EVALUATION OF AN ARTIFICIALLY COOLED CHEMICAL PROTECTIVE GLOVE SYSTEM

By

LADAWN STILES SIMPSON

Bachelor of Science

Oklahoma State University

Stillwater, OK

1992

Submitted to the Faculty of the
Graduate College of
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 1994

OKLAHOMA STATE UNIVERSITY

EVALUATION OF AN ARTIFICIALLY COOLED CHEMICAL PROTECTIVE GLOVE SYSTEM

Thesis Approved:

Donna H. Branson
Thesis Adviser

Liza Ibrahim

Cheryl A. Farr

Gerald H. Brusewitz

Jana Stufflebean

Thomas C. Collins
Dean of the Graduate College

ACKNOWLEDGMENTS

First, I would like to express my sincere appreciation to Dr. Donna Branson. Her guidance and encouragement throughout my graduate program have far exceeded my expectations. Also, I wish to thank my graduate committee, Dr. Tana Stufflebean, Dr. Cheryl Farr, Dr. Gerald Brusiwitz and Dr. Liza Abrahams Murili. They have all been very supportive throughout my study.

Next, I want to thank my family. Each has been wonderful in their acceptance of me as a part-time wife, mother, daughter, granddaughter and grandmother. My husband, Thomas, has stood beside me through all of my times of exultation and frustration. Words can never express how important his love and support are to me. My children, Shannon, Michael, KaTina and LeeAnn have willingly accepted my absence as I poured myself into my studies. My parents, Alfred and Pat Stiles, have always been by my side providing their love. I thank my grandmother for all of her prayers, they have sustained me when I felt I could no longer go on. My thanks also go to Ninny, I know that she is looking down from heaven with pride in our accomplishments. BJ has provided me with a ray of sunshine and an opportunity to play when I would have been more inclined to work. Last, I want to thank God, his guidance has given me the strength to accomplish this portion of my dream. As each has shared in the work, they also share in the accomplishment.

TABLE OF CONTENTS

LIST OF TABLES

Table Page

CHAPTER I

INTRODUCTION

A growing emphasis to reduce worker dermal exposure to pesticides has developed over the past several years. An emphasis has been placed upon the use of personal protective equipment (PPE) in an effort to accomplish a reduction in exposure. Pesticides may enter the body via three routes: respiratory, oral, and dermal contact (Durham and Wolfe, 1962). Occupational skin diseases such as dermatitis can be caused by chemical exposure. Dermal exposure during mixing, loading, applying, and cleaning after application of pesticides is a serious concern (Wolfe, Armstrong and Durham, 1966). Of special concern are the hands of those working with pesticides. Studies have shown that between 20% and 97% of the dermal exposure to pesticides occurs on the hands (Bonsall, 1985; Grover, Cessna, Muir, Riedel and Franklin, 1988; Popendorf, 1988; Urbain, 1988; Leonas and Kun Yu, 1992). The amount of pesticide exposure to various regions of the body is dependent upon the work activity, equipment used, and the method for determining deposition patterns and exposure. The wide range of reported differences in deposition patterns may be partially accounted for by the varying methods of measurement.

Adverse Health Effects

Adverse health effects due to exposure to pesticides are becoming universally recognized. Many pesticides are found to be teratogenic, mutagenic, and carcinogenic. A study examining the frequency of spontaneous abortions, live births, still births, neonatal deaths, and congenital defects in the wives of 1016 males exposed to pesticides in cotton fields compared to a control group of 1020 males that were not regularly exposed to pesticides was conducted in 1990 (Rupa, Reddy and Reddi, 1991). The researchers found a significant decrease in the number of fertile males and live births in the exposed group. A significant increase in neonatal deaths, still births, and congenital defects also occurred in the exposed group.

Fenske (1988) implemented a visual and quantitative approach in evaluating the effectiveness of protective clothing. A florescent agent that binds to the skin was added to the pesticides used for application. A computer based imaging system interfaced with a television camera was employed to quantify dermal fluorescence on subjects after pesticide application. Although neoprene gloves were worn, measurable hand exposure was visible on workers. In cooperation with Fenske, Successful Farmer used this method of identifying pesticide deposits on the skin to alert the American farmer of the need to wear protective clothing while working with pesticides (Allen, Sommers and Tevis, 1986).

A 1984 survey of Iowa pesticide applicators found that 59% of the respondents wore protective clothing as defined by the Federal Register in 1974. This clothing system consists of a long-sleeved shirt, long legged trousers or coveralls, a hat or suitable head covering, shoes, and socks. Thirty percent of the respondents reported wearing waterproof gloves. Of the 728 useable questionnaires, 43% reported experiencing one to four of the listed pesticide poisoning symptoms, and 30% reported experiencing five to 18 symptoms. Symptoms most commonly reported as experienced include skin and eye irritation, dizziness and tiredness, and headaches (Stone, Eichner, Kim and Koehler, 1988).

Glove Practices

Various studies have examined the clothing practices of persons using pesticides on a regular basis (Durham et al., 1962; DeJonge, Vredevoogd and Sweeney-Henry, 1983-84; Keeble, Norton and Drake, 1987; Branson, Slocum and Stone, 1988; Nelson, Rucker, Olson, Rucker, Branson, Nelson, Olson, Slocum and Stone, 1988; Stone, Branson, Nelson, Olsen, Rucker and Slocum, 1989; Ramaswamy and Boyd, 1992). Keeble et al. (1987) found that 36% of the fruit growers and workers surveyed wore waterproof gloves when working in insecticide-treated fields. Rucker et al. (1988) found 37% of the farm families surveyed wore vinyl or rubber gloves. Farr-Popelka and Branson (1991) found 60% of the pest control operators responding to a survey reported wearing protective gloves.

The type of chemical that will be used must be taken into account when selecting a chemical protective glove. In general, the most effective gloves in providing chemical protection to a variety of chemicals are made of Viton®, nitrile, and butyl elastomers. Glove manufacturers claim laminated gloves such as the 4-H® and the Silver Shield® gloves provide more protection than other gloves. Permeation and/or penetration of chemicals may occur when wearing gloves of various materials.

Contamination may occur during subsequent wearing of gloves. The ASTM Committee F-23 has developed standardized test methods to determine both penetration and permeation of chemical potential protective materials.

It is hypothesized that gloves are not worn because of discomfort from heat, moisture retention, and decreased manual dexterity. The U.S. military routinely uses glove liners to alleviate the problem of hand sweating while wearing chemical protective gloves. Research was conducted to evaluate the liners presently in use by the U.S. Army. Sweat rate, comfort, and psychomotor task performance were studied using the existing Army and Air Force liners plus two additional candidate liners. The research team found that regardless of liner fabric, perceived temperature, actual skin temperature, and perceived thermal discomfort increased over the two-hour test protocol (Branson, Abusamra, Hoener and Rice, 1988).

Ve'lez-Torres (1993) developed and tested glove liner prototypes with proprietary cooling gel devices inserted into pockets on each liner. The glove liner was worn as the interior component of a three part glove system. The 4-H® chemical protective glove was the second component, and a nitrile glove with good abrasion and puncture resistance was the outer layer. In general, the study demonstrated the potentially beneficial effect of the concept of artificial cooling for the hand.

Standards for assessing and keeping within safe limits in respect to thermal load of workers in moderate and hot thermal environments has been investigated (Olesen and Dukes-Dobos, 1988). A series of international standards have been developed, but when working outside in high temperatures and high relative humidities the conditions of the work space may not be controlled. Workers in cold environments may control their comfort by donning multiple layers of clothing. Pesticide applicators working in high temperatures and high relative humidity conditions do not have the luxury of removing clothing without risking the effects of chemical exposure.

Conceptual Framework

This study of thermal comfort as influenced by fabric and design of protective handwear used the theoretical framework proposed by Branson and Sweeney (1987). After an extensive review of clothing comfort models, the researchers proposed a clothing comfort model that views clothing from a larger perspective than previously viewed. The researchers incorporated the frequently used concept of the triad consisting of a person, his/her clothing, and his/her environment. Branson and Sweeney (1987) however, noted that each element of the triad had physical and non-physical dimensions which may influence an individual's resulting response and comfort judgment to stimuli. The researchers viewed clothing comfort as a true Gestalt, and used the concept of a filter as an influence on clothing judgment as shown in figure 1.

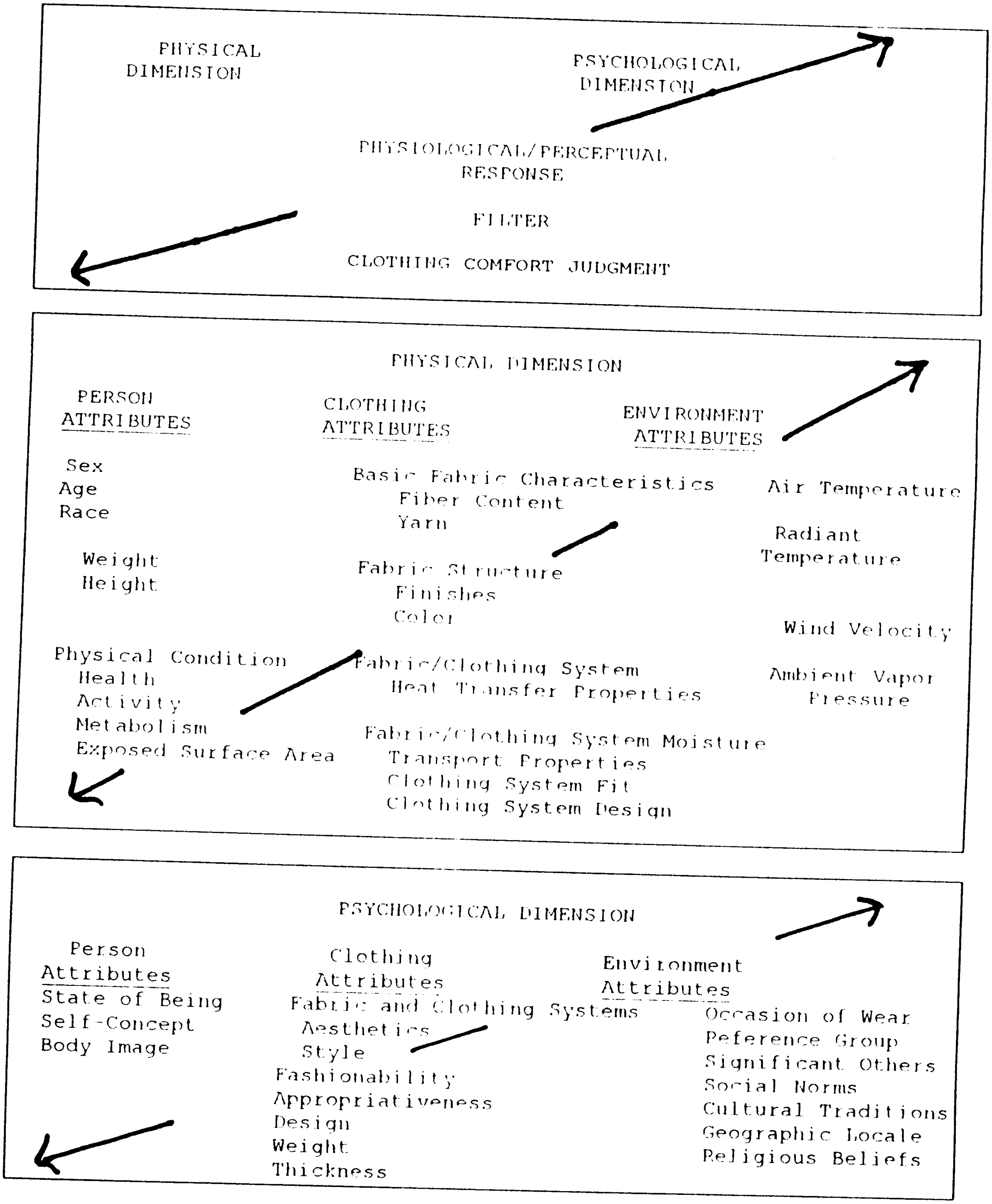


Figure 1. Branson and Sweeney Comfort Model
Reprinted with permission of the authors

Statement of the Problem

The purpose of this investigation is to evaluate an artificially-cooled prototype glove with and without a glove liner that will improve thermal comfort without inhibiting dexterity. This glove shall be worn while working in environments with high temperatures and high relative humidities.

Justification

The prevention of pesticide contact with the skin is of vital importance in protecting the health of persons working with pesticides. It is generally thought that protective handwear is not readily worn due to thermal discomfort problems. The use of protective handwear will minimize dermicidal contact, lowering the risk of exposure to pesticide related illness.

Objectives

The following objectives were established:

1. To determine the effect of wearing an artificially-cooled glove on subjects' perceived comfort (thermal and sensorial), skin temperature, sweat rate, and manual dexterity performance.
2. To determine the effect of the presence of a glove liner worn under the artificially-cooled glove on subjects' perceived comfort (thermal and sensorial), skin temperature, sweat rate, and manual dexterity performance.
3. To study the interactive effects between the artificially-cooled glove and the glove liner.

Hypotheses

The following null hypotheses were stated for objectives one through three.

1. There are no significant differences in perceived thermal comfort, sensorial comfort, skin temperature, sweat rate, and manual dexterity performance between subjects wearing chemical protective gloves with and without artificial cooling.
2. There are no significant differences in perceived thermal comfort, sensorial comfort, skin temperature, sweat rate, and manual dexterity performance between subjects wearing a glove liner and those not wearing a glove liner.
3. There is no significant interaction effect between gloves with and without artificial cooling worn with and without a glove liner.

Definition of Terms

The definitions of terms used in the study are listed as follows:

"<u>Clothing comfort</u>: A state of satisfaction indicating physiological, psychological and physical balance among the person, his/her clothing and his/her environment" (Branson and Sweeney, 1991, p.102).

" <u>Thermal Comfort</u>: The condition of mind which expresses satisfaction with the thermal environment" (American Society of Heating, Refrigeration and Engineering, 1981).

<u>"Sensorial Comfort</u>: A state of satisfaction with how a fabric or garment is perceived by a wearer's sensations, i.e. how it feels against the skin, as well as the sight, the smell, the sound, and even the taste of it" (Branson and Sweeney, 1991, p. 102).

Limitations

The author limited the study to the following:

1. Eight male volunteers between the ages 18 and 30 (mean 19 years) who fit size 9 of the selected chemical protective glove.
2. Environmental temperatures of 31° ± .5°C and relative humidity of 78% ± 2% to simulate a typical Oklahoma summer day.

Assumptions

The following assumptions were identified:

1. The subjects performed manual dexterity tasks to the best of their ability.
2. A dew-point hygrometer system measured sweat rate per manufacturer specification.
3. Surface thermocouples measured temperature within a range of ± 1°C as per manufacturer specifications.

CHAPTER II

LITERATURE REVIEW

This chapter is organized into the following major subdivisions: Clothing Comfort Model, Hand and Thermoregulation, Measurement of Pertinent Variables, and Clothing Studies.

Comfort Model

Thermal comfort has been examined by many researchers, and each has attempted to develop a definition. Some have examined the broader concept of clothing comfort. Most have conceptualized comfort as the interaction of a person with his/her clothing in an environment thus, forming a triad (Fourt and Hollies, 1970). Goldman (1977) identified four environmental factors to consider in the simplest thermal environment analysis. They include air temperature (ambient dry bulb temperature), ambient vapor pressure, wind velocity, and thermal radiation.

Tactile comfort, which is included in the broader concept of clothing comfort, is influenced by the mechanical and surface character of fabrics worn next to the skin. The feeling of thermal wetness and discomfort may occur during periods of inadequate movement of heat and moisture through a garment structure. Clothing may act as a barrier during the evaporation of moisture from the skin by prohibiting perspiration. It has been suggested that thickness and air permeability are important factors in the fluctuation of skin temperature (Woodcock, 1962; Laing and Ingham, 1983-1984). Irritating sensations such as roughness, scratchiness, and prickliness may be intensified during periods of humidness. Hollies, Custer, Morin and Howard (1979) found that perspiration aggravated the sensations of stiffness, stickiness, clamminess, dampness, roughness, and clinginess of prototype shirts.

Branson and Sweeney (1987) proposed the model shown in figure 1 as a conceptual framework to examine clothing comfort. In the model, each element of the triad has both physical and non-physical dimensions. Physical dimension attributes for the person include: sex, age, race, temperature, weight, height, physical condition, health, activity, metabolism, and exposed surface area. Clothing attributes include: basic fabric characteristics, fiber content, yarn, fabric structures, finishes, color, fabric/clothing system, heat transfer properties, fabric/clothing system moisture, transport properties, clothing system fit, and clothing system design. Environmental attributes include: air temperature, radiant temperature, wind velocity, and ambient vapor pressure. Physical attributes are more easily measured than non-physical attributes.

Non-physical attributes are referred to as the psychological dimension in the model. Person attributes in this dimension may include state of being, self-concept, and body image. Non-physical clothing attributes include: fabric and clothing systems, aesthetics, style, fashionability, appropriateness, design, weight, and thickness. Environmental attributes in this dimension are comprised of items such as occasion of wear, reference group, significant others, social norms, cultural traditions, geographic locale, and religious beliefs.

The diagonal arrows across the physical and psychological (non-physical) dimensions illustrate the interaction among attributes within each dimension and across dimensions. The interaction of the physical and/or non-physical dimensions combine to produce a physiological and/or perceptual response in the individual. Skin and core temperature, sweat rate, heart rate, and oxygen consumption are frequently measured physiological responses.

The next component of the model is that of a filtering system. The filter consists of past experiences, expectations, and remembrances which may consciously or unconsciously influence comfort judgment. The actual clothing comfort judgment makes up the final component of this model. This component consists of sensorial, thermal, and overall clothing comfort judgments. Each of these may differ from individual to individual and may be influenced by past knowledge or experiences.

Physical responses occur prior to the application of the filter. An example of a physical response was demonstrated by Sweeney and Branson (1990a). Subjects were required to make judgments of the presence or absence of moisture randomly placed on their backs. Since subjects were unable to see the stimulus, they were required to respond based totally upon their ability to feel moisture.

Perceptual responses to stimuli are distinguished through the last element of the model. Measured perceptual responses include moisture sensation, tactile sensation, and perceived temperature.

Hand and Thermoregulation

Hand Structure

The wrist and hand are constructed of numerous bones, joints, muscles, and skin (figure 2). The carpals are the bones of the wrist, metacarpals the bones of the palm, and the phalanges the bones of the fingers.

