DEVELOPMENT AND EVALUATION OF A GLOVE LINER PROTOTYPE FOR HIGH TEMPERATURE AND HIGH RELATIVE HUMIDITY ENVIRONMENTS

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CHAPTER I

INTRODUCTION

During the past twenty years, pesticide use has greatly increased, thus helping farmers to increase production and to improve quality of products in agriculture (Stone, Branson, Nelson, Olson, Rucker & Slocum, 1989). This increase of pesticide use has also been related to environmental and health concerns; and, it should be highly related to clothing precautions. When the appropriate clothing precautions are taken, exposure to pesticide chemicals can be greatly reduced. There is limited information on governmental regulations that include clothing recommendations for workers exposed to these hazardous chemicals.

The climatic conditions in which workers are exposed to pesticide chemicals are often high temperature and high relative humidity. These conditions affect the clothing decisions made by agricultural workers. When high temperatures are combined with high relative humidity, evaporation of sweat is impeded and thermal discomfort is likely to occur. If these conditions are also combined with non-breathable protective clothing, heat stress is a probability and the results can be fatal. An important factor in reducing pesticide chemical exposure is to produce chemical resistant and comfortable chemical protective clothing that meets users' needs of convenience, comfort and self-assurance (Tremblay, 1989; Branson & Sweeney, 1991).

The use of chemical protective clothing that protects against dermal exposure to pesticides is vital for those working with pesticides on a daily basis. The hazards related to the use of pesticides depend on the extent of exposure, formulation, concentration and amount of the pesticide used, the application method, and the personal protection adopted (Waldron, 1985). In circumstances where the use of hazardous chemicals is involved, hands are the most likely point of contact with the chemicals (Grover, Cessna, Muir, Riedel & Franklin, 1988). Studies show that the hands receive 20% to 97% of the total body exposure (Bonsall, 1985; Popendorf, 1988; Grover et al., 1988). Personal protective gloves might be the worker's only defense against injuries or illnesses associated with chemical exposure (Mansdorf, 1987). Further, hands can be an indirect carrier of pesticide chemical residues to the digestive and respiratory systems.

Although dermal exposure to the hands is a significant problem, many of those who work with pesticides do not wear protective gloves. A survey conducted on attitudes and practices of farm families related to pesticides and work clothing stated that only 37% of the farmers reported using some kind of protective gloves (Branson & Sweeney, 1991). Some of the reasons given for not using gloves are poor dexterity and sweat build-up within the glove. Wet skin absorbs chemicals more readily, thus increasing the risk associated with dermal exposure (Zimmerer, Lawson & Calvert, 1986). Further, wet hands are more susceptible to dermatological problems such as abrasion, friction and microbial growth (Zimmerer et al., 1986). According to the 1980s Bureau of Labor Statistics, "skin diseases account for almost half of all occupational illnesses" (Wood & Guarhieri, 1991). The use of chemical protective gloves is a way to provide a barrier between the skin and hazardous chemicals (Slocum et al., 1988) but the serious problem of sweat build-up inside the gloves needs to be resolved.

The design of chemical protective gloves is a compromise between protection, comfort and dexterity. Artificial cooling devices may be one way to increase wearability of chemical protective handwear. Artificial cooling may increase comfort in high temperatures and high humidity environments without decreasing protection against pesticide chemicals.

Statement of the Problem

The purpose of this investigation is to develop and evaluate a prototype glove liner that provides improved dexterity and thermal comfort properties for those wearing chemical protective gloves while working in high temperature and relative humidity environments.

Objectives

The following objectives were established:

1. To develop an artificially-cooled glove liner prototype that provides increased thermal comfort and dexterity when worn under chemical protective gloves.
2. To compare subjects' perceived comfort (thermal and sensorial) and skin temperature between the gloved hand without artificial cooling and

the gloved hand with artificial cooling while performing tasks in a high temperature and relative humidity environment.

3. To compare subjects' dexterity between the gloved hand without artificial cooling and the gloved hand with artificial cooling while performing manual dexterity tasks at a high temperature and relative humidity environments.

4. To compare pre and post weights of the glove conditions.

Hypotheses

The following null hypotheses were stated:

1. There is no significant difference in perceived thermal and sensorial comfort between the gloved hand with liner without cooling device and the gloved hand with liner with cooling device.
2. There is no significant difference in terms of dexterity between the gloved hand with liner without cooling device and the gloved hand with liner with cooling device.
3. There is no significant difference in skin temperature between the gloved hand with liner without cooling device and the gloved hand with liner with cooling device.
4. There is no significant difference in the amount of sweat build-up within the glove liner between the gloved hand with liner without cooling device and the gloved hand with liner with cooling device.

Definition of Terms

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

Clothing Comfort: A state of satisfaction indicating physiological, social-psychological and physical balance among a person, his/her clothing, and his/her environment (Branson & Sweeney, 1991).

