	90.178

*All times had n = 96, except t-30, 35 had n = 93 and t-40 had n = 95
**Times connected by a line were not significantly different
***$p < .05$, DF = 641, MSE = 2.486
****Skin temperature in ^{0}F

TABLE 94. DUNCAN'S MULTIPLE RANGE TEST FOR SKIN TEMPERATURE SITE T7 (LOWER BACK)

Time	15	20	10	25	5	30	40	35
Mean	92.459	92.290	92.228	91.771	91.653	90.340	89.650	89.568

*All times had the same n = 96

*Times connected by a line were not significantly different

***$p < .05$, DF = 92, MSE = 1.679

****Skin temperature in ^{0}F

APPENDIX M

GRAPHS OF SKIN TEMPERATURE AND WETNESS SENSATION BY ENVIRONMENT OVER TIME

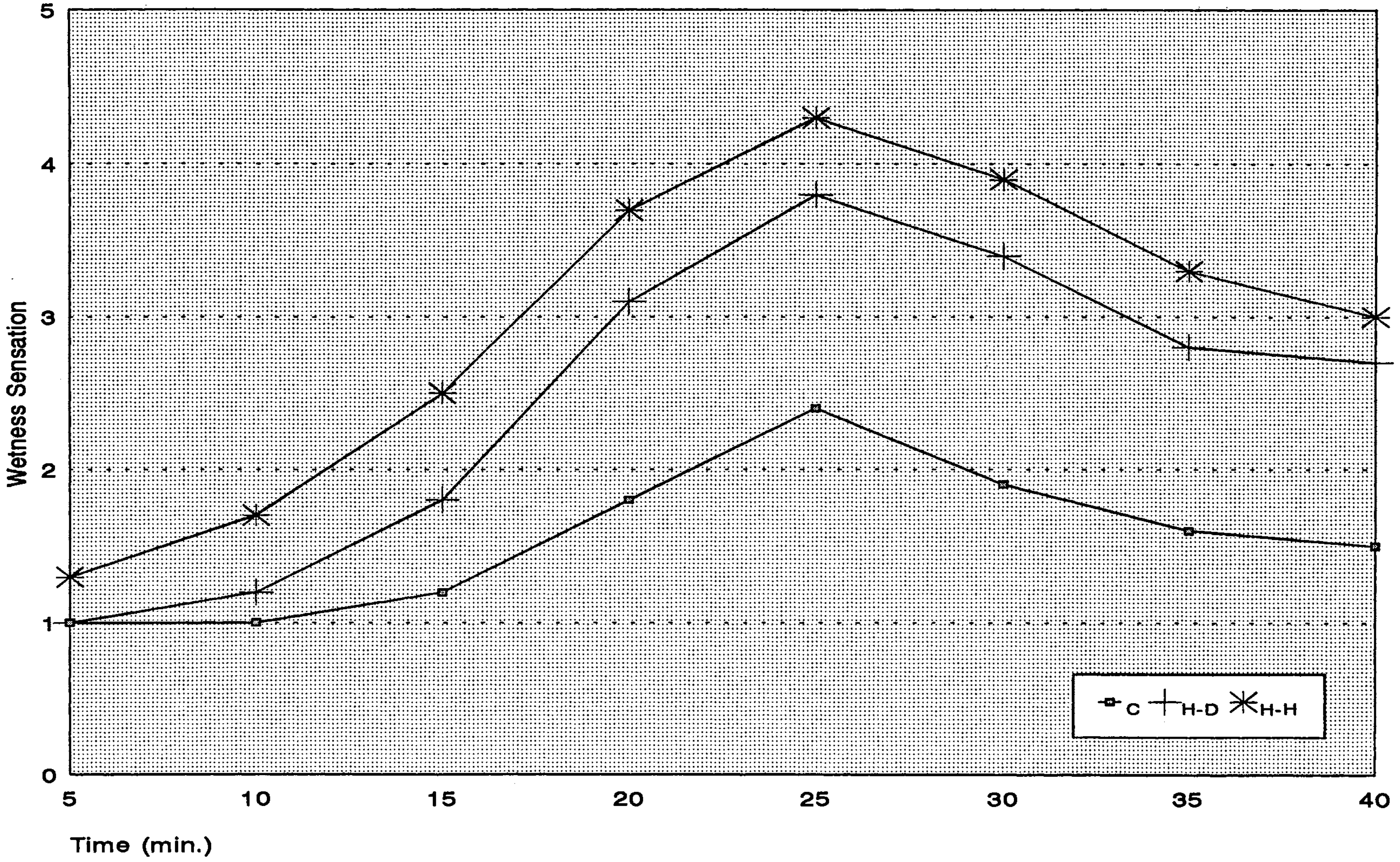


Figure 16. Wetness Sensation by Environment Over Time

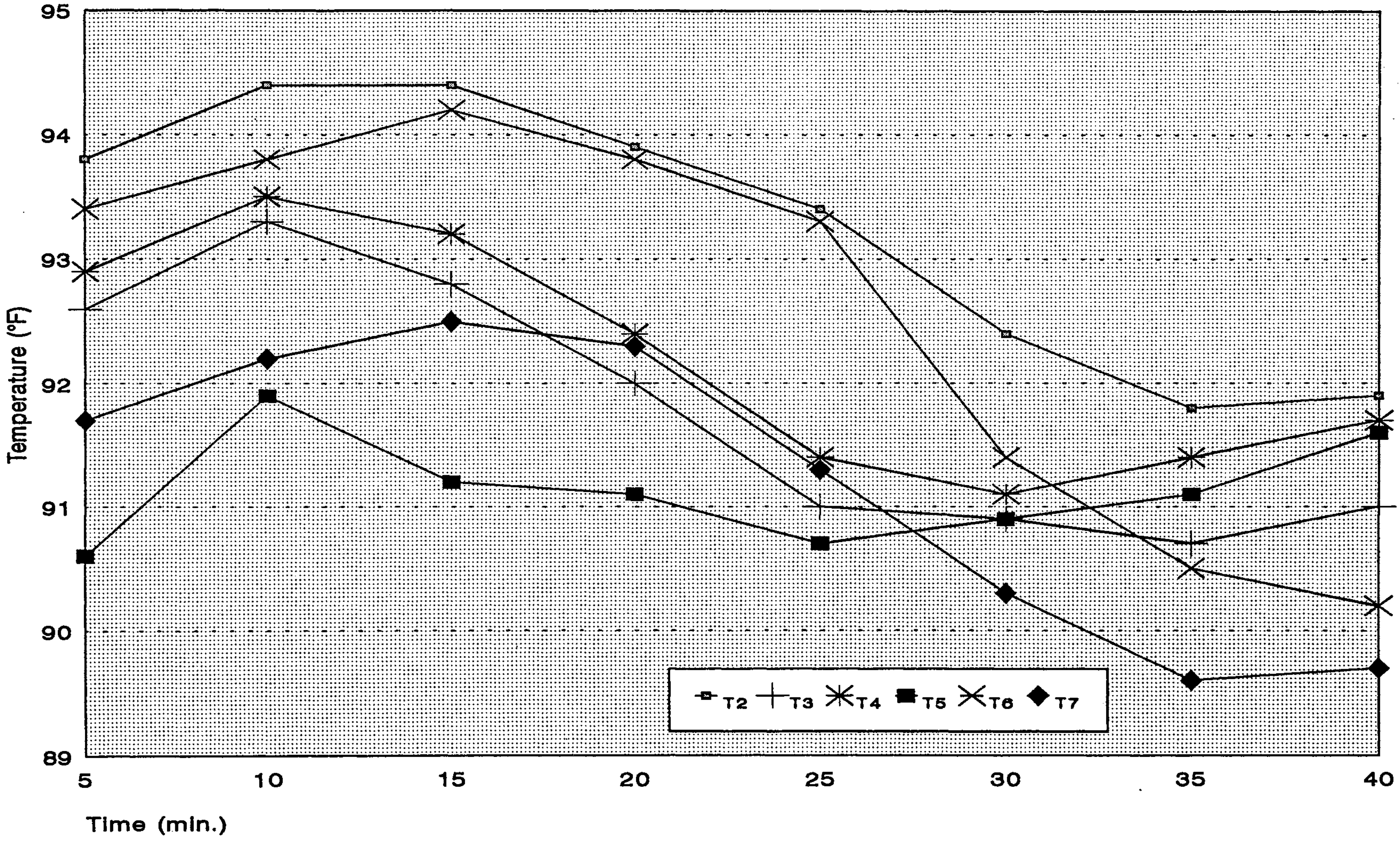


Figure 17. Skin Temperature (in °F) Averaged over Environment by Time

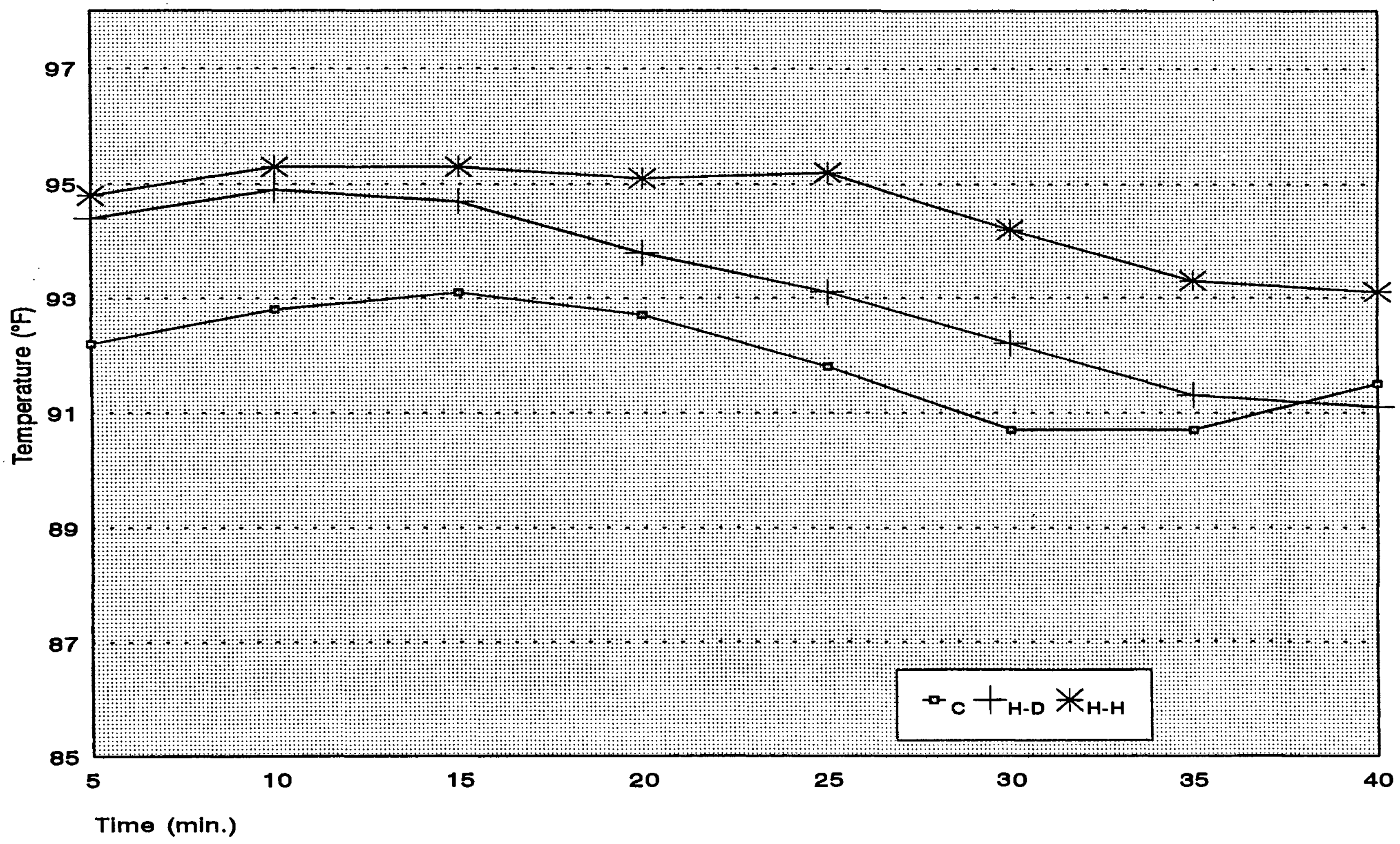


Figure 18. Skin Temperature (in °F) at Site T2 by Environment over Time

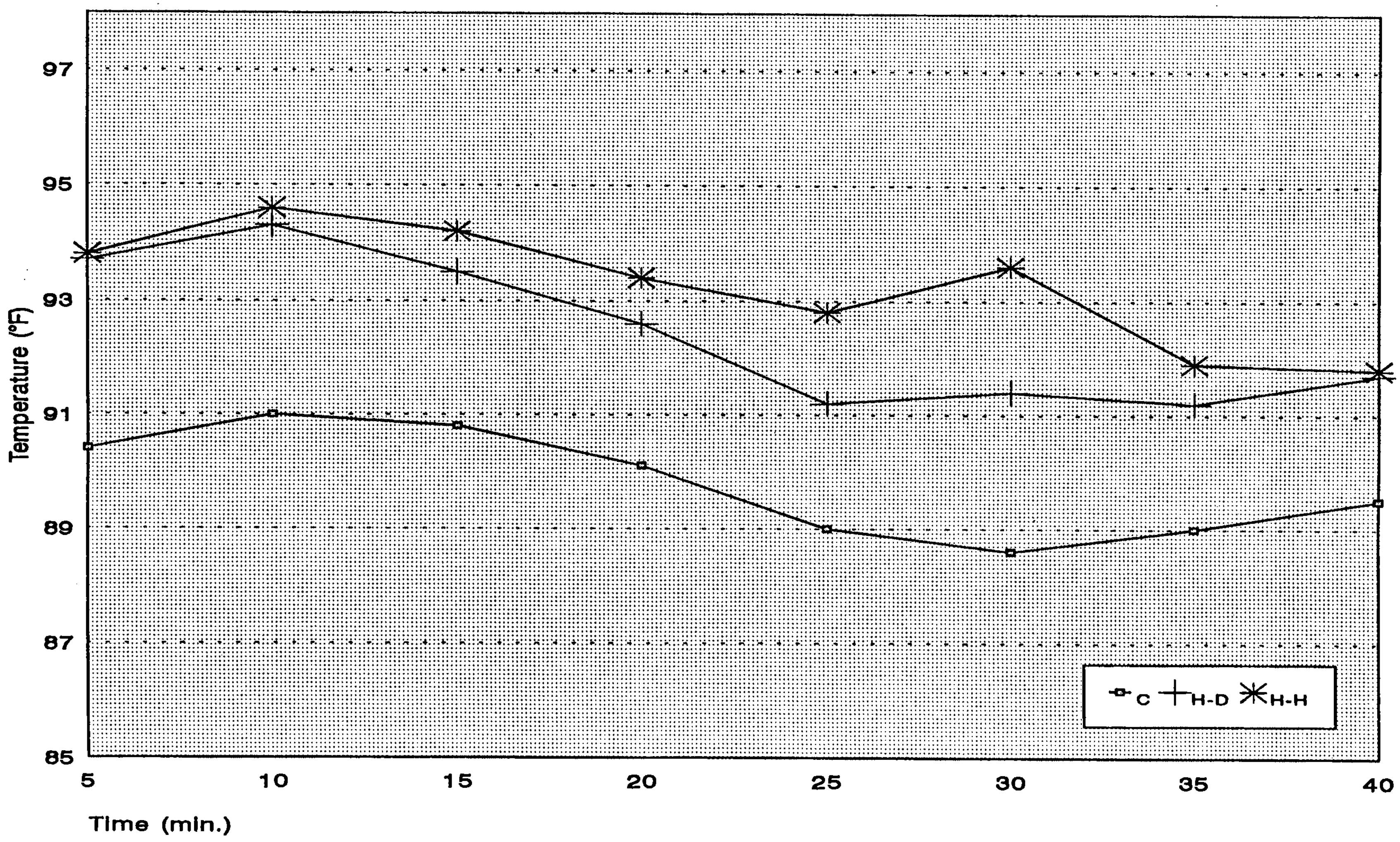


Figure 19. Skin Temperature (in ^{0}F) at Site T3 by Environment over Time