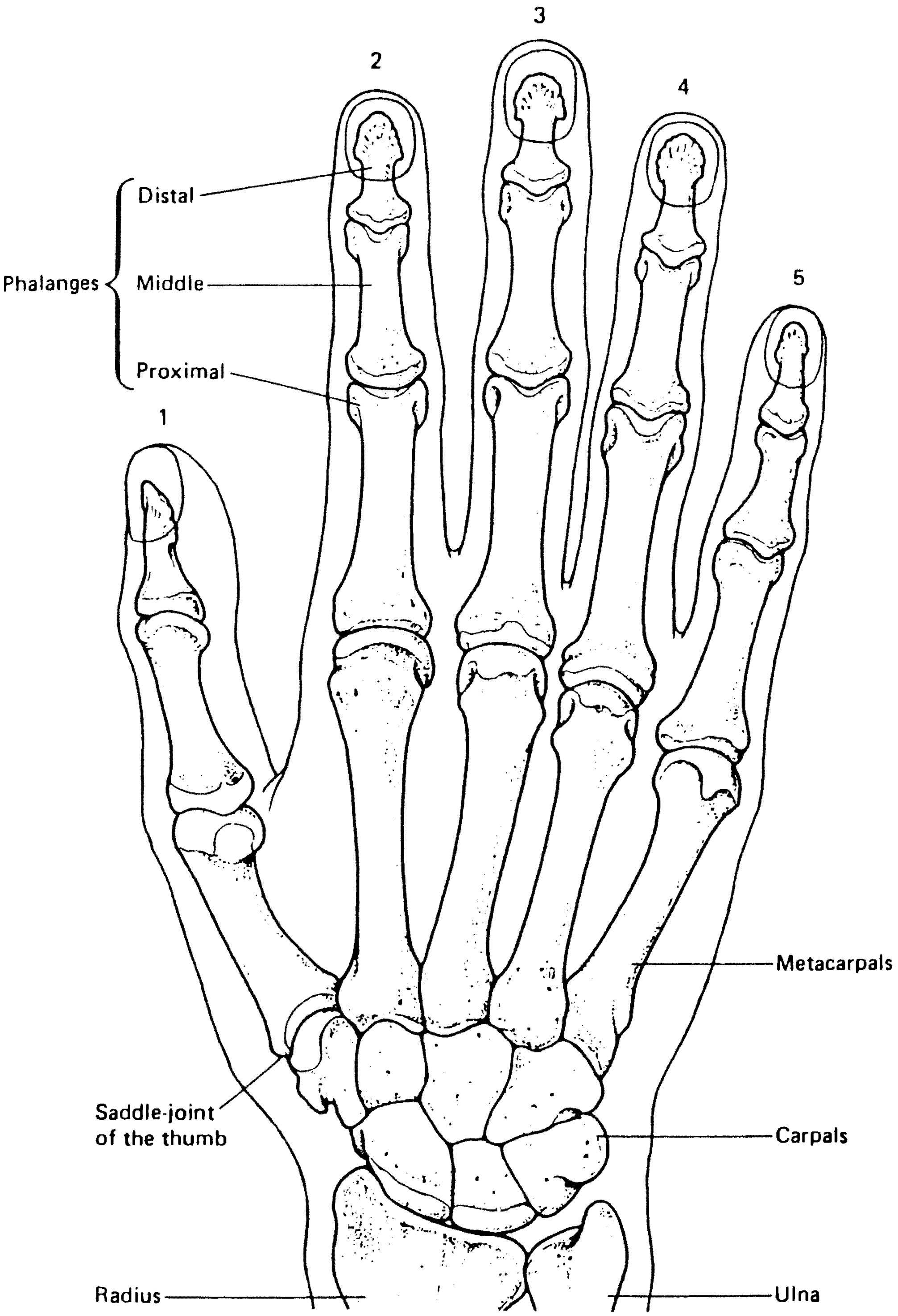


*Figure 2. Bones of the hand.

Hypothenar refers to the muscular projection on the little finger side, and thenar describes the projection and muscles on the thumb side of the hand. The front of the hand is referred to as palmar, and back of the hand is called the dorsal side (Cailliet, 1975; Napier, 1980; Luttgens and Wells, 1982; Memmler and Wood, 1987; Martini, 1992).

The fingers are commonly referred to as digits. The digital formula refers to the projection of the digits when the hand is laid flat with the palmer side facing a surface. The middle finger (third digit) is slightly longer than the index (second digit) and ring fingers (fourth digit). The fingers consist of three phalanges and the thumb consists of two phalanges. Two rows of carpal bones (seven total) form the wrist (Cailliet, 1975; Napier, 1980; Luttgens and Wells, 1982; Memmler and Wood, 1987; Martini, 1992).

Numerous joints provide the hand and wrist with mobility. The thumb has a saddle-type joint that provides greater mobility than the gliding joints of the fingers. The joints between the metacarpals and phalanges and between individual phalanges permit flexion/extension and abduction/adduction (Cailliet, 1975; Napier, 1980; Luttgens and Wells, 1982; Memmler and Wood, 1987; Martini, 1992).

Ten of the 19 muscles of the fingers and thumb are located entirely within the hand. These are referred to as intrinsic muscles. Muscles of the forearm provide crude control and strength of the fingers and palm. Those muscles located on the outside of the hand are referred to as extrinsic muscles. Muscles that originate on the carpals and metacarpals provide fine motor control. Only tendons extend across the distal joints of the fingers. Opposition, the placement of the pulp (finger print) surface of the thumb against the pad of any of the digits, is the most important movement of the human hand. The hand is capable of two classes of movement, prehensile and non-prehensile. When an object is held by gripping or pinching between the palm and digits, it is referred to as prehensile movement. Non-prehensile movements include pushing, punching, tapping, and lifting. Prehensile patterns include: power grip, hook grip, precision grip, and scissor grip (Napier, 1980).

A power grip utilizes the surface of the fingers and the palm of the hand with the thumb acting as a reinforcing agent. Precision is a secondary concern when using a power grip. A hook grip may be used in carrying heavy items such as a suitcase. The two terminal joints are bent and the knuckle-joints are kept straight while implementing a hook grip. Precision grips may involve one or more of the digits and the thumb. Gripping small objects may require the use of only one digit while gripping larger ones may require the use of all digits and the thumb. This type of grip is used for accuracy and delicacy with power taking a secondary role. A scissor grip consists of seizing an object between two terminal phalanges similar to holding a cigarette (Napier, 1980).

Body Temperature

The hypothalamus is located in the rear portion of the brain and acts as a thermostat for the body. It works as a control center for the central nervous system and pituitary gland to send messages to dilate or constrict the blood vessels near the skin surface in order to maintain normal body temperature. Vasodilation and sweating occurs when the hypothalamus senses that the body is becoming too warm. Inversely, vasoconstriction and shivering occurs when the body becomes too cool (Jensen, 1980).

Rectal temperature is indicative of the core body temperature, and is subject to only slight fluctuations due to environmental and individual variations. The body core must be kept at 37.5° ± 0.5°C to function properly (Jensen, 1980). This temperature is often referred to as the body's set point, and the skin labors to keep core temperature within a narrow range (Podolsky, 1957). Normal oral temperature is 0.5°C below rectal temperature. Skin temperature fluctuates more than either oral or rectal temperature because it operates in the process of thermoregulation. The feet and hands are subject to the greatest temperature variations due to the rate and volume of blood flow to these areas (Jensen, 1980; Laing and Ingham, 1983-84; Watkins, 1984).

When the mean skin temperature rises to meet the rectal temperature it is referred to as convergence. Persons working under very hot conditions which inhibit evaporative cooling may suffer from convergence. Nunneley, Antunano and Bomalaski (1992) conducted a study to examine the ability of subjects to work after their body reached convergence. Each of the subjects was instrumented with skin thermistors, rectal thermometers, and heart monitors for participation in eight exercise sessions. These sessions consisted of walking on a treadmill under eight environmental conditions. Sixty-percent of their subjects were able to work beyond the point of convergence with no subjects suffering from breakdown.

Sweating Mechanism

The skin consists of three layers: the epidermis, dermis (corium) and subcutis (Podolsky, 1957). The epidermis, the thinnest of the three layers, is the outer most layer of skin. The epidermis is thickest on the soles of the feet and the palms of the hands. Sweat glands are found in the dermis. The subcutaneous tissue is the deepest layer of the skin and is responsible for shock absorption and insulation (Kuno, 1956; Podolsky, 1957; Montagna, 1962).

Among the most characteristic of the human organs are the eccrine sweat glands. All sweat glands are developed during the fourth or fifth month of gestation (Kuno, 1956; Podolsky, 1957; Montagna, 1962). Due to body size, sweat glands have the greatest density right after birth. As the body grows the density of the sweat glands decreases (Kuno, 1956). Adult men average two to five million sweat glands with a density of 143 to 339 per square centimeter of body area. Active sweat glands are most dense on the palms and soles (Kuno, 1956).

The eccrine system acts as a thermoregulator by moistening the skin. A constant internal balance is maintained through evaporation of sweat on the skin (Podolsky, 1957). Eccrine sweat glands are tubules that form a corkscrew-like course downward from the epidermis to approximately the middle of the dermis (Kuno, 1956; Montagna, 1962). The sweat pores are very small and funnel-like in shape. They open into a crater-like cavity. Small amounts of sweat called insensible perspiration are continuously discharged from these glands. The palms and soles secrete more insensible perspiration than any other parts of the body (Kuno, 1956).

Sweating is controlled by the hypothalamus. As the blood temperature rises droplets of sweat are secreted through the skin to the surface. After reaching the skin surface the sweat is vaporized if uninhibited by clothing and environmental conditions, causing the body temperature to lower. With high humidity and temperature, the evaporation process is less successful, and sweat may drip off the body. If this takes place the body does not cool efficiently (Watkins, 1984). Thermal and wetness discomfort may occur if there is not adequate movement of heat and moisture away from the skin (Hollies et al., 1979; Hatch, Woo, Barker, Radhakrishnaiah, Markee and Maibach, 1990).

Measurement of Pertinent Variables

This section of the Review of Literature presents an overview on the most commonly used methods for measuring manual dexterity, body temperature, sweat rate, and perceived comfort.

Manual Dexterity

Ease of mobility is of great importance when completing fine motor tasks. Muscular exertion, strain, and discomfort may decrease effectiveness and accuracy. Tremblay (1989) found that lightweight, flexible, thin gloves were described as fitting better than stiff, heavy gloves that fit loosely. It was also concluded that optimal performance in completion of fine motor tasks occurred with the tighter fitting gloves. The author pointed out that a problem exists with location of the thumb and the depth of the thumb crotch in all types of gloves tested.

Two types of dexterity problems are encountered when wearing handwear.

Buckling of glove material in the palm of hand and a loss of sensitivity in the finger tips may occur. The various types of manipulations involved in hand and finger movements for a given task complicate the choice of manual dexterity tests to simulate a given task. Major questions outlined by Teicher, Kobrick and Dusek (1954, p.3) which must be asked prior to selection of measurement techniques include the following:

1) What are the limits of bare-hand dexterity under different climatic conditions, primarily temperature and wind, for varying periods of exposure?
2) What are the critical manual components affected by climatic conditions, i.e., what aspects of which manual joints are affected and to what degree?
3) What are the fatigue functions of manual dexterity?
4) What are the sensory requirements, particularly touch and kinesthesis, of efficient manual performance?
5) What are the relationships between the characteristics of the glove and manual dexterity, e.g., what is the relationship between bulk and dexterity, between shape and dexterity? Which manual components are affected? What are the fatigue functions?
6) What is the nature of interaction between the characteristics of the gloves, the nature of the task and the environmental factors?

It is recognized that a gloved hand does not perform in exactly the same manner as the ungloved hand (Bradley, 1969a; Bradley, 1969b; Bensel, 1993). A 1954 research project examined the usefulness of three of the commonly used tests of manual dexterity in evaluating handwear including the Minnesota Rate of Manipulation Test, Block-Packing Test and Craik Screw Test. All tests showed highly significant differences between the hand conditions and between the subjects. It was suggested that since the amount of relative impairment exhibited varied among tests that these tests measured different types of manual dexterity (Teicher et al., 1954).

Ve'lez-Torres (1993) used the Manipulative Aptitude Test and the Purdue Pegboard Test (model 32020) while testing a three component prototype glove system. The manipulations were conducted both while wearing the system with an artificially-cooled treatment and without the treatment. Significant differences were found on four out of eight of the manual dexterity tests. Teichner et al. (1954) found test validity increased when subjects mastered dexterity tests prior to data collection.

Body Temperature

Yellow Springs instrument probes are commonly used in measuring core temperature. This may be done via rectal temperature, oral temperature, and ear temperature. Skin temperature is primarily measured with thermistors and thermocouples. Skin temperature has been measured on multiple points of the body in numerous studies (Banta and Braun, 1992; Falco, Nielsen and Endrusick, 1992; Hennessey, Braddom and Goldberg, 1992; Kakitsuba and Katsuura, 1992; Nunneley et al., 1992; Sullivan and Mekjavi'c, 1992). Various formulas exist to compute mean skin temperature (Falco, et al., 1992; Nunneley, et al., 1992; Torii, Yamaski, Sasaki and Nakayama, 1992).

Sweat Rate

Historically, sweat loss has been measured through various methods. Overall sweat rate of the body may be measured through pre- and post-weighing of subjects and/or their clothing. Measurement of sweating over a small portion of the body may be gauged by sweat collection boxes. Both temperature and air flow may cause error in this method. Sweat accumulation on individual body sites may be measured by placing clothing in tared tin cans or polyethylene bags and weighing prior to and immediately following wearing (Fourt and Hollies, 1970; Ve'lez-Torres, 1993)

Dew-point hygrometer systems are more accurate in measuring localized sweating than the above methods. In addition to accuracy, sweat rate may be continuously monitored over time. Some studies have employed dew-point hygrometers to determine the amount of sweat released from individual body sites (Berglund, Cunningham, Graichen, H. Rascati, R. and Gonzalez, R. R., 1982; Berglund, 1985; Branson et al., 1988; Nielsen and Endrusick, 1992).

Miniature resistance type dew-point sensors may be secured to the skin in order to determine skin wettedness. The dew-point sensor includes a commercially available Peltier module with an electrically conductive top surface. The surface of the sensor is divided into half through the metalized surface to the nonconductive substrata of the module. As the module cools, moisture is able to accumulate on the surface thereby lowering the resistance between the conducting plates. A high-impedance amplifier circuit detects the change and activates a servo amplifier and the appropriate circuitry to reverse the flow of current through the module turning on the heating mode. Water vapor may then be evaporated and the cycle is repeated.

A computer attached to the sensor may be programmed to use the ideal gas law ($m_s = \Delta (PH_2O) (AF)/(RwA \cdot T)$ [$g \cdot min.^{-1} \cdot cm.^{-2}$] to calculate sweat rate (Graichen, Rascati and Gonzalez, 1982).

Branson et al. (1988) used a General Eastern System 1100 dew-point hygrometer to measure ambient room temperature and dew-point of the nondominant hand via a sweat capsule attached to the skin while wearing four different glove liners. A hypoallergenic skin glue was used in securing the sweat capsule to the skin and providing a seal. Skin temperature, sweat rate, and dew-point were recorded at five-minute intervals throughout the testing sessions via a computer.

Nielsen and Endrusiek (1992) tested a prototype garment ensemble in a climatic chamber in an effort to determine how temperature and humidity varied at and between various body sites. Automatic dew-point sensors were attached both directly to the skin and between clothing layers at various sites. Dew-point was automatically recorded every 60 seconds during the test.

Complementary research has been conducted to investigate the physiological responses of the skin such as capillary blood flow and hydration when in contact with fabric. Three instruments, the focused microwave probe, the laser Doppler velocimetry instrument, and the Evaporimeter have been developed to measure alteration in skin hydration. Evaporative water loss may not occur when the skin is totally occluded. Transepidermal water accumulates within the stratum corneum (outer most layer of the epidermis) when the skin is occluded, and when uncovered after an extended period of occlusion a burst of evaporative water loss occurs. Hatch, Markee, Prato, Zeronian, Maibach, Kuehl, and Axelson (1992) found that fabric moisture content and stiffness of the fibers in the fabric had an influence on stratum corneum hydration.

Perceptual Variables

Perceptual variables may be measured in various ways. Most often a scale of some type is used to quantify the measurement. Psychological scaling is the most common method to measure perceptual variables with psychophysical methods offering a second approach.

Psychological Scaling

Psychological scaling is a widely used method for assessing subjective aspects of clothing comfort. Sensations such as thermal comfort or temperature perception, tactile comfort, and overall clothing comfort are often measured to describe sensations (Sweeney and Branson, 1990).

Hollies (1977) used a subjective rating scale for measuring fabric wetness of shirting fabrics. The scale consisted of four variables ranging from dry to wet in which subjects were to rate their perception of wetness.

Sontag (1985-86) used a semantic differential instrument consisting of 124 sets of randomly ordered bipolar adjective pairs to assess people's evaluations of actual and ideal insulative indoor clothing. The project was designed to evaluate physical, psychological, and social comfort of insulative clothing.

Branson, DeJonge, and Munson (1986) used a nine-point Likert scale used by Rohles and Milliken (1981) to collect perceived thermal sensation data. Subjects were asked to respond using a rating of one (very cold) and a rating of nine (very hot).

This scale is a two-category expansion of the ASHRAE comfort ballot (ASHRAE, 1981). The researchers also used a semantic-differential scale developed by Rohles, Millikin and Kristic (1979) consisting of bi-polar adjectives separated by nine spaces to collect information on perceived thermal comfort.

Hollies (1977) developed a comfort intensity scale consisting of 11 comfort descriptor terms for use in measuring perceived comfort intensity of a given sensation. A rating of one (totally uncomfortable) to five (completely comfortable) was given to each of the descriptors.

Ve'lez-Torres (1993) adapted Hollies' Subjective Rating Chart by adding a descriptor, eliminating three, and adding short definitions for each characteristic to aid in consistency of responses. Subjects were asked to rank the intensity of nine comfort characteristics on a scale of one (totally) to five (not at all). Subjects were also asked to indicate on a scale of one (very comfortable) to seven (very uncomfortable) the overall comfort of the prototype garment. The final comfort ballot included an open ended question asking subjects to explain aspects they found uncomfortable.