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

Thermal Comfort: Condition of mind which expresses satisfaction with the thermal environment (ASHRAE, 1981).

Limitations

The author will limit the study to the following:

1. Ten male college students between the ages of 18 to 25 who fit size 10 of the selected chemical protective glove system.
2. The selected currently available chemical protective glove system (a PE/PVAE/PE laminate pancake inner glove and a soft nitrile disposable outer glove).
3. Environmental temperature and relative humidity conditions that simulate a typical Oklahoma summer day will be specified within ±2°C of temperature and ±5% of relative humidity.

Assumptions

The study will assume the following:

1. Subjects will perform manual dexterity tasks to the best of their ability.
2. Surface thermistors from Yellow Springs Instrument Co., Inc. will measure temperature within a range of ±0.1°C as per manufacturer specifications.

CHAPTER II

REVIEW OF LITERATURE

Human Thermoregulation

An essential function of the human body is to safely control core temperature by balancing metabolic heat production in the body and heat dissipation to the environment. The well being of the human body depends on the heat exchange between the body and the environment. "In order to maintain a constant internal body temperature the organism must balance its rate of heat dissipation against its heat gain from metabolism plus any heat gain from the environment by radiation, convection, and conduction." (Newburgh, 1949, p.193) This exchange should occur within limits of tolerance for heating or cooling the body (Fourt & Hollies, 1970).

Temperature regulation in humans depends on central nervous system controls. Different receptors in the human body send messages that are integrated in the central nervous system. The central nervous system activates the appropriate mechanisms to alter temperature when a situation of imbalance occurs (Rueschhoff, 1982). There are three temperature regulation mechanisms:

peripheral temperature receptors located in the skin, central temperature receptors found particularly in the hypothalamus in the mid brain and in other parts of the brain, and in the spinal cord. The peripheral receptors fall into two groups, those that initiate nerve impulses under cold conditions and those that do so under warm conditions (Ross, 1982; Sharkey, 1984). Regulation of body temperatures is a compromise to maintain steady temperatures. This process will permit correct functioning of all body parts. Different parts of the body function at different temperatures. During thermal equilibrium, the core, which consists of about two thirds of the whole body including the heart, lungs, abdominal organs, and the brain, functions at a more constant temperature than any other part of the body. The core normal temperature should be in the range of 98°F to 98.6°F. Rectal temperature is commonly 0.6 to 1 degree higher. Skin temperature will fluctuate depending on the environmental temperature within normal limits of tolerance in order to maintain balanced core temperatures (Ross, 1982; Newburgh, 1949). Areas with variable temperatures are regulated but not at a uniform level. The skin is the organ in the body that is in contact with the environment; therefore, it plays an important role in temperature regulation. "Skin temperature, in contrast to the core temperature, rises and falls with the temperature of the surroundings. This is the temperature that is important when we refer to the ability of the skin to loose heat to the surroundings." (Jensen, 1980, p.797)

The changes in temperature in the environment affect the behavior of our body systems during temperature regulation (Jensen, 1980). Temperature, relative humidity/moisture content of the air, air movement, and radiant heat are the four characteristics to take into consideration when describing the environment. Measurements of these environmental characteristics are needed in following the flow of energy from the body to the environment or the reverse.

Energy transfer can occur by each of four main routes: conduction, convection, radiation, and evaporation (Fourt & Hollies, 1970). Conduction and convection involve direct heat transfer to the material that is in direct contact with the body. Radiation contributes to the relation of heat transfer between the body and its environmental surroundings. Evaporation is the heat transfer mechanism that is more important in cooling the body (Ross, 1982).

Conduction

Conduction occurs when heat flows through a medium without the physical exchange of molecules in materials. This heat transfer mechanism occurs mostly in solids when heat is conducted from within the human body to the skin surface and from the skin into any cooler objects with which the body may be in contact. The heat exchange occurs until both surfaces seem to be at the same temperature (Newburgh, 1949; Watkins, 1984).

Convection

This heat transfer mechanism refers to the exchange of heat between hot and cold objects by the physical transfer of the liquid or gas molecules with which the objects are in contact. It depends upon the existence of a fluid medium between the warm and cold objects and upon the actual streaming movement of warm molecules from the warm object to the cooler one. There are two types of convection, forced and natural convection. Natural convection decreases when forced convection increases. When air temperature is higher than skin temperature, heat is gained in the body from the environment by convection (Goldman, 1977). Forced convection results from air or liquid streams generated by outside forces or by the movement of the body through the medium. The relative velocity of the air stream with respect to the warm skin or clothing is the added variable which is introduced when one considers forced convection rather than natural convection (Newburgh, 1949).