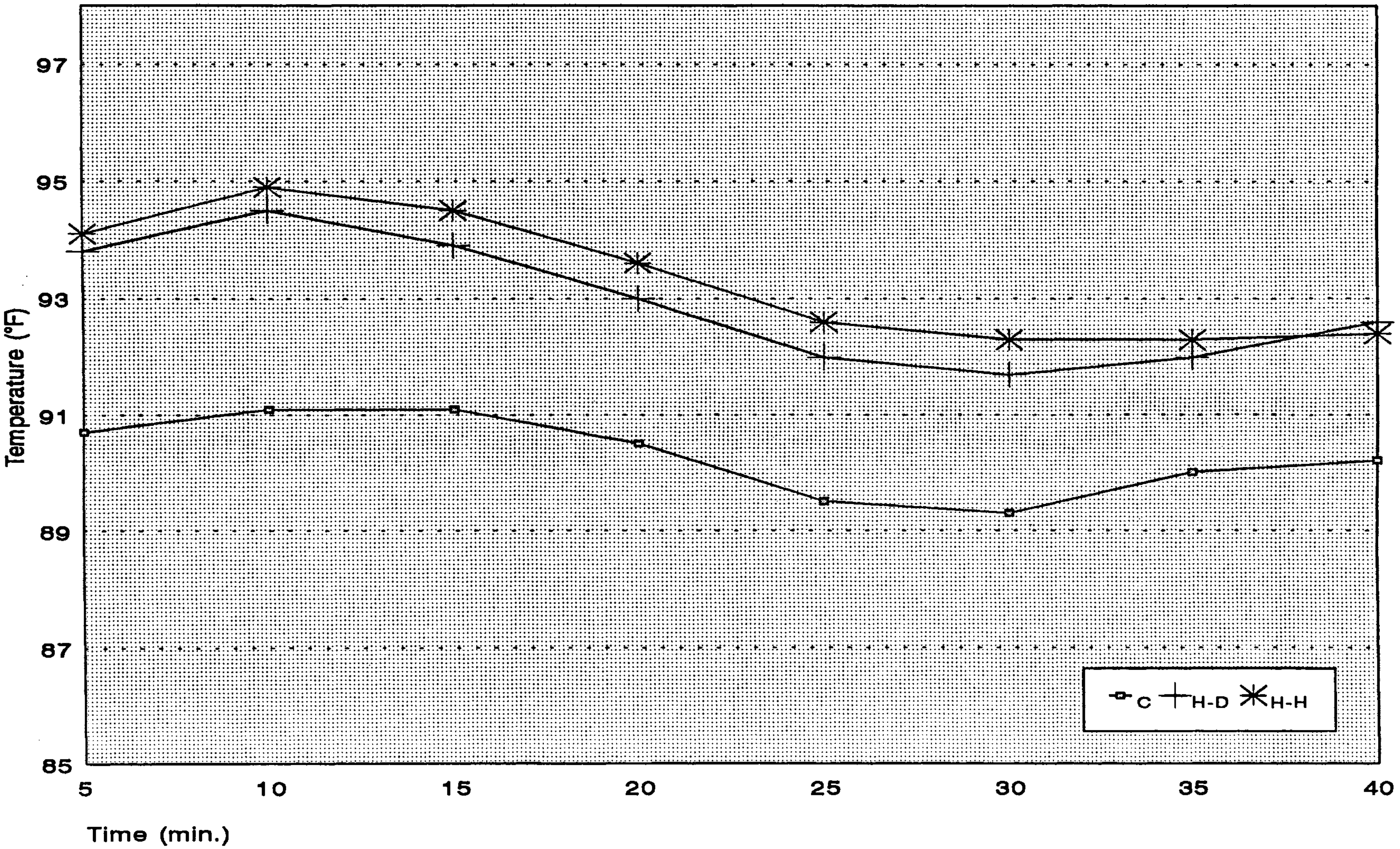


Figure 20. Skin Temperature (in °F) at Site T4 by Environment over Time

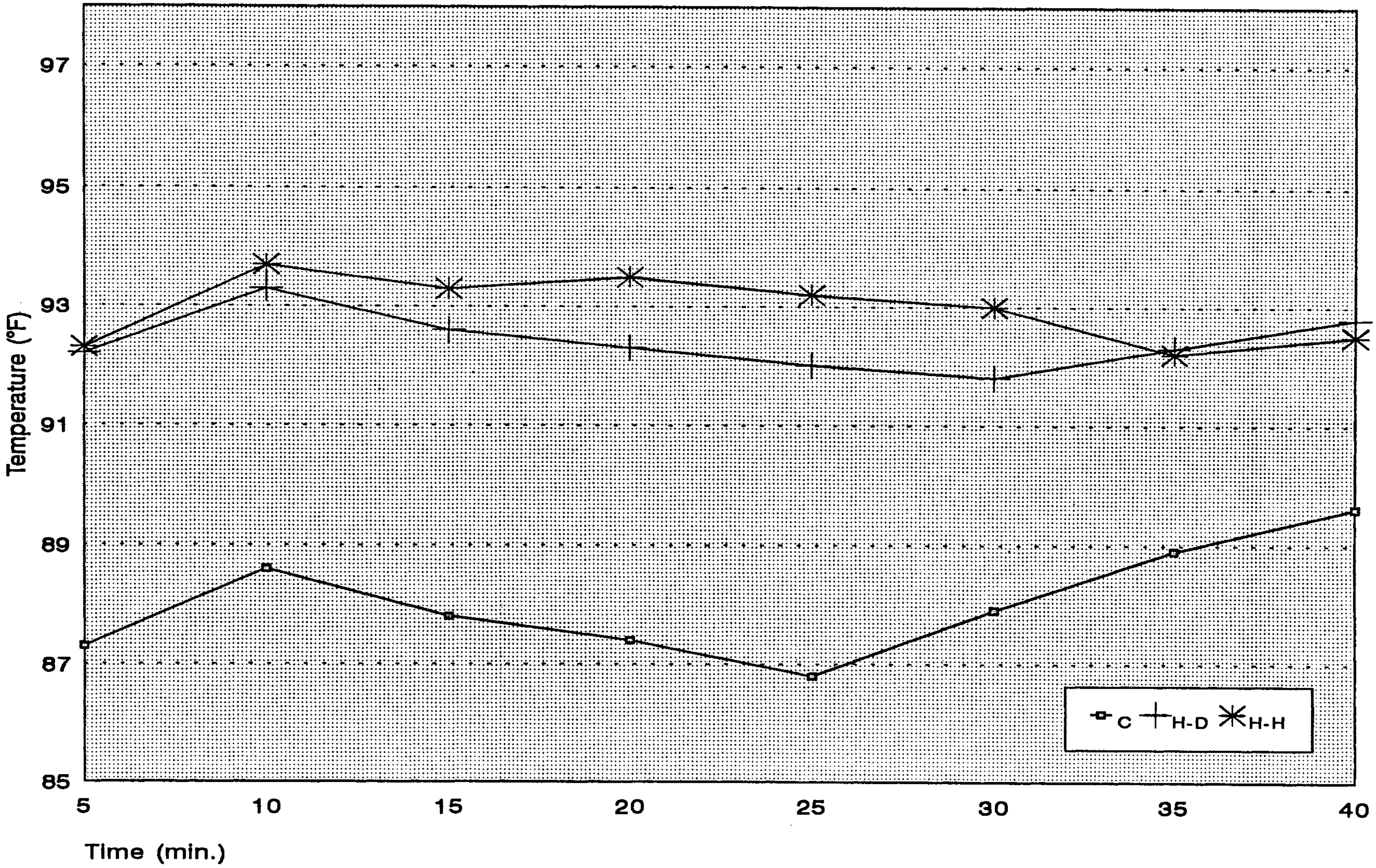


Figure 21. Skin Temperature (in °F) at Site T5 by Environment over Time

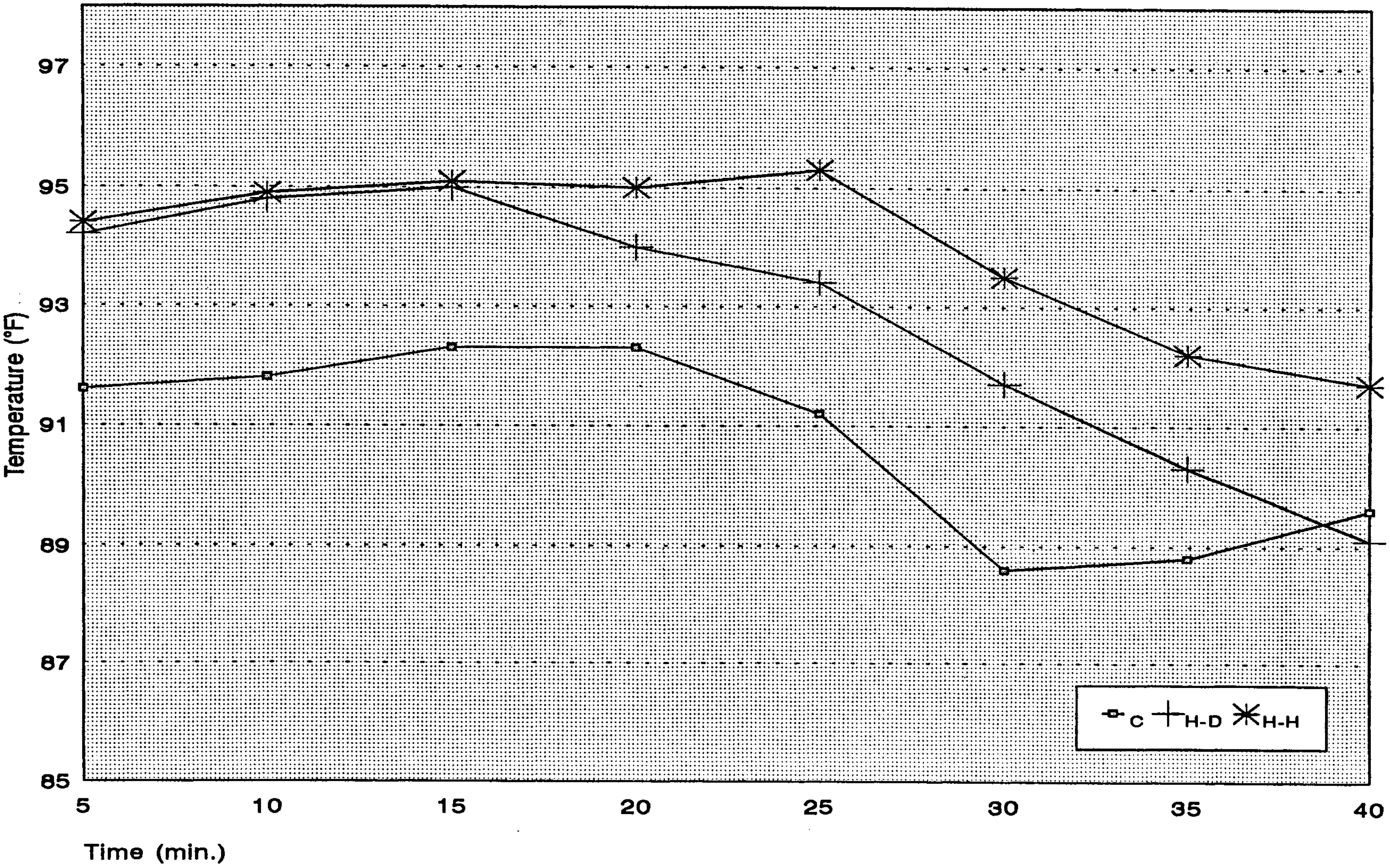


Figure 22. Skin Temperature (in °F) at Site T6 by Environment over Time

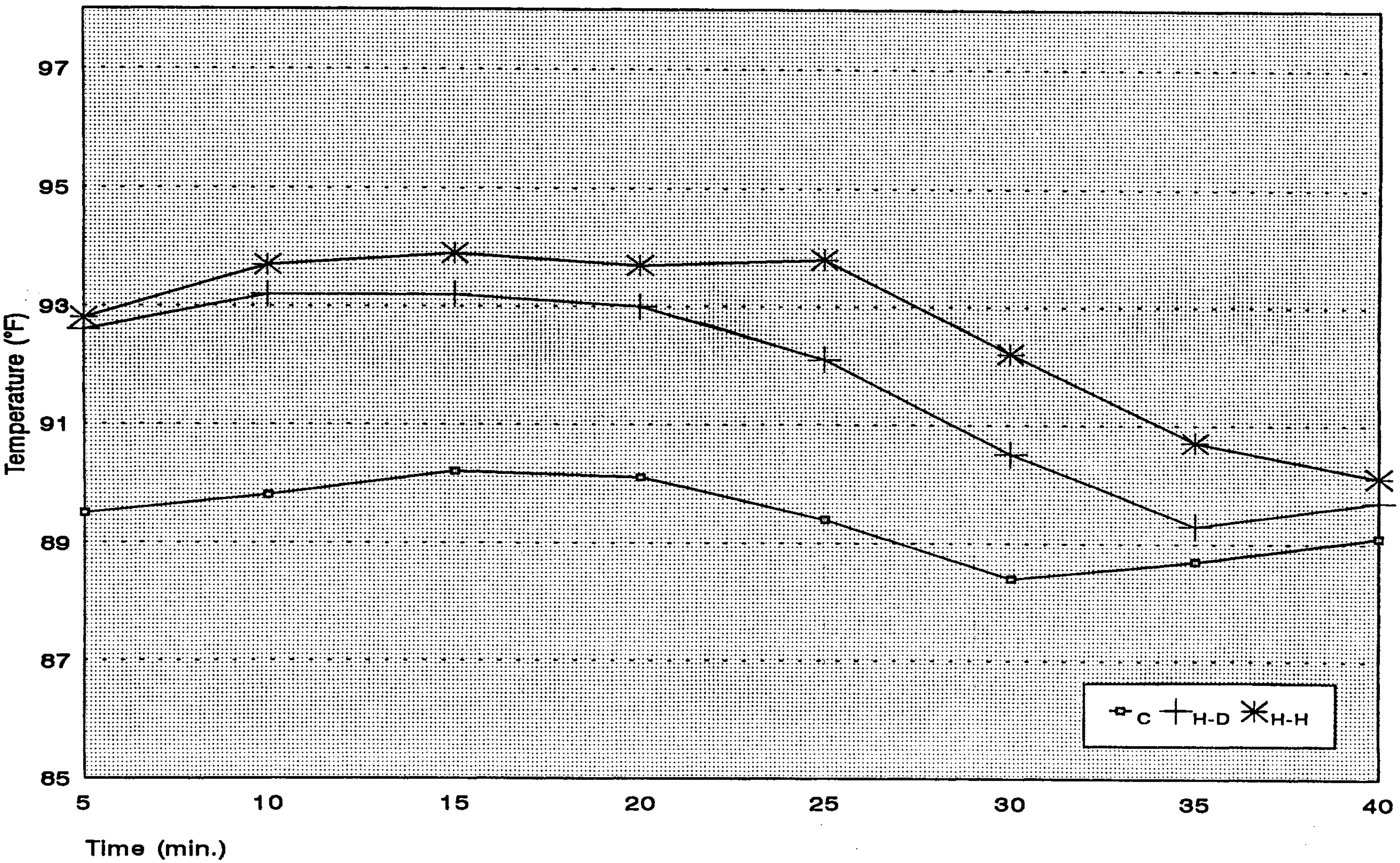


Figure 23. Skin Temperature (in ^{0}F) at Site T7 by Environment over Time

APPENDIX N