Psychophysics

Psychophysics is the scientific study of the relationship between stimuli in sensations in the psychological domain and the physical domain (Sweeney and Branson, 1990a; Branson, 1990b). Psychophysical scaling requires the subject to make simple sensation judgments, such as the presence or absence of a sensation. The minimum value of a physical stimulus that evokes a sensation is referred to as the absolute threshold, and the difference threshold refers to the amount of stimulus that is required to produce a noticeable difference in sensation.

Sweeney and Branson (1990a) used magnitude estimation, a system of direct psychophysical scaling in which the subject is asked to use numbers in estimating the magnitudes of specific sensations. Subjects were exposed to wetted pieces of fabric which experimenters arbitrarily labeled as having an intensity of ten. Subjects were then exposed to additional swatches of fabric and instructed to choose a number greater than or less than the initial ten in describing the intensity of wettedness. Subjects varied in the numbering of intensity, but ranked the swatches in a similar order of intensity of wetness. The researchers found that some areas of the body were less sensitive to moisture than others and that sensitivity may differ greatly from person to person.

Clothing

Hollies et al. (1979) found that mild or heavy sweating corresponded with strong tactile sensations. Subjects reported discomfort when test garments contained 4% moisture above regain. This is probably not enough regain to activate wicking. Said research indicated that vapor diffusion is the dominant mechanism for moisture transport through clothing.

A 1990 (Markee, Hatch, Maibach, Barker, Radhakrishnaiah, and Woo) study examined the relationship of environmental conditions, level of activity, fiber, garment design, fabric, physiological and psychological state to perceptions of comfort. Ten female subjects were instructed to exercise in conditions of high humidity and high temperature while skin temperature, and capillary blood flow were measured. Subjects responded to an overall comfort scale ranging from one (comfortable) to seven (very uncomfortable) and a wetness sensation scale ranging from one (dry) to seven (very wet). Subjects rated thermal sensation on a scale of one (very cold) to nine (very hot). A contact sensation scale consisting of ten variables was supplied for subjects to rate from one (no contact sensation) to five (extreme contact sensation). Skin temperature and wetness sensation were found to be related to the subjective assessment of clothing comfort (Markee et al., 1990).

Sullivan and Mekjavi'c (1992) simulated helicopter cockpit conditions (ambient temperature of 40°C and minimal air movement) while measuring skin temperature, core temperature and microenvironment vapor pressure while wearing garments of varying materials. The researchers found that the temperature within the microclimate in each of the suits was similar indicating that during hot air exposures of this magnitude the resistance of the garment and fabric to dry heat transfer plays little role in the thermal status of the wearer. The relative humidity (vapor pressure) of air within the microenvironment varied greatly between suits of various fabrics.

Artificial Cooling

Various attempts to create a microenvironment around the person via the use of artificially-cooled garment devices have been examined. Personal cooling garments which utilize frozen water were first devised in South Africa in the 1950s. These garments consisted of vests, jumpsuits or jackets covered with small pockets in which ice packets could be placed. This provided direct body contact with the cooling pockets (Kamon, Kenny, Deno, Soto, and Carpenter, 1986; Hansen, 1988). Major disadvantages of this type of garment include coldness next to the skin and added weight. Hansen (1988) reported that an ice vest may weigh up to 15 pounds. This weight may cause the wearer to tire faster, therefore taking away the benefit of the cooling.

Forced air systems are also available for personal cooling. These systems call for the wearer to be connected to a heavy compression unit by tubes that can inhibit movement (Hansen, 1988). The expense of purchasing such a unit, and the inability to move around freely decreases the probability that persons working in moderately high temperatures and relative humidity would benefit from such a system.

Thermacore manufactures a vest that is described as a "soft refrigerator." This vest, weighing approximately two pounds, utilizes a Freon unit of about six pounds to cool the body (Hansen, 1988). Added weight as well as restrictions upon Freon usage are issues which should be contemplated when considering this type of unit.

MSA International offers a total-encapsulating suit that may be worn inside protective clothing. These garments are available in three-piece suits consisting of a long-sleeved shirt, pants, and hood. They utilize a cooling unit charged with a battery to pump ice water to tubing throughout the garment system. The cooling unit may be waist-mounted, front-mounted, or back-mounted. For short term very high temperature situations this system may prove beneficial. Due to the expense and weight, this system, does not address the needs of persons working with pesticides in a satisfactory manner.

Naval operations in the Persian Gulf in the summer of 1988 prompted researchers to test a poncho-style, cotton canvas, positive buoyant, passive (ice) cooling vest. The vest containing six frozen (gel) thermostrips was worn under standard flight equipment. A T-shirt was donned prior to the vest to provide a means of separating the vest from the skin. The cooled vests were found to be successful in reducing cardiac strain and mean skin temperatures (Banta and Braun, 1992).

Ve'lez-Torres (1993) applied the cooling strategies for vests by Banta and Braun (1992) to hand wear. The challenge of developing a protective glove system that provides cooling to the hand was addressed as a means of increasing the number of persons wearing hand protection while working with potentially harmful chemicals. A glove liner with cooling gel pockets was successful in lowering the overall mean skin temperature of the hand and increasing manual dexterity performance. Problems encountered during this research project include: skin temperature lower than perceived comfortable by some subjects, limited cooling time, and bulkiness.

CHAPTER III

METHODOLOGY

The purpose of this investigation was to evaluate the effects of an artificially-cooled chemical protective glove and glove liner system on manual dexterity and thermal comfort properties of subjects under conditions of high relative humidity and high temperature similar to a typical Oklahoma day.

Testing and Evaluation

The testing of the prototype glove and glove liner took place in an environmental chamber located in the College of Human Environmental Sciences at Oklahoma State University. A temperature of 31° ± .5°C and a relative humidity of 78 ± 2% provided the researchers with an environment typical to Oklahoma conditions during the spring and summer months.

Sample

A convenience sample consisting of eight male subjects between the ages of 18 years and 25 (mean = 19) years was selected for the study. A pre-screening session consisting of a glove fitting and practice on each of the manual dexterity tests was completed prior to acceptance as test subjects. The nature of the experiment was then explained, and the Informed Consent and Disclosure Agreements were signed prior to testing (Appendix C).

Variables

Independent Variables

The independent variables include the two glove treatments (cooled and uncooled) and the glove liner treatment. A pancake style glove liner was constructed out of a 65% nylon/25% polyester/ 10% spandex two-layer knit. Preliminary textile tests on the fabric show the fabric possesses good absorbency and moisture vapor transport characteristics. The fabric is purported to have a unique push/pull relationship that allows the body to push the moisture away from the skin while the Hydrofil® nylon pulls the moisture to the outer surface. Excellent stretch characteristics (103% lengthwise and 93% crosswise) reduce the need for various sizes of liners as well as aiding in donning and doffing of the liner.

Prototype gloves were constructed of two Pioneer TRIonic® gloves made of neoprene, unpigmented natural rubber, and nitrile. This glove provides elasticity, resiliency, abrasion resistance, and penetration resistance to many of the chemicals used in pesticide related work.

After removing the fingers from one glove, they were secured together with a cementing agent. Next, a hole approximately 2.5 cm (1 inch) in diameter was cut in the dorsal side of the glove and glove liner allowing the researcher to attach the sweat monitor to the skin during testing. A cooling gel substance, similar to that used for treating sprains, was injected between the layers of the glove to provide coolness (see figure 3). Prior to testing the gloves were refrigerated for a minimum of 24 hours. The mean temperature for cooled gloves was 3.7°C.

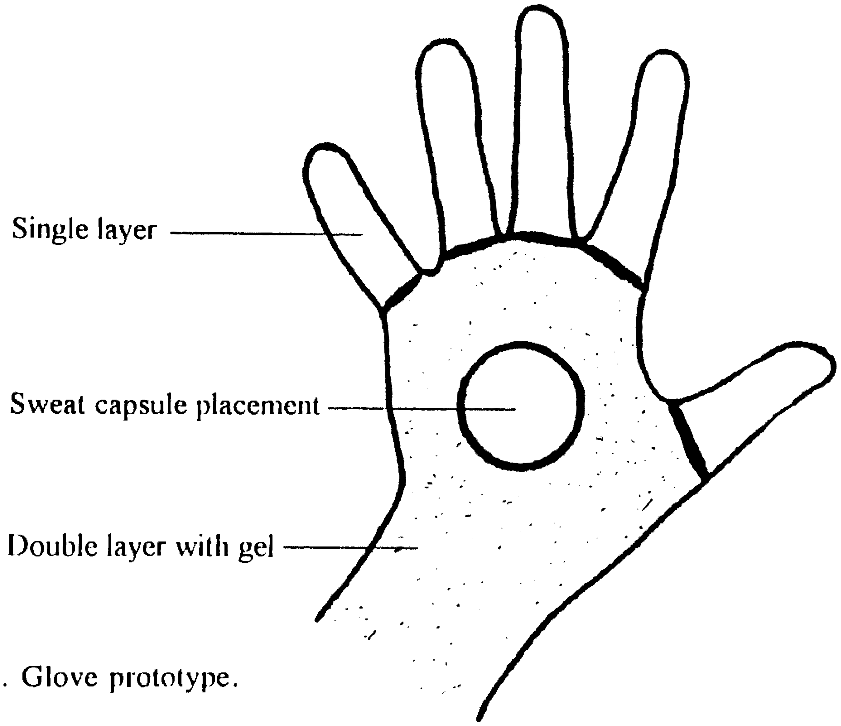


Figure 3. Glove prototype.

Dependent Variables

Manual dexterity, perceived thermal comfort, skin temperature, and sweat rate were the dependent variables. Manual dexterity was measured by administering the Manipulative Aptitude Test devised by Wesley S. Roeder and the Purdue Pegboard from Lafayette Instrument Company (model 32023). An adaptation of Hollies (1977) Subjective Rating Scale was used to assess perceived comfort. The descriptors snug and heavy were added and staticky, clammy and picky were deleted in an effort to confine the measurement of variables to those relevant for to this study. Short definitions were also included for clarification of descriptors. Comfort ballots were completed by subjects immediately upon donning the gloves and at ten-minute intervals (a total of seven ballots) throughout each session. Upon completion of the final testing session, subjects were asked to write down any comments they had concerning the overall comfort of the glove system.

Skin temperature and sweat rate were measured on the nondominant hand at three-minute intervals. Thermocouples taped to four sites on the hand were used to measure skin temperature every 180 seconds (figure 4). This system automatically records temperature at pre-determined intervals. Dew-point was measured via a dew-point hygrometer system connected to a personal computer. Sweat rate of the dorsal side of the nondominant hand was calculated by monitoring dew-point at 180 second intervals (20 readings) throughout the test session.

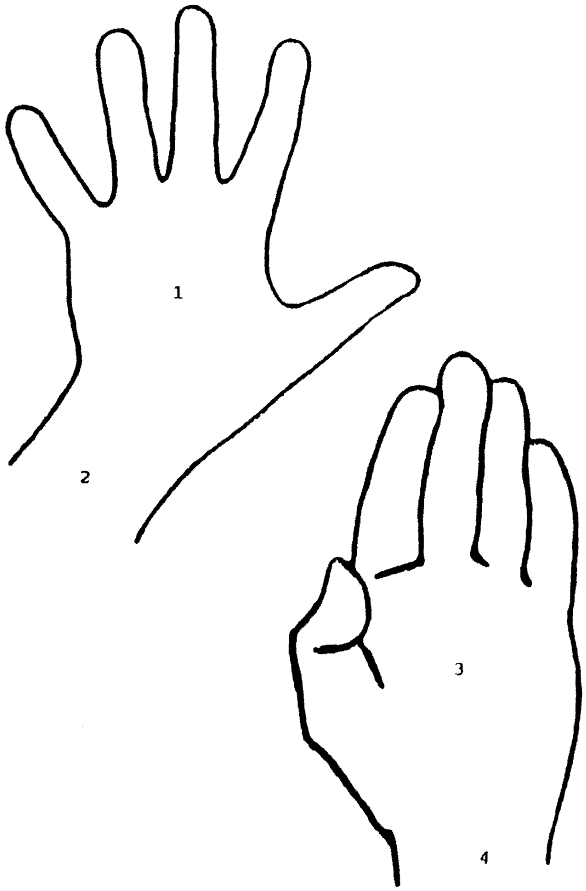


Figure 4. Thermocouple placement.

Experimental Design

A Latin square, repeated measures experimental design was used. This design was chosen in an effort to prevent a presentation bias of treatments. Each of the subjects completed four test sessions consisting of a simulation of pesticide application ith a hand held sprayer and manual dexterity tests.

Statistical Analysis

Initially, all mean dependent variables were measured and graphed over time. An analysis of variance (ANOVA) was performed to determine significant differences by treatment for perceived thermal comfort, manual dexterity, skin temperature, and sweat rate.

Experiment Protocol

Each test session included two repetitions of a simulation exercise protocol and completion of four exercises of each manual dexterity test. The exercise protocol was developed to simulate mixing, loading, and spraying of pesticides and cleaning pesticide application equipment. Subjects were instrumented with thermocouples, glove systems and sweat capsules upon entering the testing chamber. Immediately after donning the prototype glove system an initial comfort ballot was completed. The subjects then completed the following activities in this order: 1. simulation of exercise protocol; 2. four exercises of the Purdue Pegboard; 3. four exercises of the Manipulative Aptitude Test; 4. simulation of exercise protocol; 5. four exercises of the Purdue Pegboard; and 6. four exercises of the Manipulative Aptitude Test. The comfort ballots were administered at 180 second (ten-minutes) intervals throughout the protocol.

Two types of activity are measured by the Purdue Pegboard test. Gross movement of hands, fingers and arms are measured by the first activity. Assembly or fingertip dexterity are measured with the final activity. For all activities, pins, collars, and washers are placed in four cups across the top of the board. The first activity includes three components which require subjects to place pins with the right hand, then the left hand, and finally with both hands in the holes down the center of the board. The assembly portion of the test requires the subject to use both hands to place a series of pins, washers, and collars in the holes as quickly as possible.

The Manipulative Aptitude Test is used to determine how quickly and accurately a person can work with their hands. The test consists of a T-bar, rods, washers, and nuts. The rods are threaded on both ends to enable them to be screwed in the sockets and then capped by a nut. The first activity requires the person to screw as many rods into the holes as possible followed by the placement of nuts on them. The second activity requires the person to use both hands to place washers and nuts on the T-bar at the same time. The right and left hand are measured separately by placing washers and nuts with one hand at a time during the final activity.

CHAPTER IV

MANUSCRIPT I

LaDawn Stiles Simpson

Department of Design, Housing and Merchandising

Oklahoma State University

Stillwater, Oklahoma 74078-0337, U.S.A.

Abstract

Dermal exposure to pesticides is a growing concern. The use of chemical protective gloves while working in conditions of high temperatures and relative humidities has been limited due to the decrease in comfort and manual dexterity skills. The purpose of this investigation was to evaluate the practicality of an artificially cooled chemical protective glove system. Four glove system conditions were tested (an artificially cooled glove with and without a glove liner and an uncooled glove with and without a glove liner) in an environmental chamber with controlled conditions (temperature of 31 ± .5°C and relative humidity of 78% ± 2%). Eight male college students (mean age 19 years) performed manual dexterity tests and a simulation of pesticide handling. Skin temperature and sweat rate data were recorded every 180 seconds, and subjective comfort ballots were completed every 600 seconds. The prototype glove system that included artificial cooling and a liner was effective in lowering skin temperature and in increasing perceived comfort. However, manual dexterity scores were significantly lower when the liner was used. The authors believe that the liner increased bulkiness at the fingertips and that this bulkiness hindered manual dexterity. A fingerless liner may alleviate this problem.

1. Introduction

Over the past 20 years pesticide application to agricultural crops has escalated in an effort to increase productivity and quality of products (Stone *et al.* 1989). As the usage of pesticides has increased, a growing awareness has developed concerning the adverse health effects attributed to pesticide exposure. Pesticides have been reported to be teratogenic, mutagenic, and carcinogenic in nature (Rupa *et al.* 1991). Pesticides exposure has been linked to occupational skin disease such as dermatitis as well as infertility, neonatal deaths, spontaneous abortions, still births, and congenital defects (Durham and Wolfe 1962, Rupa *et al.* 1991).

Pesticides may enter the body via three routes: oral, respiratory, and dermal contact. Past studies indicate that between 20% and 97% of all dermal exposure occurs on the hands (Bonsall 1985, Grover *et al.* 1988, Popendorf 1988, Urbain 1988, Leonas and Kun Yu 1992). Variation in the reported percentage of exposure may be accounted for by examination of the methods of measurement, work activity, and equipment used in application. Regardless of the variation in extent of exposure, there is generally widespread agreement on the need to protect the hands from exposure through the use of protective gloves.

It is estimated that between 37% and 60% of the population handling pesticides on a regular basis wear chemical protective gloves (Rucker *et al.* 1988, Farr-Popelka and Branson 1991). Reasons commonly found for not wearing chemical protective gloves include decreased thermal comfort, reduced manual dexterity skills and moisture retention. Glove liners have been used to alleviate the moisture retention problem. Research by the U.S. Army examined the differential effects of wearing glove liners of three different fabrics on the above variables. The researchers found that regardless of the liner fabric, skin temperature and perceived thermal discomfort and temperature increased over a two-hour testing session (Branson *et al.* 1988). There was also a tendency for sweat rate to increase over time more markedly with the liner.

Portable cooling devices have been developed to increase worker comfort when exposed to high temperatures and relative humidities. Designs of garments with artificial cooling differ considerably, including frozen water vests, jumpsuits and jackets; garments cooled via forced air compressor units; refrigerated vests; and total-encapsulating suits (Kamon *et al.* 1986, Hansen 1988, Banta and Braun 1992). Although these devices have merit, there is concern that the garments are cumbersome and heavy.

Ve'lez-Torres (1993) developed a glove liner with proprietary cooling devices to be worn with a commercial chemical protective glove system. Evaluation of the prototype showed the cooling was successful in lowering skin temperature and manual dexterity was not adversely affected, in fact manual dexterity was improved for selected tasks. This study established the need for future research in the use of artificial cooling for the hand while working in conditions of high heat and relative humidity.

The purpose of this study was to evaluate a prototype chemical protective glove system with artificial cooling in which the protective glove was designed to cool the hand. The Branson and Sweeney 1987 model for examining clothing comfort (figure 1) was used as a framework for this study. The model posits that every element of the triad (person, clothing and environment) has both physical and non-physical dimension (authors used the physical and psychological dimensions). Interactions between and among the physical and non-physical dimensions of the triad combine to elicit physiological and/or perceptual responses. Past experiences act as a filter influencing the final clothing comfort judgment.