Evaporation

Evaporation takes place at the skin surface, the liquid sweat passing into the vapor stage at about skin temperature and finally passing into the environment to cool and to expand to the saturation of the environment (Newburgh, 1949). Evaporation of sweat is the main mechanism of the human body to regulate and cool body temperatures under high environmental temperature conditions. Evaporation takes place from the lungs, respiratory and oral passages and skin (sweat and insensible perspiration). Almost 25% of the metabolic heat is carried away from the body by the water evaporated from the skin and lungs. The rest is lost by conduction, convection, and radiation (Ross, 1982). Insensible perspiration is initiated in the skin surface at 95°F. Vapor pressure and humidity play an important role in evaporation. At high relative humidity, evaporation is harder if not impossible (Goldman, 1977; Ross, 1982; Newburgh, 1949). When high temperature and high humidity environmental conditions are present the rate of moisture intake by the air limits cooling by evaporation. At extremely high relative humidity levels, the air is saturated with moisture and evaporation becomes almost impossible. The skin then becomes wet and feeling of discomfort occurs. "The amount of sweat wasted in this way is particularly great in work and increases as the rate of work and metabolism are increased" (Newburgh, 1949, p.201). Direct transfer of heat and evaporation becomes insufficient or impossible if the temperature of the environment combined with relative humidity rises above allowable upper limit of mean surface temperature. Indirect transfer of heat energy is still possible if the environment is able to accept water vapor and the heat can be evaporated from the body to the environment (Newburgh, 1949; Ross, 1982).

Emotional Responses

Human stress, anxiety, and other psychological states can influence and activate the nervous system in addition to metabolism. These psychological states can increase sweat rate and heat loss/heat gain in the body. These psychological states of the human being are difficult to measure because unpredictable factors due to the different responses of each individual for similar or equal situations have to be taken into consideration. Personal, psychological and physical problems and necessities will influence what workers wear in a certain job situation. Blood vessels of the skin, particularly those of the face, hands and feet, undergo a wide variety of responses to emotions (Ross, 1982). Emotions are linked in a non-explicable way to vasodilation/vasoconstriction of blood vessels of the skin. When an individual is anxious sweat appears on the skin surface of the face, hands and feet. This loss of heat through the face and the extremities is not linked to environmental changes but to psychological changes. It is stated by Ross (1982) that emotions and temperature regulation are intimately involved with the hypothalamus. Responses of our organism to certain situations are involved with activities of the nervous system. This link between the emotions and the body functions is not yet completely explained by physiology.

Blood Flow

The main function of the circulation of blood through the skin is to participate in regulation of body temperature. If temperature changes, a change in blood flow also occurs bringing greater or lesser amounts of blood to the surface of the skin. This phenomenon can be accomplished by an increase or decrease in the rate of blood flow or the volume of the blood flow to the outer surface (Watkins, 1984). Blood from the interior of the body is circulated close to the external surface or skin through a series of tubes that greatly increase the surface area available for conduction, convection, radiation, or evaporation of heat. In some exposed parts of the skin such as palms, fingers, soles, toes, ears, and nose, anastomoses or connection of blood vessels is present. When open, these vessels permit blood flow directly to the surface of the skin influencing insulating properties. When the vessels are dilated (vasodilation), the vessels' insulating power is reduced, facilitating heat loss (Ross, 1982; Jensen, 1980). Exposure of the body to high temperatures causes a greater increase of cutaneous blood flow.

Heat and Metabolism

Heat is a product of metabolism. Heat production increases at high air temperatures, high relative humidity, high radiant heat, when in contact with hot objects and when induced by physical exercise (Ross, 1982). Metabolic energy appears as heat to maintain basal metabolic conditions when no work is done. During physical exercise more than 75% of the increased metabolism appears as heat within the body, while the remainder of energy is converted to work (Newburgh, 1949).

Since heat is continually produced within our body at different rates, heat flow from the body to the environment must adapt to the heat production by the body's own temperature-regulating system. At high environmental temperatures, metabolism in the peripheral tissues increases as the skin temperature rises to approach that of the core. Evaporation increases with increased dilation of vessels in the skin (Ross, 1982). The quantity of heat loss to the environment by sweating depends on the rate at which water is secreted by the sweat glands and on the ability of the ambient environment to remove water vapor (Jensen, 1980). Regulatory adjustments of metabolism are relatively small in hot environments compared with the high metabolic rates produced when warming the body (Newburgh, 1949). As long as a balance is maintained by adaptation of heat loss to heat production, a steady-state of heat content in the body can be kept. If, however, heat loss is higher than heat production (or vice versa), the heat content of the body decreases (or increases). Such conditions can be maintained only for certain tolerance periods until a dangerous state of either hypothermia or hyperthermia will be reached (Hollies & Goldman, 1977).