TABLES OF SKIN TEMPERATURE AND WETNESS SENSATION BY ENVIRONMENT OVER TIME

TABLE 95

SKIN TEMPERATURE (^{0}F) BY BODY SITE AVERAGED OVER ENVIRONMENT

	ACCLIMATION		**EXERCISE**			**RECOVERY/REST**		
TIME (MIN.)/ BODY SITE	**05**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
T2 (chest)	93.8	94.4	94.4	93.9	93.4	92.4	91.8	91.9
T3 (stomach)	92.6	93.3	92.8	92.0	91.0	90.9	90.7	91.0
T4 (groin)	92.9	93.5	93.2	92.4	91.4	91.1	91.4	91.7
T5 (thigh)	90.6	91.9	91.2	91.1	90.7	90.9	91.1	91.6
T6 (upper back)	93.4	93.8	94.2	93.8	93.3	91.4	90.5	90.2
T7 (lower back)	91.7	92.2	92.5	92.3	91.8	90.3	89.6	89.7

TABLE 96

SKIN TEMPERATURE (°F) BY BODY SITE FOR ENVIRONMENT -- COMFORTABLE

	ACCLIMATION		**EXERCISE**			**RECOVERY/REST**		
TIME (MIN.)/ BODY SITE	**05**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
T2 (chest)	92.2	92.8	93.1	92.7	91.8	90.7	90.7	91.5
T3 (stomach)	90.4	91.0	90.8	90.1	89.0	88.6	89.0	89.5
T4 (groin)	90.7	91.1	91.1	90.5	89.5	89.3	90.0	90.2
T5 (thigh)	87.3	88.6	87.8	87.4	86.8	87.9	88.9	89.6
T6 (upper back)	91.6	91.8	92.3	92.3	91.2	88.6	88.8	89.6