Environmental physical conditions related to temperature and relative humidity were controlled. Controlled person attributes included age, sex and body stature of subjects. Test clothing was controlled to include denim jeans, a work shirt and baseball cap. The test glove system was manipulated to determine its effect on specific person attributes. Comfort clothing judgments were also assessed. Some information was obtained on past work experiences to attempt to obtain information related to the filter.

2. Methodology

The evaluation of thermal properties, manual dexterity skills, and perceived thermal comfort as evaluated while wearing four prototype protective glove treatments in controlled environmental conditions.

2.1. *Variables*

The experiment was conducted inside an environmentally controlled chamber in the College of Human Environmental Sciences at Oklahoma State University. The temperature (31 ± .2°C) and relative humidity (78% ± 2%) were controlled throughout the experiment. These conditions were chosen to simulate a typical Oklahoma summer day. Ve'lez-Torres (1993) derived these conditions after studying climatological data obtained from the National Oceanic and Atmospheric Administration (NOAA) for the months of March through September for five years.

2.2. *Sample*

Eight male subjects between the ages of 18 and 25 (mean 19.375) were selected for the study. Subjects were contacted via an advertisement placed in the college newspaper and flyers affixed on college bulletin boards. Prior to testing, subjects donned prototype glove systems to ensure proper fit and signed Informed Consent and Disclosure Agreement forms. Subjects were required to fit jeans, sizes 32 to 34 waist, and size medium work shirts provided by the experimenters.

2.3. *Dependent Variables*

Dependent variables included perceived thermal comfort and manual dexterity skills of both hands and skin temperature and sweat rate of the non-dominate hand. Since Ve'lez-Torres (1993) found no significant difference in skin temperature and sweat rate of the dominant and nondominant hand, only the non-dominant hand was instrumented.

2.4. *Independent Variables*

Independent variables for this investigation included four glove treatment combinations. These consisted of an uncooled chemical protective glove with and without a liner and an artificially cooled chemical protective glove with and without a liner. The glove liner was a pancake style glove constructed of a 2-layer knit of 65% nylon/5% polyester/10% spandex. This fabric was chosen due to its good stretch qualities and manufacturer claims of moisture transfer. The prototype artificially-cooled glove was constructed by sealing two Pioneer TRIonic® gloves together and injecting a cooling agent between the layers. This glove was chosen based on its elasticity, resiliency, abrasion resistance, penetration resistance to various chemicals used in pesticide application, and farmers' preferences determined in a study involving 380 agricultural workers (Tremblay 1989).

2.5. *Instruments*

Skin temperature was measured and recorded every 180 seconds via thermocouples (20 readings per session). A dew-point hygrometer system recorded dew-point and calculated and reported sweat-rate via a personal computer at 180 second intervals throughout the testing sessions (20 readings per session).

Hollies Subjective Rating Scale (1977) was adapted by reducing the number of descriptor terms from 15 to 9 and adding definitions to minimize subject's differing concepts of the given terms. The comfort ballot was administered immediately upon instrumentation and at 600 second intervals throughout each of the testing sessions (7 ballots per session).

Four exercises of the Purdue Pegboard Test (insertion of pins and washers with the right hand, left hand and both hands and an assembly operation) and four exercises of the Manipulative Aptitude (placement of rods and caps with the dominant hand, washer and nut placement with both hands, left hand and right hand) were conducted twice during the test session.

Total operations completed were recorded for each portion of both the Manipulative Aptitude Test devised by Wesley S. Roeder and the Purdue Pegboard from Lafayette Instrument Company to measure fine motor skills. An additional category author labeled as preference hand was formed for both tests to indicate data obtained for the dominant hand since both left and right-handed subjects were included in the study.

2.6. *Testing protocol*

Four 3600 second testing sessions were conducted in which subjects wore one prototype treatment per session. Upon arrival, subjects were instructed to change into jeans, work shirt, and baseball cap provided by the researchers. The subject and experimenter then entered the environmental chamber where the experimenter applied thermistors, glove treatments, and sweat capsules to the non-dominant hand of the subject.

Immediately following instrumentation, which took approximately 30 seconds to complete, the first temperature and sweat rate readings were recorded. At the same time, the subject was instructed to fill out the first of seven comfort ballots. Upon completion of the initial ballot, the subject proceeded with a 600 second pesticide simulation protocol. The protocol was developed and administered to simulate mixing, loading and application of pesticides with a hand-held sprayer. The subjects were observed to determine if the gloves hampered movement and fine motor skills required for the operation. The activity also allowed the researchers to obtain physical data (skin temperature and sweat rate) during activities similar to actual pesticide application. At the conclusion of 600 seconds, the comfort ballot was again administered followed by the Purdue Pegboard Test, a third comfort ballot, the Manipulative Aptitude Test and a fourth comfort ballot. At the conclusion of the fourth comfort ballot, subjects repeated the entire procedure again ending with the seventh comfort ballot. At the end of the fourth and final session, subjects were asked to write any additional comments and glove comparisons.

3. Results

Manual Dexterity

ANOVA results indicated significant differences in all manual dexterity skills of both the Purdue Pegboard and the Manipulative Aptitude Test by subject and liner treatment. In each case, the liner was found to negatively impact manual dexterity. No significant differences were found due to the presence or the absence of cooling treatment.

The Purdue Pegboard tests consisted of five components. The first three operations require subjects to alternate placing pins and washers in holes on a peg board, first with the right hand, next the left and finally with both hands. These operations are totaled and recorded as R+L+B on the tabulation sheet. The fourth and final operation consists of assembling pins, collars, and washers, the total number of pieces assembled is then recorded. Preference hand results were also calculated. Preference hand data refer to data from the subject's dominant hand.

ANOVA results showed significant differences by preference hand for subject ($p = 0.0163$) and liner treatment ($p = 0.0127$). Significant differences were also indicated by both subject ($p = 0.0013$) and liner treatment ($p = 0.0006$) for the R+L+B hand totals. Examination of table 1, which provides means and standard deviations for all dexterity tests shows that for all tests of the Purdue Pegboard, higher totals were found for subjects not wearing the liner treatment. Thus, the presence of the liner reduced subjects' ability to perform the Purdue Pegboard Test.

TABLE 1

The Manipulative Aptitude Test consists of four separate operations. First, subjects are required to screw small rods into holes on the testing board and to cap the rods. Totals are recorded for rods and caps separately. The final three operations require the subject to alternate placing washers and nuts on a T-bar first with both hands, then the left hand and finally the right hand. Upon completion of each task, the total number of washers and nuts is recorded. ANOVA results indicate significant differences on all measures of this test by subject and liner treatment. Table 1 shows that means were significantly greater for all tests of the Manipulative Aptitude Test while subjects did not wear the liner. Thus, the liner reduced manual dexterity as measured by both the Purdue Pegboard Test and the Manipulative Aptitude Test.

Table 1 also shows some tendency for the cooling treatment to adversely impact manual dexterity. Three versions of the Manipulative Aptitude Test (rods, caps and washers and nuts both hands) seem noteworthy.

Skin Temperature

ANOVA tests were used to analyze skin temperature data. Mean temperatures for all four hand sites over time are shown for all glove treatments in figure 5. Location three (palm) had consistently higher mean temperature readings. Locations one (dorsal side of the hand) and four (wrist on palmar side of the hand) had similar readings throughout the test sessions. Location two (the dorsal side wrist) consistently had the lowest mean temperature readings.

Mean skin temperature by treatment over time is shown in figure 6. The uncooled glove treatments had similar temperature readings with and without a liner. Temperature for subjects wearing the uncooled glove treatments, both with and without a liner generally rose for the first nine hundred seconds then remained approximately 36°C. Mean skin temperature while wearing the cooled glove also gradually rose throughout the entire testing session regardless of the presence of the liner. Without the liner, subjects' mean temperatures were lower for the first half of the test session.

In general, regardless of liner or location, the cooling treatment kept the hand cooler over a longer amount of time.

Sweat Rate

With the uncooled glove treatment, figure 7 suggests that subjects experienced higher sweat rate when wearing the liner. However, the cooled glove treatment data shown in figure 3 is not so consistent.

Analysis of variance of sweat rate as repeated measures over time indicated only a significant time effect. That is, regardless of liner or cooling treatment, the subjects experienced a similar increase in sweat rate over the time of the experiment.

Perceived Comfort

Psychological comfort variables examined included variables related to moisture perception, tactile comfort and overall comfort. Moisture variables included descriptors such as sticky, damp, and clingy. Those related to tactile comfort included roughness, scratchiness, and stiffness. Subjects were also asked to rate the perceived heaviness, snugness and overall comfort of each treatment.

Figure 8 shows the comfort variable sticky over time. ANOVA results shown in Table 2 indicate a significant liner ($p > 0.0001$), subject ($p = 0.043$) and time ($p = 0.001$) effects as well as significant liner by time interaction ($p = 0.0005$). Perception of stickiness increased over the experiment, particularly when the subjects were not wearing the liner.

TABLE 2

ANOVA results (table 2) indicate significant liner ($p = 0.0002$), subject ($p = 0.0076$), and time ($p = 0.0113$) effects for the comfort variable clingy (figure 9). In general, subjects perceived a slight increase in clinginess over the experiment. When the liner was worn, however, regardless of the presence of absence of the cooling treatment, subjects perceived less clinginess in the glove system. This indicates that the liner mitigated the subjects' perception of clinginess and stickiness.

Significant liner ($p = 0.0003$) and time ($p = 0.0002$) effects plus two interaction effects, cool by liner by time ($p = 0.0478$) and cool by time ($p = 0.0016$) for the quality dampness were found as given in table 2. In general, over time subject perception of dampness gradually increased, but this effect was more pronounced when cooling was not present (figure 10). The presence of the liner significantly lessened subjects' perception of dampness. Excluding the first two readings, the uncooled/unlined glove was rated as definitely damp. The cooled treatment without a liner was consistently perceived as mildly damp for all time periods.

The liner significantly lessened perception of dampness, clinginess and stickiness. There was a trend toward a decrease in perception of dampness and clinginess for the combination of liner and the cooling treatments, although this was not significant.

With the cooling treatment, subjects perceived the glove systems slightly rougher (figure 11) and considerably more snug (figure 12). This was more noticeable at the beginning of the experiment.

No significant effects were found for the descriptor scratchy (table 2). Regardless of glove treatment, subjects rated the gloves as being not at all scratchy throughout the experiments.

Significant subject ($p = 0.0022$), cooling ($p = 0.0034$) and liner ($p = 0.0207$) effects and a cooling by liner by time ($p = 0.0271$) interaction were indicated for the descriptor heavy (table 2). As expected, subjects perceived the glove with the cooling treatments as heavier and the system with neither cooling or liner treatments as the least heavy (figure 13).

Subjects did not perceive any of the glove systems to be stiff with mean responses varying from 4.446 to 4.821, where 4 equals partially and 4 equals not at all (table 2).

As expected, without the cooling treatment (figure 14), subjects perceived little coldness over the experiment, regardless of liner treatment. With the cooling treatment, subjects perceived greater coldness and the perception of coldness decreased over the experiment. Also, the perception of coldness was lessened by the presence of the liner. ANOVA results, as shown in table 2, indicated significant effects for the cooling ($p > 0.0001$) and liner ($p = 0.0284$) treatments and the interaction of cooling treatment by time ($p > 0.0001$).

Significant subject ($p > 0.0001$), liner ($p = 0.0464$) and time ($p > 0.0001$) effects, as well as significant cool by liner over time ($p = 0.0472$) and subject by cool by liner ($p > 0.0001$) interactions were found for overall comfort (table 2). In general, over time there is a tendency for the perception of comfort to decrease as shown in figure 15. This was particularly characteristic of the glove system with both cooling and liner treatments and the glove with neither. By the end of the experiment, the glove system with neither treatment was perceived as most uncomfortable.

ANOVA results for the comfort variable cold indicate subject effects, cool treatment effects and coolness over time effects. The artificially cooled glove started out with a rating of definitely cool and gradually rose. This rating stabilized between partially and not at all cool during the fourth time period.

Discussion

The development and testing of an artificially cooled prototype glove system was undertaken in an attempt to address thermal and sensorial discomfort while wearing standard chemical protective handwear. The prototype system consisting of a pancake style glove liner and an artificially cooled chemical protective glove were proven successful in lowering the overall skin temperature of the hand. Mean skin temperature gradually rose throughout the test session regardless of glove treatment.

The rise was least dramatic when subjects donned the cooled glove treatment. The presence or absence of the liner treatment did not affect skin temperature when combined with the cooled glove provided.

Although not significant, the presence of the glove liner reduced the perception of moisture related comfort variables (sticky, clingy, and damp). Each increased over time, but to a lesser extent in the presence of the liner treatment.

At the beginning of the experiments, subjects indicated that gloves that included the cooling treatment were considerably more snug and slightly rougher than those without cooling. None of the glove treatments were perceived as being scratchy or stiff. As expected, the gloves with the cooling treatment were perceived as heavier than those without.

Tactile comfort variables appear to be unaffected by the presence or absence of the liner treatment. None of the glove treatments were perceived as being stiff or rough.

It is not surprising that the uncooled/unlined glove is perceived as generally less heavy than any of the other glove treatment due to its actual weight. However, it should be noted that the cooled glove received ratings between 2 and 3 on a 5 point scale with 1 equaling totally and 5 equaling not at all.

When subjects were asked to rate the overall comfort of the gloves, the cooled/with liner glove treatment was rated the most comfortable treatment. As figure 15 shows for all of the treatments, perceived overall comfort decreased over time. The uncooled/unlined treatment was rated the least comfortable. These observations indicate that there is merit in wearing an artificially cooled glove system when working in conditions of high temperature and relative humidity. The glove system was most effective during the beginning of the test.

No significant differences were found due to cooling treatment for dexterity measures. The liner treatment negatively impacted all components of the manual dexterity tests.

The addition of artificial cooling to the glove system was shown to lower skin temperature without affecting manual dexterity. The presence of the liner negatively impacted manual dexterity but improved subjects' perception of moisture related variables. When asked to rate the glove systems overall, subjects rated the cool treatment with a liner as more comfortable than the other treatments.

The data suggests that the concept of artificially-cooled glove has merit, yet a number of issues with the glove liner remain to be further refined. An additional recommendation includes testing the glove for a greater time period under controlled conditions. Finally, it might prove useful to field test the glove systems.

References

BANTA, G. R. and BRAUN, D. E. 1992, Heat strain during at-sea helicopter operations and the effect of passive microclimate cooling. *Aviation, Space, and Environmental Medicine*, **63(10)**, 881-890.

BONSAL, J. L. 1985, Measurement of occupational exposure to pesticides. In *Occupational Hazards of Pesticide Use* (Taylor and Francis, Philadelphia, PA) 1-66.

BRANSON, D. H. and SWEENEY, M. 1987, *Clothing comfort conceptualization and measurement: Toward a metatheory.* Paper presented at meeting of the Association of College Professors of Textiles and Clothing-Central Region, Dearborn, MI.

BRANSON, D. H., ABUSAMRA, L., HOENER, C. AND RICE, S. 1988, Effect of glove liners on sweat rate, comfort, and psychomotor task performance. *Textile Research Journal*, **58(3)**, 166-173.

DURHAM, W. F. and WOLFE, H. R. 1962, Measurement of the exposure of workers to pesticides. *Bulletin of World Health Organization*, **26**, 75-90.

FARR-POPELKA, C. and BRANSON, D. H. 1991, unpublished manuscript. Pesticide Operator Survey Data, Oklahoma State University.

GROVER, R., CESSNA, A. J., MUIR, N. I., RIEDEL, D. and FRANKLIN, C. A. 1988, Pattern of dermal deposition resulting from mixing/loading and ground application of 2,4-D dimethylamine salt. In Mansdorf, S. Z., Sager, R. and A. P. Nielsen (Eds.) *Performance of Protective Clothing: Second Symposium, ASTM STP 989* Philadelphia, PA: American Society for Testing and Materials), 625-629.

HANSEN, P. 1988, Technological advances may solve problems of heat stress and clothing. *Occupational Health and Safety*, **57(5)**, 62-68.

HOLLIES, N. R. S. 1977, Psychological scaling in comfort assessment. In Hollies, N. R. S. and Goldman, R. F. (Eds.), Michigan: Ann Arbor Science 107-120. *Clothing Vomfort Interaction of Thermal Ventilation,*

KAMON, E., KENNY, W. L., DENO, N. S., SOTO, K. I. and CARPENTER, A. J. 1986, Readdressing personal cooling with ice. *American Industrial Hygiene, Association*, **47(5)**, 293-298.

LEONAS, K. K. and KUN YU, X. 1992, Deposition patterns on garments during application of lawn and garden chemicals: A comparison of six equipment types. *Archives of Environmental Toxicology*, **23**, 230-234.

POPENDORF, W. 1988, Mechanisms of clothing exposure and dermal dosing during spray application. In Mansdorf, S. Z., Saeger, R., and Nielsen, A. O. (Eds.), *Performance of Protective Clothing: Second Symposium. ASTM STP 989* (Philadelphia, PA: American Society for Testing and Materials). 611-624.

RUCKER M., BRANSON, D., NELSON, C., OLSON, W., SLOCUM and STONE, J. 1988, Farm families' attitudes and practices regarding pesticide application and protective clothing: A five-state comparison. Part 1: Applicator data. *Clothing and Textiles Research Journal*, **6(4)**, 37-46.

RUPA, D. S. REDDY, P.P. and REDDI, O. P. 1991, Reproductive performance in population exposure to pesticides in cotton fields in India. *Environmental Research*, **55(1)**, 123-128.

STONE, J. F., EICHNER, M. L., KIM, C. and KOEHLER, K., 1988, Relationship between clothing and pesticide poisoning . . . Symptoms among Iowa farmers. *Journal of Environmental Health*, **50(4)**, 210-215.

STONE, J., BRANSON, D. H. NELSON, C., OLSEN, W., RUCKER, M. and SLOCUM, A. 1989, *Use and care of clothing worn for pesticide application: A five state survey report.* Fargo: North Dakota State University.

TREMBLAY, J. F. 1989, Evaluation of functional fit and comfort of chemical protective gloves for agricultural workers. Unpublished master's thesis, University of Alberta, Edmonton, Alberta.