Heat stress is an important factor in many work places due to environmental conditions, work demands and clothing requirements (Bernard et al., 1991). Heat stress problems include worker fatigue, poor decision making, poor worker safety, short work periods, and low productivity. "Heat has the potential to decrease worker productivity; at the most extreme it can kill. But for most workers heat is a source of discomfort which simply causes exhaustion at a more rapid rate than normal. For these reasons, workers must have a way to control body temperature when working in hot environments." (Vaughan, 1991, p.20)

Influence of Clothing on Thermoregulation

The amount of heat produced by an individual in a given environment must be considered in determining whether or not the individual will be comfortable. Four thermal factors in the ambient environment which affect our comfort or discomfort in clothing are ambient air, ambient vapor pressure, wind velocity and thermal radiation (Hollies & Goldman, 1977). An important characteristic in thermal comfort is whether the heat exchange allowed by the clothing between the skin surface and the ambient environment is reasonably matched to the heat that is produced by the individual (Hollies & Goldman, 1977).

Balancing heat produced and heat loss to the environment is modified by the intervention of clothing. Clothing can be considered both: part of the environment and an extension of the self. The general functional properties of clothing are thermal insulation, resistance to evaporation, and resistance to wind penetration (Fourt & Hollies, 1970). Based on one of the theories of clothing, the selection of clothing depends greatly on the basic need of protection from the adversities of the environment. One of the first reactions to the relationship of hot environment and clothing will be opening closures for ventilation. If a piece of clothing causes discomfort the natural inclination is not to wear it (Hollies & Goldman, 1977); therefore, heat and comfort are highly related. Also, the weight and friction of heavy clothing can hamper body movements considerably when a person is performing violent exercise (Newburgh, 1949). Clothing can also prevent the processes of convection and evaporation of heat to the environment. The layer of air near the skin can become saturated at high temperatures and high relative humidity environments retarding evaporation and impeding the convection of heat to the environment. In environments where healthy evaporation and convection of heat are impeded there is a necessity for clothing that will increase heat loss artificially in order to save, in extreme cases, a person from hyperthermia.

Perceived thermal comfort and discomfort responses depend upon the interactions between physical, physiological and psychological stimuli and the stored modifiers of each person, both conscious and subconscious (Pontrelli, 1977). Stored modifiers are described by G.J. Pontrelli (1977) as the individual's screening process when decoding a stimuli. The stored modifiers include past experiences, prejudices, expectations, imagery, and life style. A clothing system will get a favorable comfort response from the wearer if the "garment is properly tailored, the fabric satisfies the garment requirements, the environment does not cause undue stress and, finally the subject has a positive emotional state" (Pontrelli, 1977, p.73).

Hands

The presence of contaminants in the work environment can lead to skin related diseases. According to the 1980s Bureau of Labor Statistics, skin diseases accounted for almost half of all occupational illnesses (Mansdorf, 1987). Many researchers have shown that the use of chemical protective clothing is necessary in hazardous environments (Branson & Sweeney, 1991; Stone et al., 1989). In agriculture the use of pesticides is necessary for the protection of crops against insects and plagues. The concentration of hazardous chemicals in the pesticides is dangerous for human health. Many studies have researched exposure to pesticides and penetration of chemicals through clothing. Limited research investigated pesticide penetration to the skin (Hoar, et al., 1986). The penetration of chemicals to the skin can lead to fatal injuries and skin cancer by inhalation and ingestion (Wolfe, 1974). Of all body parts, the hands receive 20% to 97% of the total exposure (Bonsall, 1985; Popendorf, 1988; Grover et al., 1988).

The hands have a special place and function in our biological system. They are vehicles for the sensory as well as the motor systems. The way we move or use our hands is a form of non-verbal communication in which we express and communicate our thoughts and feelings.

Many jobs include some kind of hand manipulation. Many tasks, especially those which include hand manipulation of some sort and the presence of dangerous substances require some kind of handwear that will protect the hands against harmful climatic and physical situations. Farmers when dealing with pesticides, Army, NASA and other military personnel when performing missions that involve any kind of hand maneuvers (machine and weapon operators) are some examples.

In some cases hands respond to an increased in temperature in other parts of the body. This reflex causes vasodilation in the cutaneous hand area. When vasodilation occurs at high environmental temperatures the extremities (especially the hands and the feet) are as warm or warmer than, the proximal surfaces. According to Newburgh (1949), "for comfort conditions the average skin temperature of the fingers is 84°F." (p.379)

Cooling Devices

There is an extensive amount of research done on protective handwear, but none assessed the problem of comfort by using artificial cooling devices. The hands during manipulations related to the use of chemicals at high temperature and relative humidity environments can be the subject of exercise perspiration and sweat. The increase of wetness in the skin of the hand can result in abrasion and friction that can induce fatigue to the hand and forearm muscles. Cooling can be an auxiliary means of improving thermal comfort when high skin temperature and high relative humidity are present. Vaughan (1991) in his article about cooling systems explained that cooled protective clothing have provided a higher degree of safety, efficiency and comfort to wearers in high temperature environments. According to Bernard et al. (1991, p.4), "the performance of a personal cooling system is the ability of the system to reduce or manage physiological strain during exposure to heat stress."