T7 (lower back)	89.5	89.8	90.2	90.1	89.4	88.4	88.7	89.1

TABLE 97

SKIN TEMPERATURE (°F) BY BODY SITE FOR ENVIRONMENT -- HOT-DRY

	ACCLIMATION		**EXERCISE**			**RECOVERY/REST**		
TIME (MIN.)/ BODY SITE	**05**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
T2 (chest)	94.4	94.9	94.7	93.8	93.1	92.2	91.3	91.1
T3 (stomach)	93.7	94.3	93.5	92.6	91.2	91.4	91.2	91.7
T4 (groin)	93.8	94.5	93.9	93.0	92.0	91.7	92.0	92.6
T5 (thigh)	92.2	93.3	92.6	92.3	92.0	91.8	92.3	92.8
T6 (upper back)	94.2	94.8	95.0	94.0	93.4	91.7	90.3	89.1
T7 (lower back)	92.6	93.2	93.2	93.0	92.1	90.5	89.3	89.7

TABLE 98

SKIN TEMPERATURE (°F) BY BODY SITE FOR ENVIRONMENT -- HOT-HUMID

	ACCLIMATION		**EXERCISE**			**RECOVERY/REST**		
TIME (MIN.)/ BODY SITE	**05**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
T2 (chest)	94.8	95.3	95.3	95.1	95.2	94.2	93.3	93.1
T3 (stomach)	93.8	94.6	94.2	93.4	92.8	92.6	91.9	91.8
T4 (groin)	94.1	94.9	94.5	93.6	92.6	92.3	92.3	92.4
T5 (thigh)	92.3	93.7	93.3	93.5	93.2	93.0	92.2	92.5
T6 (upper back)	94.4	94.9	95.1	95.0	95.3	93.5	92.2	91.7
T7 (lower back)	92.8	93.7	93.9	93.7	93.8	92.2	90.7	90.1

TABLE 99

WETNESS SENSATION FOR ENVIRONMENTS -- COMFORTABLE, HOT-DRY, HOT-HUMID, AND AVERAGED OVER ENVIRONMENT

	ACCLIMATION		**EXERCISE**			**RECOVERY/REST**		
TIME (MIN.)/ ENVIRONMENT	**05**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
COMFORTABLE	1.0	1.0	1.2	1.8	2.4	1.9	1.6	1.5
HOT-DRY	1.0	1.2	1.8	3.1	3.8	3.4	2.8	2.7
HOT-HUMID	1.3	1.7	2.5	3.7	4.3	3.9	3.3	3.0
ENV. AVERAGE	1.1	1.3	1.8	2.9	3.5	3.1	2.6	2.4

VITA

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