URBAIN, C. D. 1988, Chemical handling in the comfort zone. *Farm Journal*, **112(2)**, 12-15.

VE'LEZ-TORRES, B. M. 1993, Development and evaluation of a glove liner prototype for high temperature and high relative humidity environments. *Second International Symposium Proceedings: Consumer Environmental Issues: Safety, Health, Chemicals and Textiles in the Near Environment.* St.Petersburg Beach, FL. 230-242.

TABLES AND FIGURES

Table 1. Overall means and standard deviations of manual dexterity by treatment.

	WITH COOLING		WITHOUT COOLING		WITH LINER		WITHOUT LINER	
PURDUE PEGBOARD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
PREFERENCE	10.03	2.76	11.28	3.33	9.59*	2.97	11.72*	2.90
RIGHT	10.06	2.79	11.38	3.28	9.59*	2.95	11.84*	2.85
LEFT	10.84	2.69	10.44	3.07	9.53*	2.60	11.75*	2.74
BOTH	14.47	4.13	15.28	4.89	12.78*	3.63	16.97*	4.37
RIGHT-LEFT-BOTH	20.88	6.31	20.41	7.55	17.36*	5.08	23.91*	7.01
ASSEMBLY	35.06	8.44	36.81	9.87	31.94*	8.15	39.94*	8.42
MANIPULATIVE APTITUDE TEST								
RODS	10.47	4.25	12.16	4.47	9.90*	3.25	12.72*	4.99
CAPS	10.38	4.35	12.09	4.53	9.84*	3.34	12.63*	5.08
WASHERS & NUTS BOTH	10.84	4.26	12.47	4.55	10.22*	3.31	13.09*	5.00
WASHERS & NUTS LEFT	8.19	3.20	8.06	2.55	7.22*	2.65	9.03*	2.83
WASHERS & NUTS RIGHT	6.66	2.19	6.84	2.05	6.16*	1.72	7.34*	2.31

* Indicates p<.05 for liner treatment

No significant differences found due to cooling treatment.

Mean data given indicates mean numbers of pieces correctly placed in a given time.

Thus, higher means indicate that more pieces were correctly placed.

Table 2. Probability values for main and interaction effects for the comfort data.

	SNUG	HEAVY	STIFF	STICKY	COLD	DAMP	CLINGY	ROUGH	SCRATCHY	OVERALL
Subject	0.0003*	0.0022*	0.0198*	0.0430*	0.0297*	0.0967	0.0076*	0.0130*	0.0661	0.0001*
Cool	0.7671	0.0034*	0.2235	0.1676	0.0001*	0.3066	0.1365	0.3223	0.7290.	0.0654
Liner	0.0081*	0.0207*	0.2235	0.0001*	0.0284*	0.0003*	0.0002*	0.8886	0.2119	0.0464
Cool * Liner	0.8242	0.9271	0.2235	0.2291	0.0661	1.0000.	0.3229	0.0252*	0.5646	0.8311
Subject * Cool * Liner (Error a)										
Time	0.0037*	0.9327	0.8200.	0.0001*	0.0001*	0.0002*	0.0113*	0.0890	0.7004	0.0001*
Subject * Time (Error b)										
Cool * Time	0.3723	0.8596	0.1590	0.9804	0.0001*	0.0016*	0.9175	0.0781	0.6280	0.9505
Subject * Cool * Time (Error c)										
Liner* Time	0.0436*	0.4963	0.4830	0.0005*	0.2429	0.4444	0.9227	0.8452	0.0564	0.5365
Subject * Liner * Time (Error d)										
Cool * Liner * Time	0.6074	0.0271*	0.0677	0.9160	0.6433	0.0478*	0.6471	0.6870	0.1628	0.0472*
Subject * Cool * Liner * Time (Error e)										

* Indicates p<.05 for the liner treatment.
No significant differences found due to cooling treatment.
Mean data given indicates mean numbers of pieces correctly placed in a given time.
Thus, higher means indicate that more pieces were correctly placed.

Figure 5. Mean temperature by location over time.

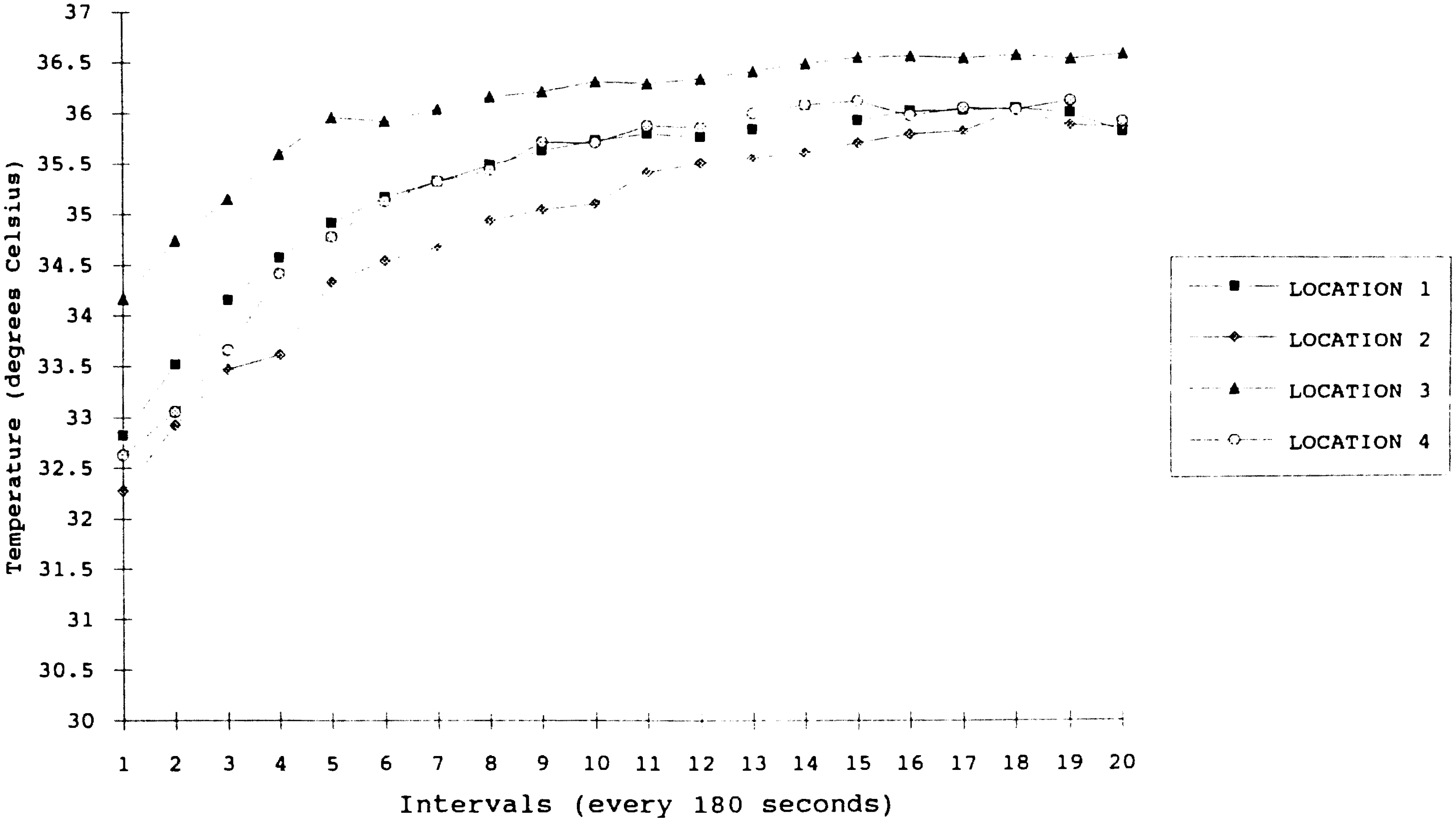


Figure 6. Mean temperature by treatment over time.

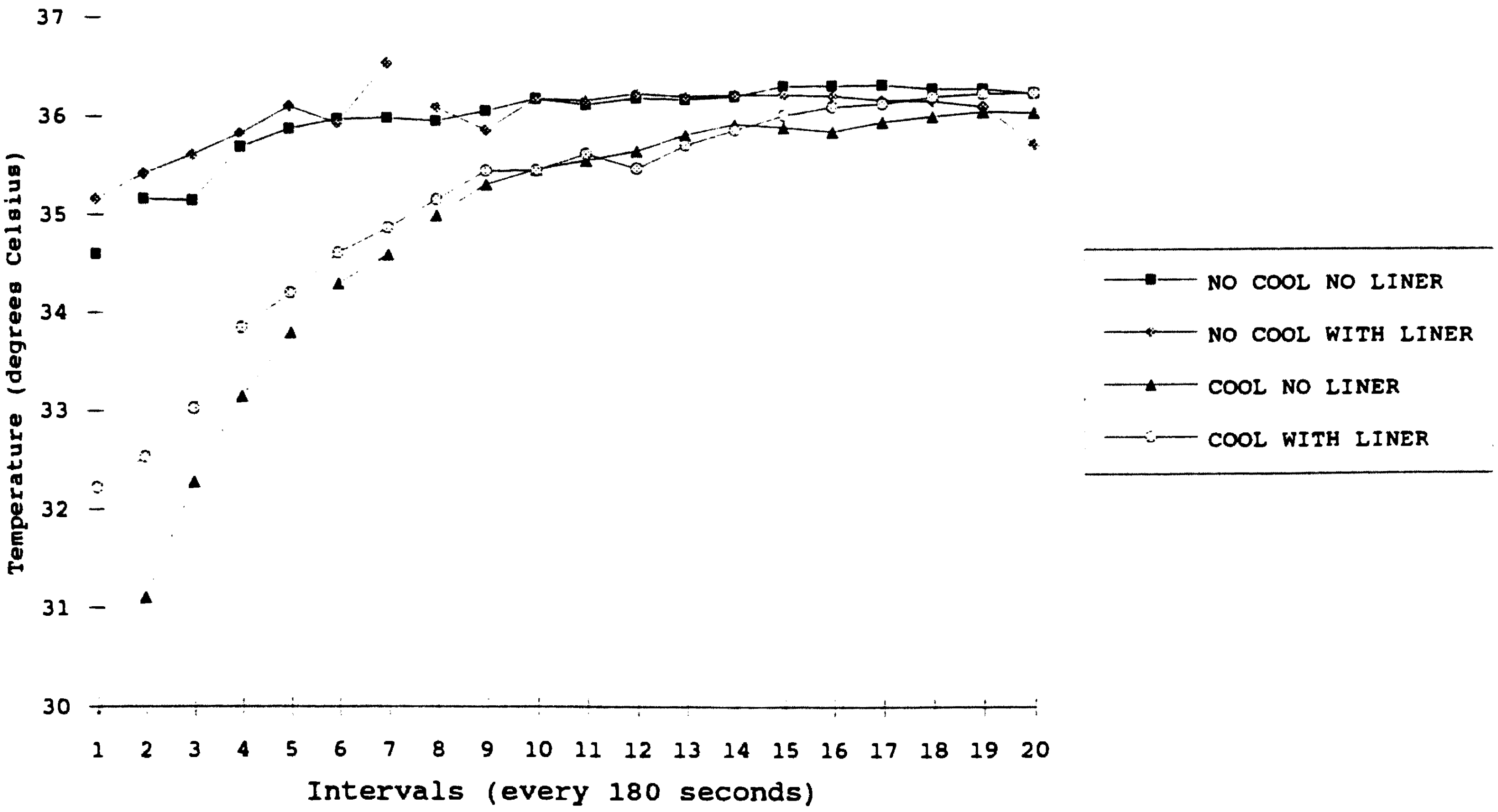


Figure 7. Mean sweat-rate over time.

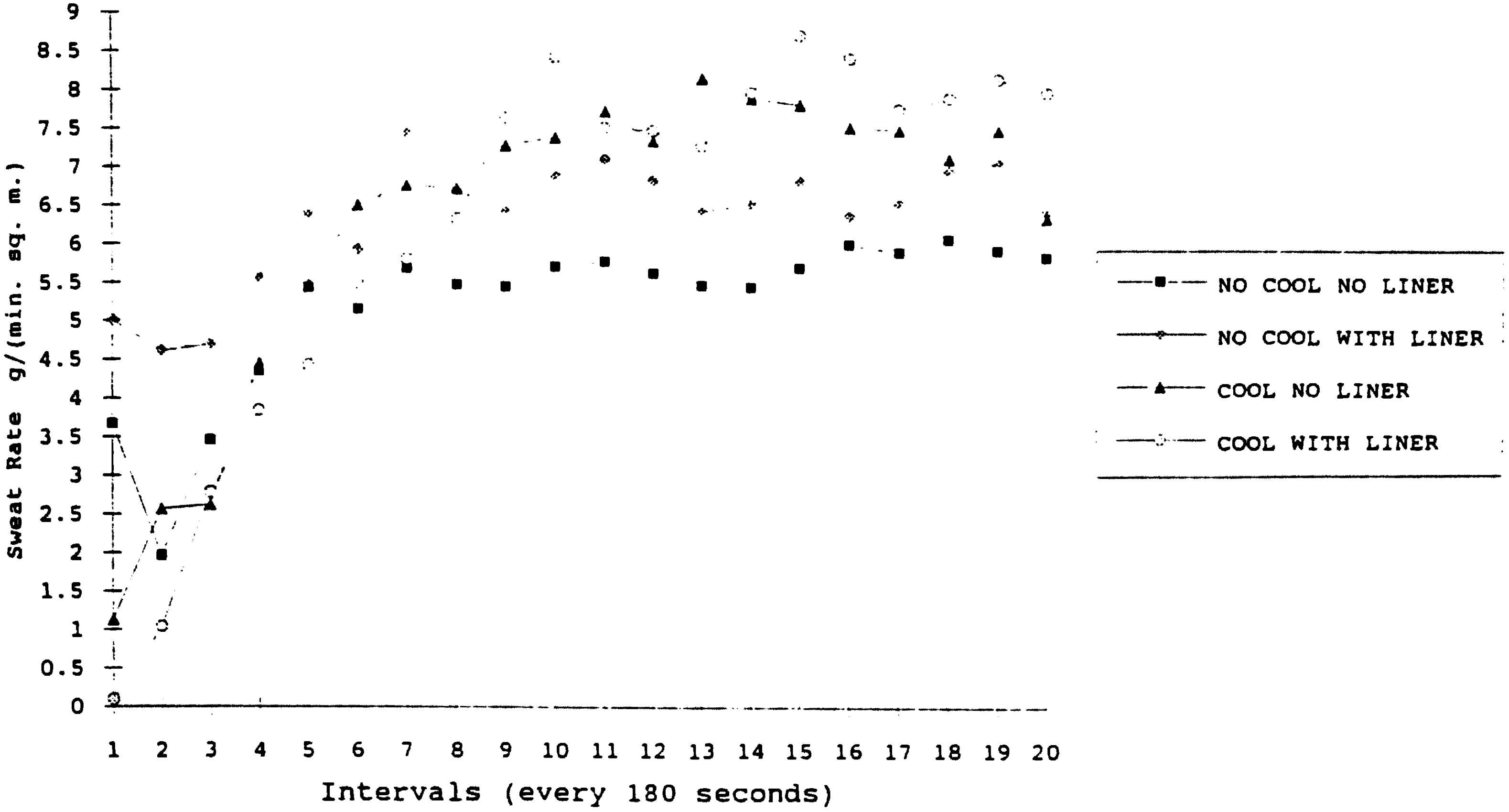
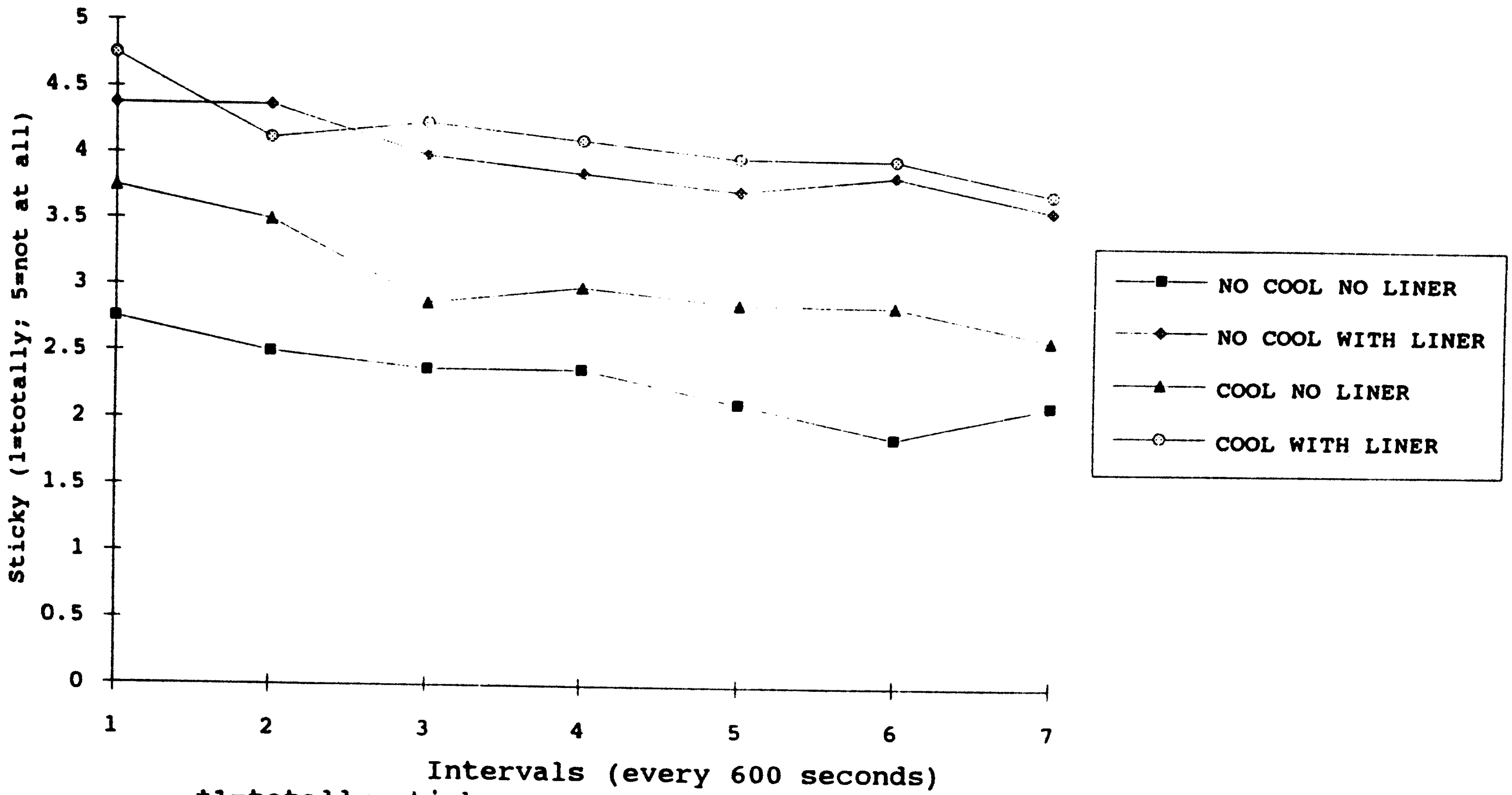
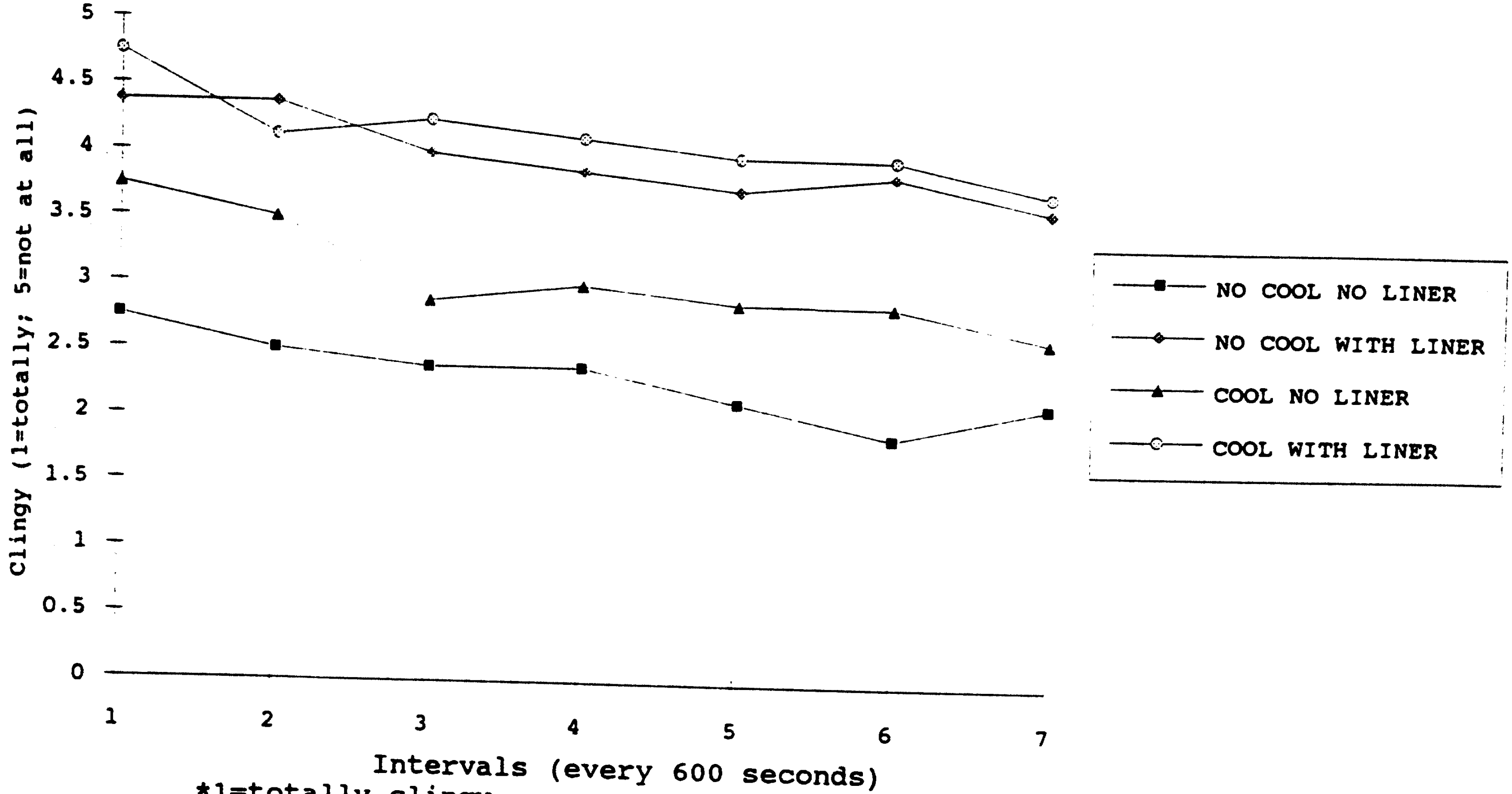