Tests done by the Mine Safety Appliances Company (MSA) at University of South Florida in Tampa, Florida demonstrated that the use of cooling devices such as air vests, ice vests, liquid vests and liquid cooling garments increased the productivity and efficiency of workers between 30% and 200% (Bernard et al., 1991). When temperature rises due to a faster metabolic rate the inner core temperature goes up and there is danger of heat stress. Maintaining safe core temperatures is vital for workers that are exposed to high temperature environments while working. Heat stress can occur under many conditions while wearing non-breathable clothing as well as wearing regular clothing. In industries that involve working under high temperature environments, heat stress is usually controlled by regulating work time and rest periods or by the use of personal cooling devices. These time regulations will increase labor costs and will mean delays in accomplishing the work. On the other hand, when incorporating personal cooling devices to clothing productivity can be greatly increased while protecting the wearer (Bernard et al., 1991). ILC Dover, Exotemp, Ltd., and KT Corporation have also developed and advertise testing results on cooling equipment (Hughes, 1991; Koslow, 1991; Vaughan, 1991). ILC Dover has a "Cool Vest" that was first introduced to the market in 1973 and is currently being tested by military personnel. Other cooling equipment by this company consists in an Ice Pack Vest and the Comfort Vest. The Exotemp, Ltd.'s CD2 cooling system shirt worn under chemical protective warfare suits was used by Canadian helicopter pilots during the Persian Gulf war allowing them and other crew members to fly three times longer than when the shirt was not present (Hughes, 1991). KT Corporation has a Microclimate Cooling Unit that has been used by military personnel during warfare situations. None of these companies include in their advertisements any kind of cooling equipment to protect the hands. Branson & Sweeney (1987) found ambient air supplied via a modified cooling vest provided minimal advantage for hands when wearing chemical protective gloves.

Some of the cooling mechanisms now being used are air cooling, ice cooling and liquid cooling (Bernard et al., 1991). Air cooling involves a circulating air system that allows breathing grade cool air to circulate around the body under the clothing and then vent out through the cuffs or special vents. The air cooling mechanism can also be used with heated or ambient temperature air. Ice cooling is another cooling mechanism that is designed to hold packets of ice close to the skin in order to cool the skin by conduction. Liquid cooling also provides conductive cooling of the skin, but it is accomplished by supplying a steady flow of cool liquid in a closed circuit over large surfaces of the body.

CHAPTER III

METHODOLOGY

The purpose of this investigation is to develop and evaluate a prototype glove liner that provides improved dexterity and thermal comfort properties for those wearing chemical protective gloves while working in high temperatures and relative humidity environments. The functional clothing design process was chosen as an appropriate systematic problem-solving approach in developing the glove liner prototype.

Development of the Prototype

One of the main objectives of designing protective clothing is to meet the specific needs of a given population (Watkins, 1984). In order to develop a glove liner prototype that will increase perceived thermal comfort and dexterity of the farmer and any other population who uses chemical protective gloves and minimize sweat build-up within their gloves, a functional clothing design systematic process was followed. This problem-solving approach is described in Watkins' 1984 book, *Clothing: The Portable Environment* involves a step-by-step plan that takes the designer from the original idea to the evaluation step of the final prototype.

The process begins with an identification of the problem, followed by an exploration of the problem in order to identify the factors that will be critical in designing the prototype. The exploration step familiarized the designer with literature available on physiology of hands, sweat rate, perceived thermal comfort, dexterity, cooling devices, materials and their chemical permeation and degradation rates, thermal and moisture transfer processes, and other related information. During the market analysis, the designer obtained information on what chemical protective glove styles and materials are now available. Other information and gloves designed for a variety of end uses were examined for ideas and possible new features that might be redesigned for chemical protective glove handwear. An observational analysis was done by watching videos of farmers mixing, loading, spraying and cleaning pesticide contaminated equipment in real-life situations. The videos provided information on activities and movements required to prepare and apply pesticide and to clean up following application. The videos covered various application methods. All these factors were used as inputs in the development of the prototype.

Results from previous studies done by Tremblay, 1989 and Branson & Sweeney, 1991 were used to assess users' preferences and values related to protective handwear. Some of the problems of protective handwear identified by these researchers were poor fit, poor dexterity, and low thermal comfort levels.

Testing and Evaluation

The testing of the prototype was conducted in an environmental chamber at Oklahoma State University at a temperature and relative humidity typical for the state of Oklahoma 75% of the time during spring and summer seasons.