Figure 8. Perceived comfort descriptor-sticky over time.



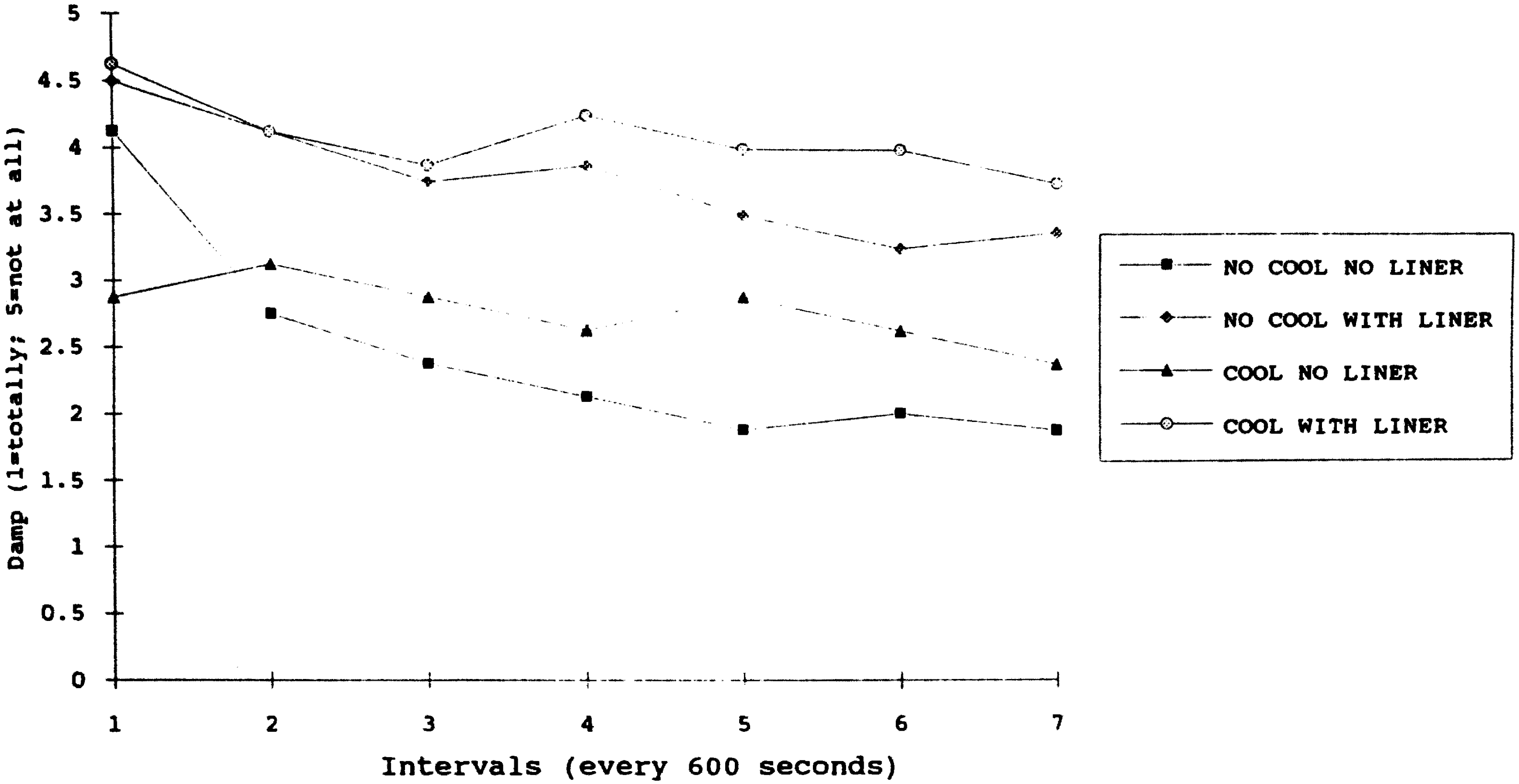
*1=totally sticky

Figure 9. Perceived comfort descriptor-clingy over time.



*1=totally clingy

Figure 10. Perceived comfort descriptor-damp over time.



*1=totally damp

Figure 11. Perceived comfort descriptor-rough over time.

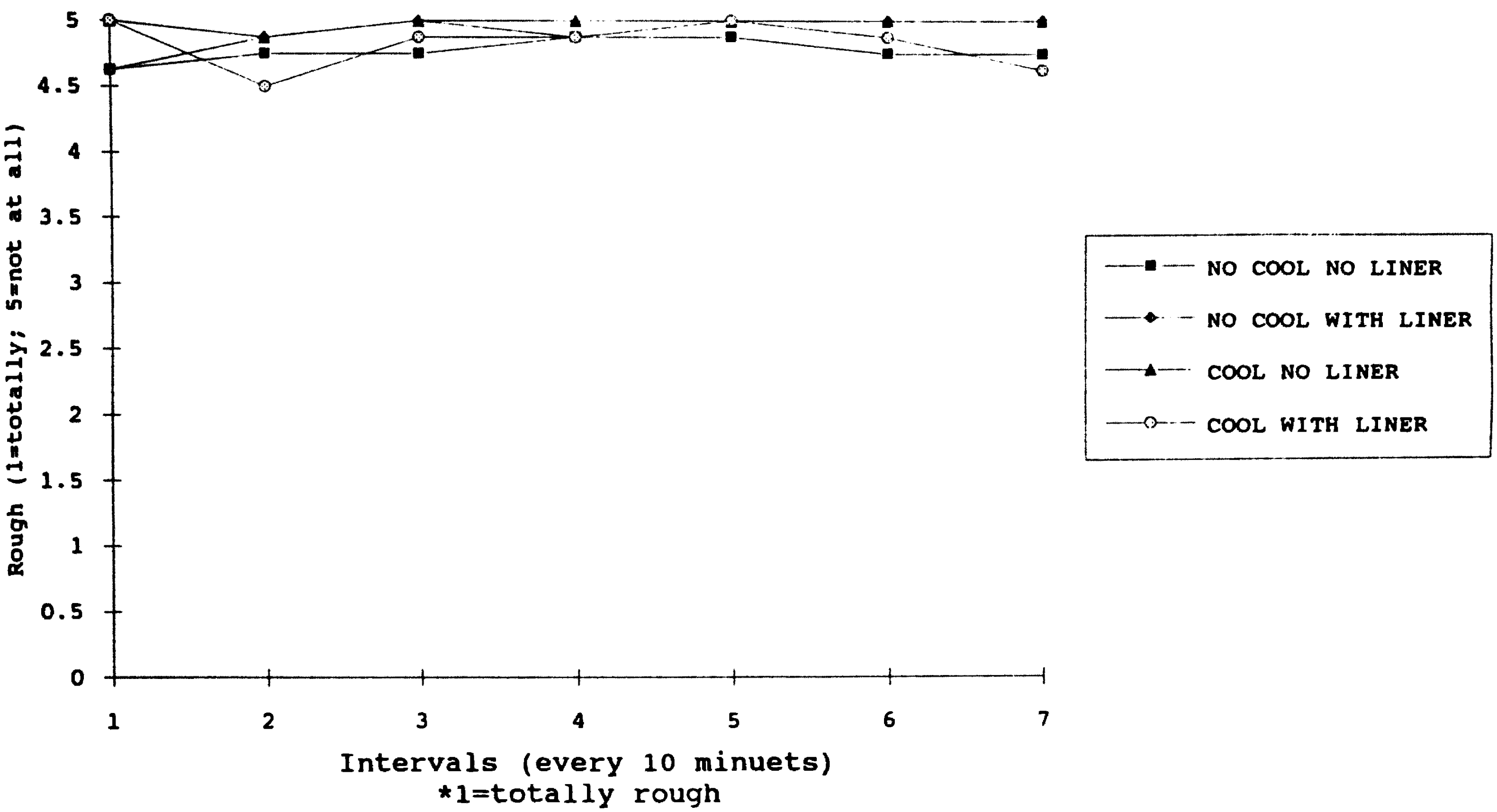
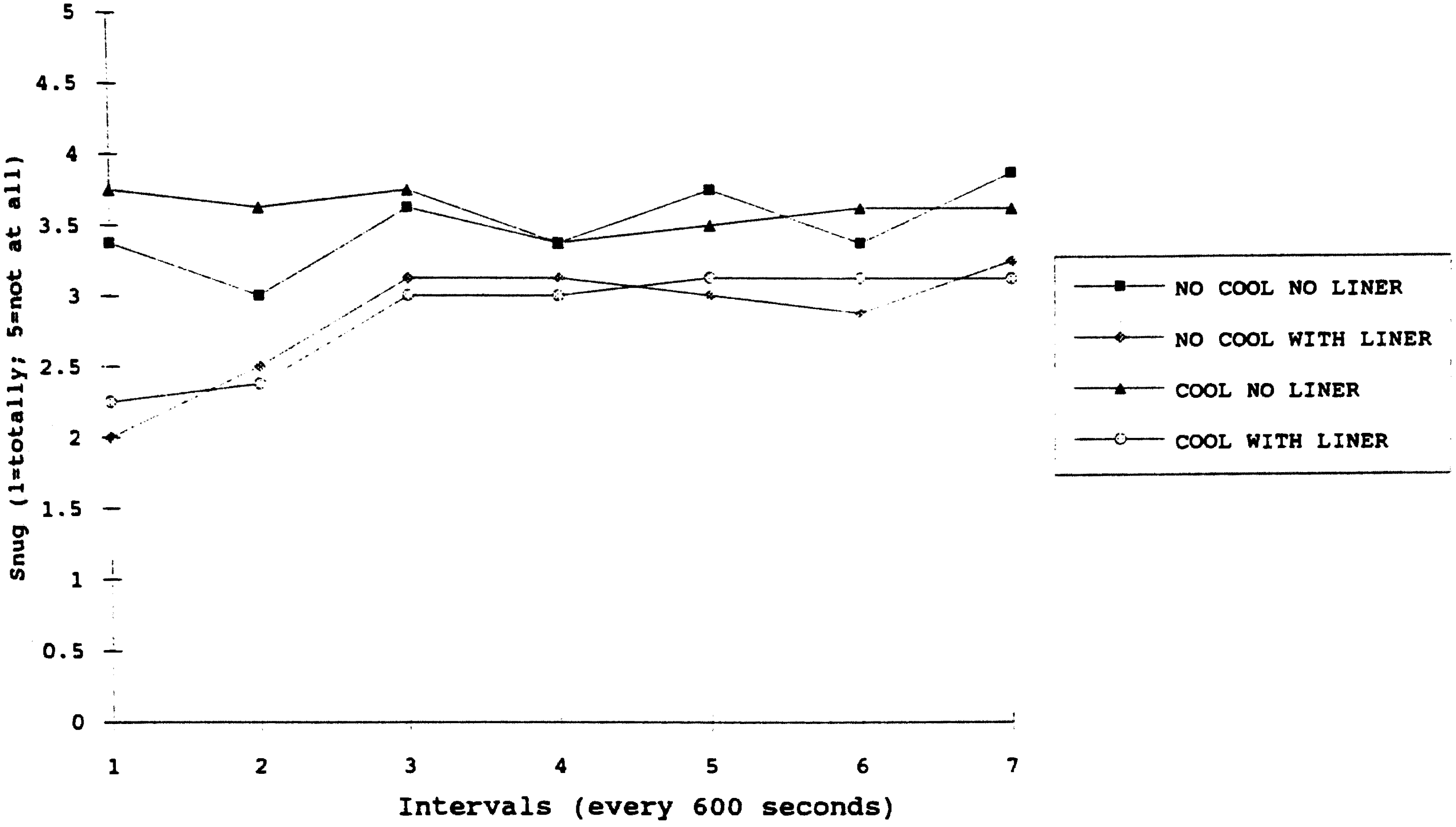


Figure 12. Perceived comfort descriptor-snug over time.



*1=totally snug

Figure 13. Perceived comfort descriptor-heavy over time.

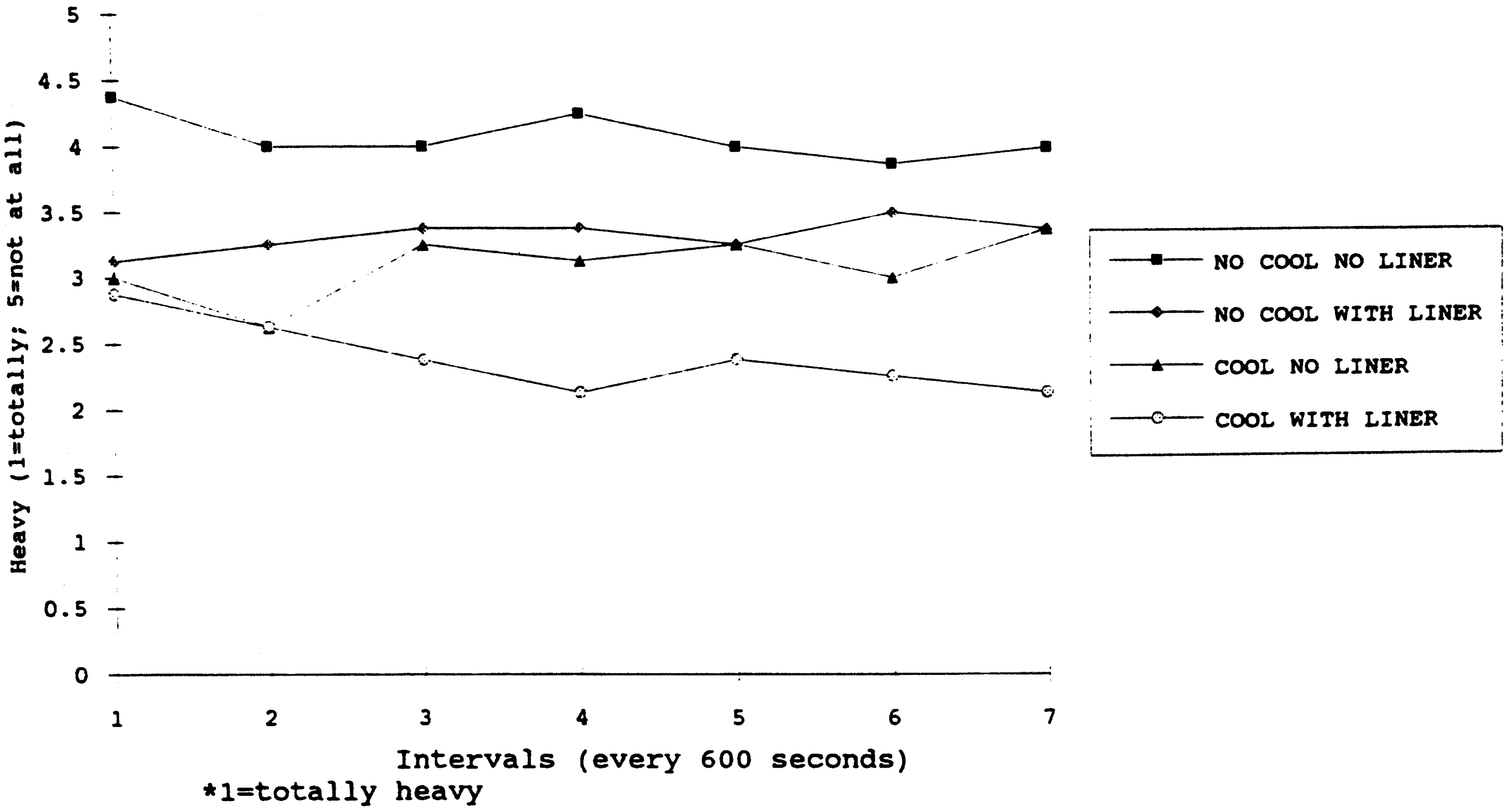


Figure 14. Perceived comfort descriptor-cold over time.

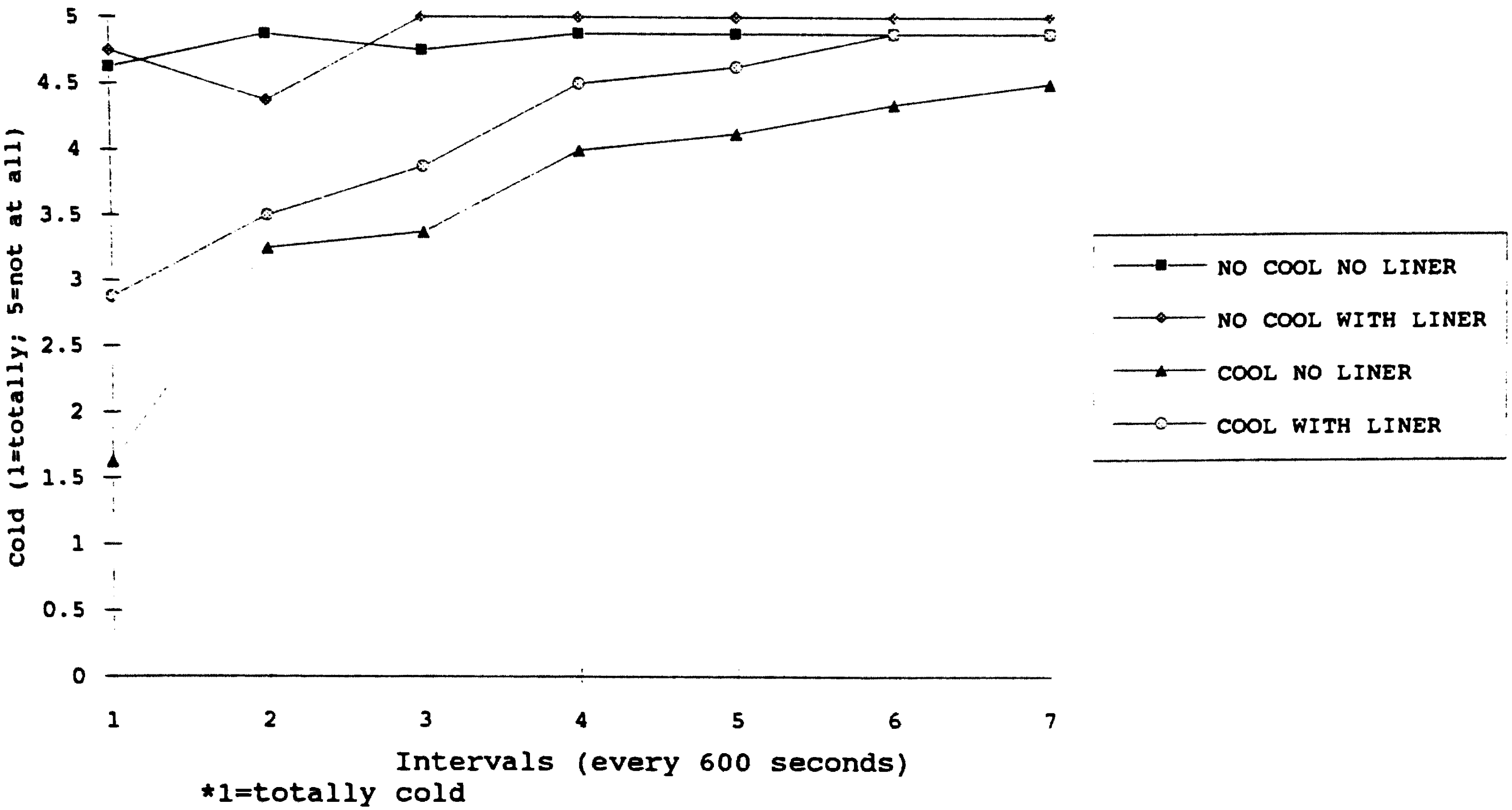
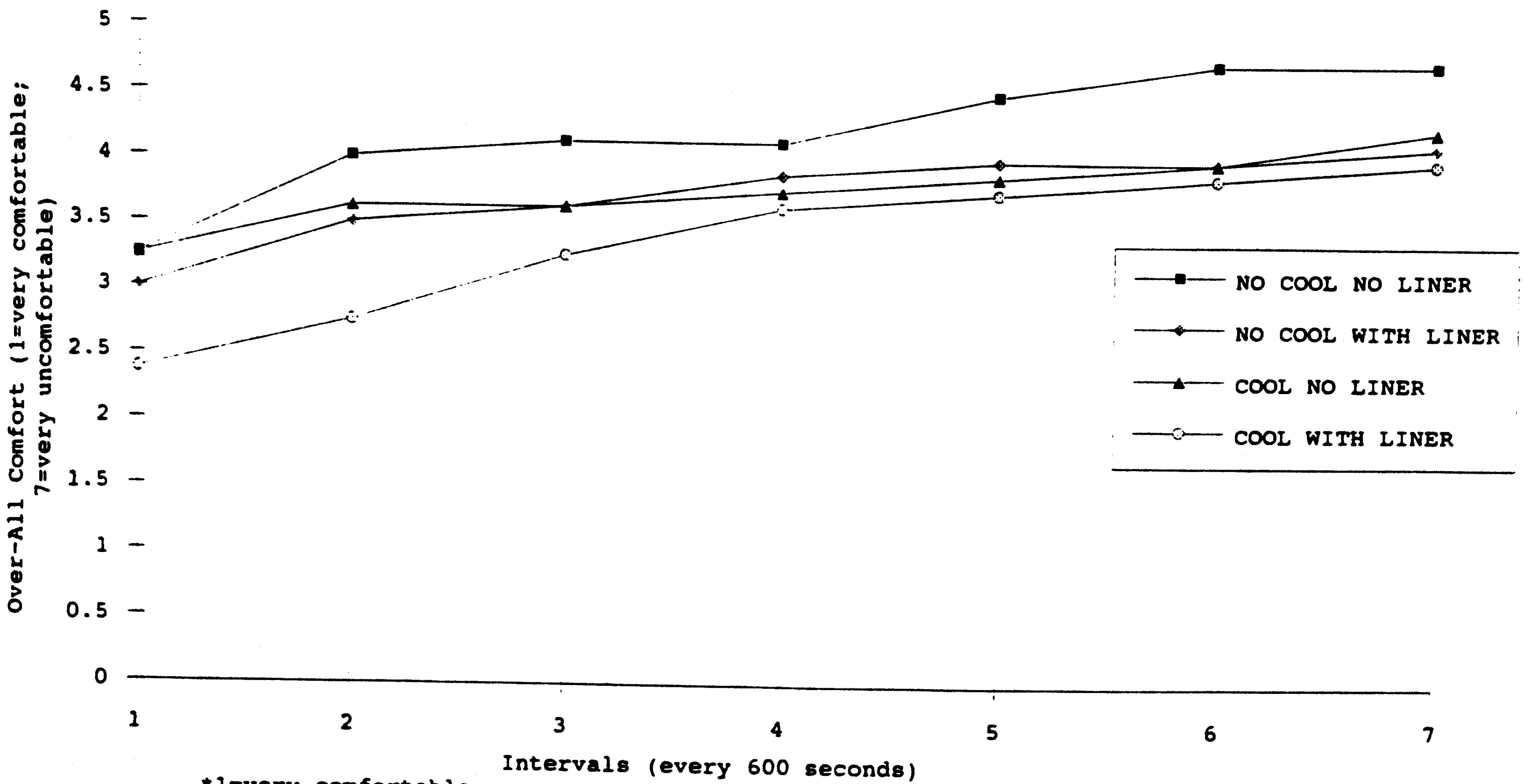


Figure 15. Perception of over-all glove comfort.



*1=very comfortable

CHAPTER V

SUMMARY AND RECOMMENDATIONS

As the need to don personal protective equipment increases, an awareness of the need for development of clothing that does not compromise comfort while providing protection also increases. Dermal exposure while working with pesticides is of great concern (Durham and Wolfe, 1962; Wolfe, Armstrong, and Durham, 1966). Although the reported amount of pesticide deposition on the hand varies dependant upon the work activity, equipment used and the method for determining deposition, there is wide agreement on the need to provide protection to the hands (Bonsall, 1985; Popendorf, 1988; Urbain, 1988; Leonas and Kun Yu, 1992).

Various methods have been employed to increase the time that workers may work in hot environments comfortably via artificially-cooled garments (Kamon, Kenny, Deno, Soto, and Carpenter, 1986; Hansen, 1988; Ve'lez-Torres, 1993). The majority of these attempts have been made via ice, Freon or cooled air circulating vests. Ve'lez-Torres (1993) developed and tested glove liners with proprietary cooling.

The purpose of this research was to refine the concept of providing artificial cooling to chemical protective gloves and to evaluate physical and perceptual data while wearing these components under conditions similarly faced by those working with pesticides.

Objectives outlined for this study included an examination of perceived thermal comfort, sensorial comfort, skin temperature, sweat rate, and manual dexterity performance between subjects while wearing chemical protective gloves with and without artificial cooling and with and without a glove liner. It was hypothesized that if one could develop a chemical protective glove system that provided protection and comfort without hampering manual dexterity, an increase in the usage of chemical protective gloves would occur.

Testing Protocol

The test was performed in the environmental chamber at the College of Human Environmental Sciences in Oklahoma State University during the Spring Semester of 1993. The environmental conditions were maintained at 31 ± .5°C and 78 ± 2% relative humidity. Eight male college students with a mean age of 19 years who responded to an advertisement in the college newspaper and flyers posted on campus served as subjects. A pre-screening process consisting of a short interview and donning of the prototype glove precluded the four test sessions. Subjects were paid $30.00 for their participation.

Testing sessions included a series of manual dexterity tests (Manipulative Aptitude Test and The Purdue Pegboard) and an exercise protocol simulating the actual mixing, loading and application of pesticides with a handheld sprayer. An adaptation of Hollies (1977) perceived comfort ballots were filled out by the subjects at the beginning of each test session and at 6000 second intervals throughout testing. Skin temperature was recorded every 370 seconds via thermocouples taped to the skin at four locations. Sweat rate was monitored on the dorsal side of the nondominate hand via a dew-point hygrometer at 360 seconds intervals.

Conclusions

It was the researchers intent to develop an artificially cooled glove system that would not compromise manual dexterity while increasing the perception of thermal and sensorial comfort. The use of artificial cooling was successful in increasing subjects' perception of overall comfort. As hypothesized, the presence of the cooling treatment decreased subjects' initial skin temperature. Regardless of liner treatment, the cooled glove remained cooler than the uncooled glove for the entire test session.

When comparing over-all comfort with skin temperature, subjects reported a decrease in comfort as skin temperature increased. Interestingly, while skin temperature regardless of treatment, stabilized between 35.9°C and 36.2°C subjects reported an increase in discomfort when both cooling and the liner were not present.

All of the measures of manual dexterity indicated a significant reduction of fine motor skills while wearing the glove liner treatment. Perhaps this occurred due to the bulkiness provided by the seams on the finger tips of the subjects. Tremblay (1989) suggested that tight fitting glove finger tips improves worker performance. The researcher believes finger tip seams compounded with the outer glove layer inhibited subject's ability to feel small components of the dexterity tests therefor decreasing manual dexterity performance.

While the design of the glove liner treatment hampered manual dexterity, it was statistically beneficial in four out of ten of the comfort descriptors.

Recommendations for Further Research

The following recommendations for further research were stated:

1. Continue to investigate the possibility of different glove liner design that would not cover the finger tips.
2. Conduct a similar investigation for a longer period of time.
3. Continue to investigate the possibility of developing a cooling agent with less weight.
4. Conduct a field study in which subjects don prototype glove systems of each type.
5. Conduct a similar investigation using fabrics of various materials for glove liner treatments.

REFERENCES

Allen, D. Sommers, C. E. and Tevis, C. (1986). A picture of pesticide exposure. Successful Farming, 84(1), 16-19.

American Society of Heating Refrigeration and Engineering (1981). ANSI/ASHRAE Standard 55-1981. Thermal environmental conditions for human occupancy, Atlanta, GA: ASHRAE.

Banta, G. R. and Braun, D. E. (1992). Heat strain during at-sea helicopter operations and the effect of passive microclimate cooling. Aviation, Space, and Environmental Medicine, 63(10), 881-890.

Berglund, L. G. (1985). Moisture measurements with a miniature resistance type dew point sensor. Moisture and Humidity: Measurement and Control in Science and Industry. 759-765.

Berglund L. G. and Cunningham, D. J. (1983). Skin wettedness and discomfort estimates from dew point measurements under clothing. Proceedings of Biophysical and Physiological Evaluation of Protective Clothing, Lyon: France, 283-246.

Bensel, C. K. (1993). The effects of various thicknesses of chemical protective gloves on manual dexterity. Ergonomics, 36(6), 687-696.

Bonsall, J. L. (1985). Measurement of occupational exposure to pesticides. In Turnbull, G. J., Sanderson, D. M. and Bonsall, J. L. (Eds.), Occupational Hazards of Pesticide Use (pp. 1-66). Philadelphia, PA: Taylor and Francis, Inc.

Bradley, J. V. (1969a). Effects of gloves on control operation time. Human Factors, 11(1), 13-20.

Bradley, J. V. (1969b). Glove characteristic influencing control manipulability. Human Factors, 11(1), 21-36.

Branson, D. H., DeJonge, J. O. and Munson, D. (1986). Thermal response associated with prototype pesticide protective clothing. Textile Research Journal, 56(1), 27-34.

Leonas, K. K. and Kun Yu, X. (1992). Deposition patterns on garments during application of lawn and garden chemicals: A comparison of six equipment types. Archives of Environmental Contamination and Toxicology, 23(2), 230-234.

Luttgens, K. and Wells, K. F. (1982). Kinesiology Scientific Basis of Human Motion. Philadelphia: Saunders College Publishing.

Markee, N. L., Hatch, K. L., Maibach, H. I., Barker, R. L., Radhakrishnaiah, P. and Woo, S. S. (1990). In vivo cutaneous and perceived comfort response to fabric part IV: Perceived sensations to three experimental garments worn by subjects exercising in hot, humid environment. Textile Research Journal, 60(10), 561-568.

Martini, F. (1992). Fundamentals of Anatomy and Physiology. Englewood Cliffs, New Jersey: Prentice-Hall.

Memmler, R. L. and Wood, D. L. (1987). Structure and Function of the Human Body. Philadelphia: J.B. Lippincott Co.

Montagna, W. (1962). Histological, histochemical, and pharmacological properties. In Montagna, W., Ellis R. A. and Silver, A. F. (Eds.). Advances in Biology of Skin, Vol. 3. (pp. 6-29). New York: Macmillan.

Napier, J. (1980). Hands. New York: Pantheon Books.

Nelson, C., Rucker, M., Olson, W., Branson, D., Slocum, A. and Stone, A. (1988). Farm families' attitudes and practices regarding pesticide application and protective clothing: A five-state comparison Part 2: Launderer data. Clothing and Textiles Research Journal, 7(1), 36-45.

Nielsen, R. and Endrusick, T. L. (1992). Localized temperatures and water vapor pressures within clothing during alternate exercise/rest in the cold. Ergonomics, 35(3), 313-327.

Nunneley, S. A., Antunano, M. J. and Bomalaski,S. H. (1992). Thermal convergence fails to predict heat tolerance limits. Aviation, Space, and Environmental Medicine, 63(10), 886-890.

Olesen, B. W. and Dukes-Dobos, F. N. (1988). International standards for assessing the effect of clothing on heat tolerance and comfort. Performance of Protective Clothing: Second Symposium, AST STP 989, Mansdorf, S. Z. Sager R., and Nielsen, A. P. (Eds.), American Society for Testing and Materials, Philadelphia, pp. 17-30.

Poldolsky, D. M. (1957). The Human Body Skin: The Human Fabric. Washington D.C.: U.S. News Books.

Popendorf, W. (1988). Mechanisms of clothing exposure and dermal dosing during spray application. In Mansdorf, S. Z., Saeger, R., and Nielsen, A. O. (Eds.), Performance of Protective Clothing: Second Symposium. ASTM STP 989 (pp.611-624). Philadelphia, PA: American Society for Testing and Materials.

Ramaswamy, G. N. and Boyd, C. R. (1992). Protective apparel survey of agricultural workers in cotton growing regions. Bulletin of Environmental Contamination, 47(4), 529-535.

Rohles, F. H., Millikin, G. M. and Kristic, I. (1979). The effect of cyclical temperature fluctuations o thermal comfort, Report No. 79-02, Manhattan, Kansas State University Institute for Environmental Research.