Although some pesticide application is performed during the entire year, the growing season and major pesticide application in Oklahoma is during the months of March to September. After studying five years (1985-1989) of the monthly (March to September) Oklahoma climatological data from the National Oceanic and Atmospheric Administration (NOAA), the temperature and relative humidity specified for the environmental chamber where 26.5±2°C and 78±5% RH. The prototype liner was worn under chemical protective gloves that can be used for pesticide mixing, loading, application and cleaning in agricultural states like Oklahoma.

Dependent Variables

Perceived thermal comfort, skin temperature of both hands, manual dexterity and sweat build-up within the glove are the dependent variables for the investigation. Perceived thermal comfort was assessed with the use of Hollies (1977) subjective comfort rating chart (See Appendix B). This comfort ballot was completed by the subjects at the beginning and conclusion of the experiment and at six-minute intervals during the protocol. In order to measure skin temperature, a digital thermometer (model no. 4002; serial 3257), a switch box (model no. 4002; serial 3251) and surface thermistors from Yellow Springs Instrument Co., Inc. were used. Skin temperature of both hands was recorded every three minutes. Manual dexterity was determined by the use of the Manipulative Aptitude Test devised by Wesley S. Roeder; and, also by the Purdue Pegboard from Lafayette Instrument Company (model 32023). Both instruments have been determined to be valid and reliable. Sweat build-up was recorded by weighting the glove liners inside "Ziploc" bags immediately before and after the experiment.

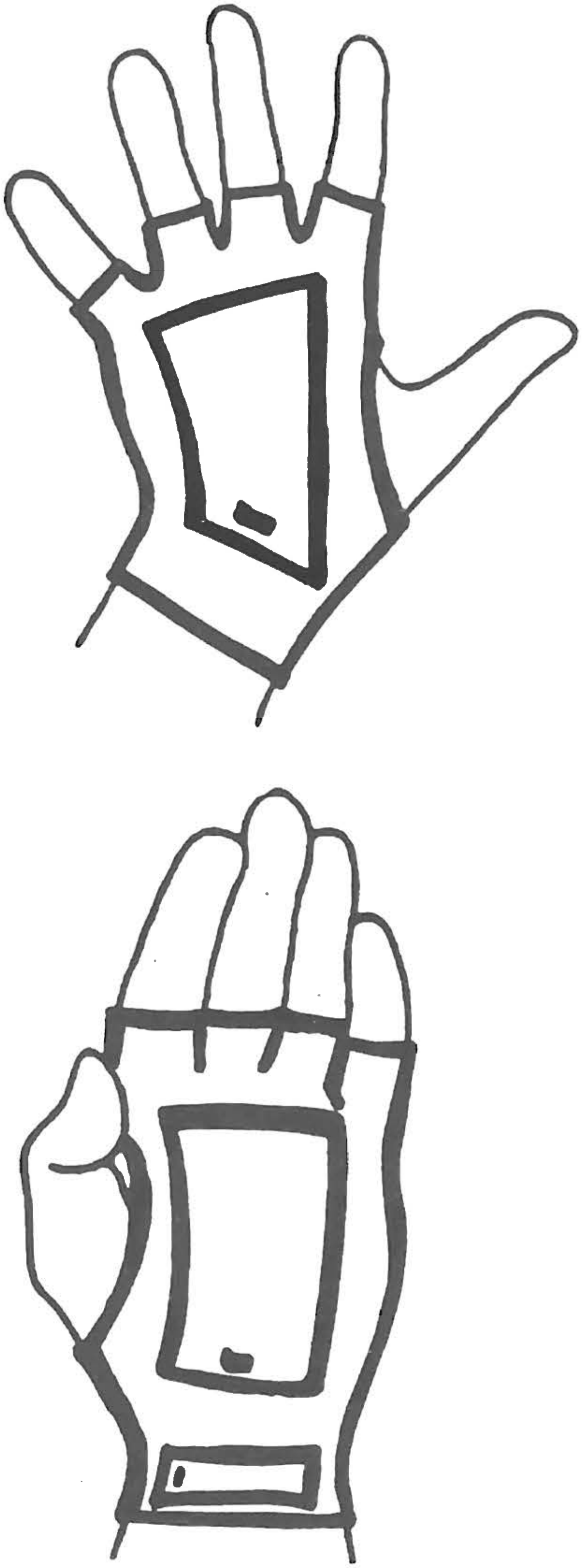
Independent Variables

Independent variables included the use of two glove treatments: the use of the glove liner condition with or without the artificial cooling device under the specified chemical protective glove system chosen for the investigation. The glove liner is the prototype developed in the first part of this methodology. The PE/PVAE/PE laminate chemical protective glove was selected on the basis of its breakthrough time and permeation rate information on the tables from protective equipment manufacturers. According to Henriksen (1990), the laminate glove has been shown to be an effective protection against water, amines, and a wide range of alcohols; and, also, shown to be an effective barrier against a wider range of chemicals. The PE/PVAE/PE laminate pancake glove is also recommended for its good mechanical properties (flexibility, strength and elongation). The chemical protective glove manufacturers also recommend the use of a puncture resistant outer glove and a cotton liner to absorb excessive perspiration. This is the first time a three layer system including a liner has been recommended as a way of providing protection against pesticides. The outer glove is a soft nitrile disposable glove advertised to have extra sensitivity, abrasion resistance, elongation recovery and puncture resistance. Nitrile is "recommended to agricultural workers because of its resistance to oils, and excellent tensile and tearing strengths." (Tremblay, 1989, p.34) The second layer or inner glove is the PE/PVAE/PE laminate pancake chemical protective glove.