Rohles, F. H. and Milliken, G. A. (1981). A scaling procedure for environmental research, presented at the 25th Annual Meeting of the Human Factors Society, Rochester, New York.

Rucker M., Branson, D., Nelson, C., Olson, W., Slocum, A. and Stone, J. (1988). Farm families' attitudes and practices regarding pesticide application and protective clothing: A five-state comparison. Part 1: Applicator data. Clothing and Textiles Research Journal, 6(4), 37-46.

Rupa, D. S. Reddy, P.P. and Reddi, O. P. (1991). Reproductive performance in population exposure to pesticides in cotton fields in India. Environmental Research, 55(1), 123-128.

Sontag, M. S. (1985-86). Comfort dimensions of actual and ideal insulative clothing for older women. Clothing and Textiles Research Journal, 4(1), 10-17.

Stone, J. F., Eichner, M. L., Kim, C. and Koehler, K. (1988). Relationship between clothing and pesticide poisoning . . . Symptoms among Iowa farmers. Journal of Environmental Health, 50(4), 210-215.

Stone, J. F., Branson, D. H. Nelson, C., Olsen, W., Rucker, M. and Slocum, A. (1989). Use and care of clothing worn for pesticide application: A five state survey report. Fargo: North Dakota State University.

Sullivan, P. J. and Mekjavi'c, I. B. (1992). Temperature and humidity within the clothing microenvironment. Aviation, Space, and Environmental Medicine, 63(3), 186-192.

Sweeney, M. M. and Branson, D. H. (1990a). Sensorial comfort Part 1: A psychophysical method for assessing moisture sensation in clothing. Textile Research Journal, 60(7), 371-377.

Sweeney, M. M. and Branson, D. H. (1990b). Sensorial comfort Part II: Magnitude estimation approach for assessing moisture sensation. Textile Research Journal, 60(8), 447-451.

Teicher, W. H., Kobrick, J. L. and Dusek, E. R. (1954). Studies of manual dexterity: I. methodological studies. Headquarters Quartermaster Research and Development Command. (Technical Report EP-3). Massachusetts: Quartermaster Research and Development Center, US Army.

Torii, M., Yamasaki, M., Sasaki, T. and Nakayama, H. (1992). Fall in skin temperature of exercising man. British Journal Sports Medicine, 26(1), 29-32.

Tremblay, J. F. (1989). Evaluation of functional fit and comfort of chemical protective gloves for agricultural workers. Unpublished master's thesis, University of Alberta, Edmonton, Alberta.

Urbain, C. D. (1988). Chemical handling in the comfort zone. Farm Journal, 112(2), 12-15.

Ve'lez-Torres, B. M. (1993). Development and evaluation of a glove liner prototype for high temperature and high humidity environments. Second International Symposium Proceedings: Consumer Environmental Issues: Safety, Health, Chemicals and Textiles in the Near Environment. St. Petersburg Beach, FL. 230-242.

Watkins, S. M. (1984). Clothing the portable environment. Iowa: Iowa State University Press.

Wolfe, H. R., Armstrong, J. F. and Durham, W. F. (1966). Pesticide exposure from concentrate spraying. Archchives Environmental Health, 13(3), 340-344.

Woodcock, A. H. (1962). Moisture transfer in textile systems, part 1. Textile Research Journal, 32(8), 628-633.

APPENDIXES

APPENDIX A

SUBJECTIVE COMFORT RATING CHART

Subjective Comfort Rating Chart (Hollies, 1977)

If you note any of the comfort sensations listed below, circle the appropriate response. Use the following scale: 5-not at all, 4-partially, 3-mildly, 2-definitely, 1-totally, according to the intensity of the sensation.

	RATING				
Snug (Close fitting)	1	2	3	4	5
Heavy (Bulky, thick)	1	2	3	4	5
Stiff (Rigid, not flexible)	1	2	3	4	5
Sticky (Viscous)	1	2	3	4	5
Cold	1	2	3	4	5
Damp (Moist, somewhat wet)	1	2	3	4	5
Clingy (Adhere)	1	2	3	4	5
Rough (Course, not smooth)	1	2	3	4	5
Scratchy (To rub, itching)	1	2	3	4	5

Please indicate how comfortable the glove was overall:

Very Comfortable 1 2 3 4 5 6 7 Very Comfortable

Upon completion of wearing each of the four treatment types please comment on your overall observations.

Adaptation of Hollies, N.R.S. (1977). Psychological scaling in comfort assessment. In N. R. Hollies and R. F. Goldman (Eds.), Clothing Comfort: Interaction of Thermal, Ventilation, Construction and Assessment Factors. (pp. 71-80). Ann Arbor, MI: Ann Arbor Science Publishers, Inc.

APPENDIX B

INFORMED CONSENT

Informed Consent

I, ______________________________, voluntarily agree to participate in this study entitled "Evaluation of An Artificially-Cooled Protective Glove System" in conjunction with the department of Design, Housing and Merchandising, Oklahoma State University.

I understand that the purpose of this study is to test a glove system that will be worn as protection during chemical application.

I understand that I will be participating in four controlled laboratory tests with environmental conditions of 85 ± 2°F and a relative humidity of 78 ± 5%. I understand that the procedure will include garments provided by the researchers. These include: jeans, a long-sleeved shirt, cotton socks, and a baseball cap. I understand that I will be instrumented with four surface temperature thermocouples and one dew-point measurement capsule on the non-dominate hand, and asked to complete 5 comfort ballots throughout each 60 minute session. I understand that I will also participate in the completion of several manual dexterity tests and an exercise protocol that will simulate the mixing, application, and cleaning of chemicals. I understand that the procedure will not involve the handling of pesticides or hazardous chemicals.

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

1) experience in research comfort study
2) knowledge that my input helped improve the acceptability of chemical protective gloves
3) payment of $30.00

I understand that minimal risks are anticipated by the investigators for participants in the study and that records of this study will be kept confidential with respect to any written or verbal reports making it impossible to identify me individually.

I have read this informed consent document. I understand its contents and I freely consent to participate in this study under the conditions described. I understand that there is no penalty if I choose not to participate and that I may withdraw at any time from participation.

I understand that I will receive a copy of this signed consent form.

______________________ Date	______________________________ Signature of Research Subject
______________________ Date	______________________________ Signature of Witness
______________________ Date	______________________________ Signature of Principal Investigator

APPENDIX C

NON-DISCLOSURE AGREEMENT

Non-Disclosure Agreement

Department of Design, Housing and Merchandising
Oklahoma State University
Stillwater, Oklahoma 74078-0337

Dear Subject:

We have developed a novel glove system that is to be worn during pesticide and hazardous chemical application. The clothing design is our confidential, unpublished property, and it will be necessary for you to have knowledge of the design in order for you to test this system.

In consideration of my disclosure of the clothing design to you, it is my understanding that you promise **not to publish or cause to be published** (in whole or in part) or **disclose or cause to be disclosed to others** (in whole or in part) **all or any portion of my glove design**. Further, it is my understanding that you promise to return all clothing to me at the end of each test period and that you promise not to divulge any part of the glove system. Please indicate your acceptance and willingness to comply with this agreement by signing below.

Agreed:

Signature of the Individual	Dr. Donna Branson Department Head

APPENDIX D

EXERCISE PROTOCOL

EXERCISE PROTOCOL

The following exercise protocol was adapted for use from a prior investigation (Ve'lez-Torres, 1990) in order to record skin temperature and sweat rate data during simulated pesticide handler's tasks. The exercise protocol will simulate worker's tasks while mixing, loading, cleaning and spraying with a hand held sprayer.

INSTRUMENTS

- Small hand held sprayer similar to those used in pesticide application
- Two small buckets for simulation of mixing and cleaning

PROCEDURE

The steps to be followed were clearly posted on the walls of the environmental chamber to ensure all subjects completed similar tasks.

ASSEMBLE

- Remove small nozzle from the sprayer.
- Replace with the long nozzle.
- Place small nozzle on the end of the long nozzle.
- Unscrew top off sprayer.
- Simulate pouring bucket of contents into sprayer.
- Screw top back onto sprayer.
- Release handle by pushing down hard and turning to the left.
- Pump the handle 20 times.
- Lock handle into place.
- Squeeze and spray until all pressure is removed.

CLEANING

- Remove top.
- Simulate emptying contents into bucket.
- Simulate filling sprayer with cleaning solution from other bucket.
- Screw top back onto sprayer.
- Shake sprayer 20 times.
- Release handle by pushing down hard and turning to the left.
- Pump the handle 20 times.
- Lock handle into place.
- Squeeze and spray until all pressure is removed.
- Remove top.
- Simulate emptying contents into bucket.
- Replace top.
- Remove long nozzle.
- Replace small nozzle.

APPENDIX E

GLOVE TREATMENT COMPARISONS MADE BY SUBJECTS UPON COMPLETION OF TESTING

GLOVE TREATMENT COMPARISONS

Subject 1
The left hand always seemed better because the tape held it tighter, but all the gloves were loose and didn't let my hands breath so I had an overall sensation of claustrophobia.

Subject 2
The black glove liners were long for my fingers; so were the rubber gloves. I think the gloves would be best if tighter fitting and sized liners. I liked the plain rubber glove with the liner best.

Subject 7
I didn't like the black liner, it made it much more difficult to grasp objects.

Subject 8
Loose should have been a category. Extra space was a problem at the finger tips.

Subject 3
Overall the gloves were fairly snug except for the fingertips which were very loose, which affected my ability to grasp and place the objects. The cooled gloves seemed to make no difference except immediately after they were place on. Within a minute or so I couldn't tell a difference.

Subject 4
The liner helped keep my hands dry, but makes the fingertips too bulky.

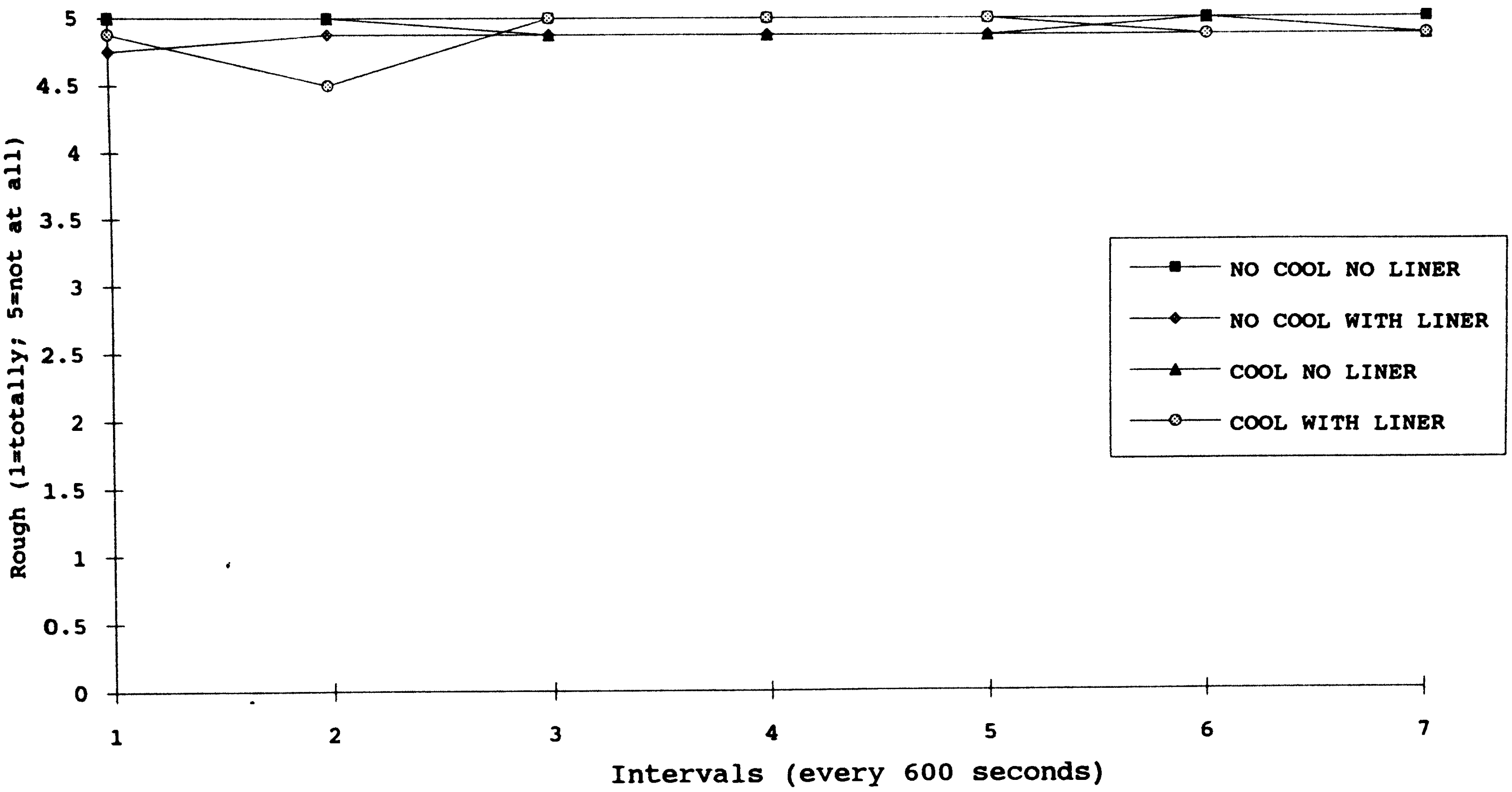
Subject 5 (left handed)
The reason my right hand was better on some of the tests is because the glove was wrapped to my hand.

Subject 6
No comments

APPENDIX F

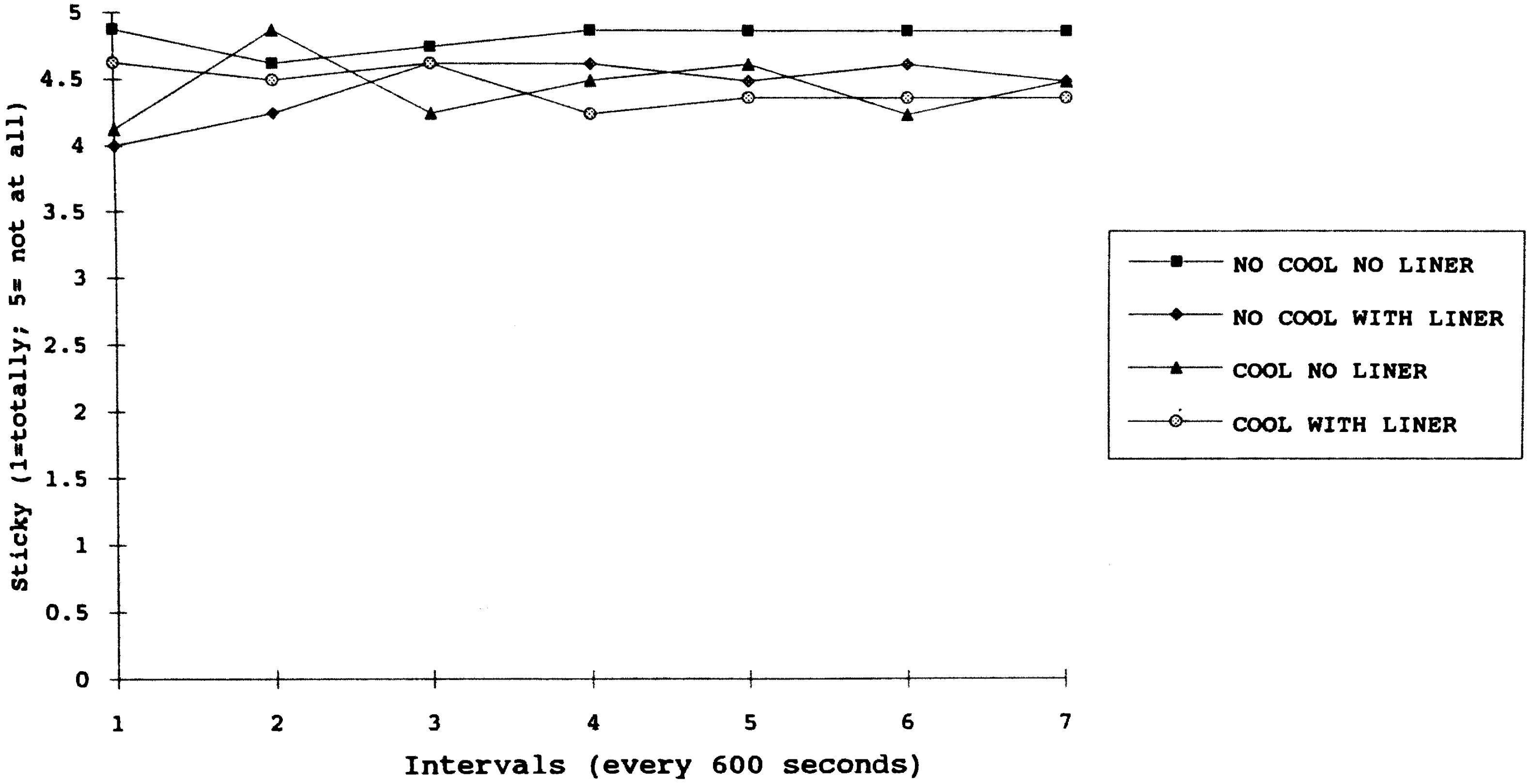
FIGURES

Figure 16. Perceived comfort descriptor-scratchy over time.



*1=totally scratchy

Figure 17. Perceived comfort descriptor-stiff over time.



*1=totally sticky

VITA

LaDawn Stiles Simpson

Candidate for the Degree of

Master of Science

Thesis: EVALUATION OF AN ARTIFICIALLY COOLED CHEMICAL PROTECTIVE GLOVE SYSTEM

Major Field: Design, Housing and Merchandising

Biographical:

Professional Experience: Graduate Research and Teaching Assistant, Department of Design, Housing and Merchandising, Oklahoma State University, Stillwater, Oklahoma.

Education: Received Bachelor of Science in Vocational Home Economics and Community Services from Oklahoma State University, Stillwater, Oklahoma, December, 1991; completed requirements for the Master of Science Degree in Design, Housing and Merchandising, Oklahoma State University, Stillwater, Oklahoma, in May 1994.

Honors: NASA Oklahoma Space Grant Fellowship Recipient. Academic year 1993-1994. Dean's Honor Roll, President's Honor Roll.