The glove liner developed for this study is a size large thumbless two-layer prototype similar to the gloves used for cycling. The glove liner is fabricated of light weight (96%/4%) nylon/spandex knit fabric and features three pockets at the upper hand, the palm and the under wrist (4.5 x 3 inches, 4.5 x 2.5 inches, 1.5 x 3.75 inches)(See Figure 1)*. The nylon fiber has a proprietary four-channel cross-section designed to facilitate wicking. The fabric was chosen because of its low water absorption, light weight, softness, high wicking, high air/vapor permeability, stretchability, and fast drying characteristics. The fabric is also resistant to odor and mildew and is machine washable and dryable. Proprietary cooling gel devices represented the artificial cooling that could be inserted into each liner pocket. The effect of the presence or absence of this cooling treatment on the dependent variables constituted the focus of this research.

Sample

A convenience sample of ten male college students between the ages of 18 and 25 was selected as subjects. School newspaper and flyer advertisements were used for recruiting the sample of male college student volunteers. A pre-screening process was performed. In order to be part of the experiment, the purchased chemical protective glove system had to fit the student volunteers. University IRB regulations were strictly followed. During this pre-screening process the nature of the experiment was explained to the volunteers and they practiced the four steps of the Purdue Pegboard (Lafayette Instrument Company-model 32023) as well as the four steps of the Manipulative Aptitude Test (Lafayette Instrument



* Figure 1. Glove Liner Prototype

Company). The selected subjects signed an Informed Consent Form and a Disclosure Agreement (See Appendixes C & D). The ten subjects were paid twenty five dollars for their participation in the two test sessions and the pre-screening and orientation sessions.

Experiment Protocol

Testing was performed in an environmental chamber in the Human Environmental Sciences building at Oklahoma State University. The subjects were phoned prior to the experiment to ensure attendance. The experiment included two sessions of one and half hours each and a pre-screening and orientation session of one hour. For each test session, the subjects wore one treatment. The treatment was chosen randomly. When the subjects arrived, they changed into a long sleeved chambray shirt (100% cotton), jeans (100% denim), 100% combed cotton briefs, 96%/4% cotton/spandex socks and a baseball cap that was provided by the researcher. These garments are typical of the ones commonly used by farmers while working with pesticides and were described as suitable protective clothing by the Federal Register in 1974 (Branson & Sweeney, 1991). The subjects entered the environmental chamber and were instrumented with three thermistors on each hand as shows Figure 2*.

The subjects wore the two selected gloves over the experimental glove liner. The experiment started with the subjects completing four exercises of the Purdue Pegboard followed by the exercise protocol developed to simulate the actual activity of farmers while mixing and loading pesticides and cleaning equipment following application (See Appendix A). This exercise protocol was developed based on the observational analysis step of the design process.

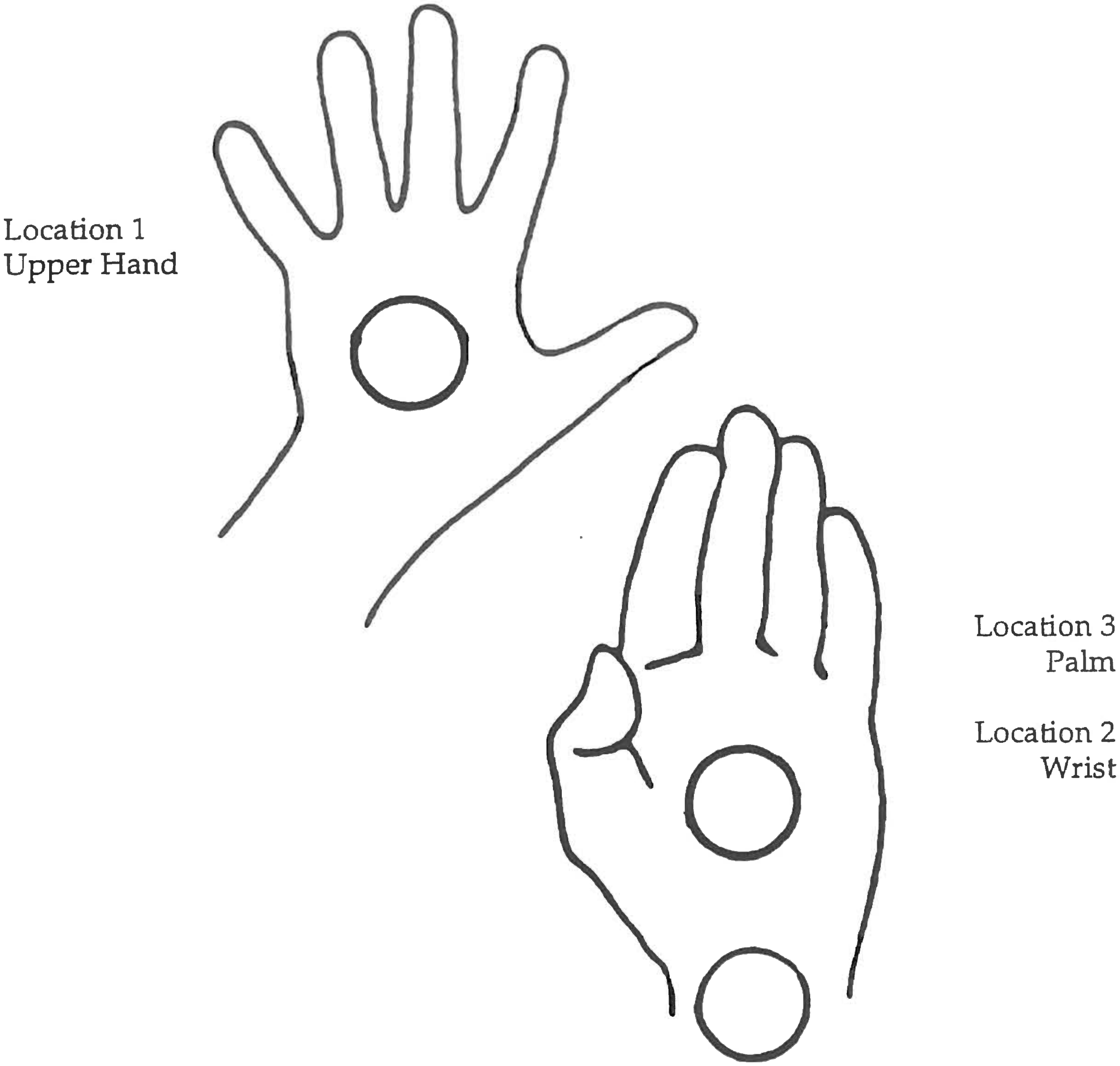


*Figure 2: Placement of Thermistors

After the exercise protocol was completed, the subjects performed the four exercises of the Manipulative Aptitude Test. Then, the subjects repeated the exercise protocol followed by the four exercises of the Purdue Pegboard. After the Purdue Pegboard, the subjects repeated the exercise protocol twice. Skin temperature was recorded at intervals of three minutes throughout the experiment. Perceived comfort ballots were completed by the subjects at six-minute intervals. The glove liners were weighed immediately before and after each session. The length of the test was 36 minutes which is estimated to be approximately twice as long as the average time that mixing and loading pesticides consumes (Tremblay, 1989). Having the test this long ensured that the test would be longer than the time required by an actual farmer performing these functions. A longer test would also most likely raise the temperature of the hand and induce sweating both of which were desired.

Statistical Analysis

Perceived thermal comfort data and skin temperature data for both hands by treatment were graphed over time. In order to determine if a significant difference by treatment existed for thermal comfort, skin temperature, manual dexterity and sweat build-up, analysis of variance (ANOVA) were performed.

CHAPTER IV

MANUSCRIPT I

Development and Evaluation of a Glove Liner Prototype for High Temperature and High Relative Humidity Environments

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Abstract

Pesticide use has been strongly related not only to environmental and health concerns but to clothing precautions. Hands are an important point of contact when mixing, loading, spraying, and cleaning pesticides. The use of chemical protective gloves is vital during these agricultural related activities. Sweat build-up within the glove, dexterity and thermal comfort are important concerns when designing and evaluating chemical protective gloves. This investigation determined if artificial cooling in a prototype glove liner influence perceived (thermal and sensorial) comfort, manual dexterity, skin temperature and sweat build-up within the gloves of subjects wearing chemical protective gloves in high temperature and relative humidity environments. Two glove liner conditions (with/without artificial cooling) were tested in a controlled temperature (26.5±1°C) and relative humidity (78±5%) environmental chamber. Ten male college students between the ages of 18 and 25 who passed the screening process followed a testing protocol for 36 minutes in the environmental chamber. ANOVA results when the cooling treatment was present showed significant differences ($p<.05$) in overall mean skin temperature for the comfort descriptor cold and for five out of the nine exercises of both manual dexterity tests. In general, whether the presence or not of the artificial cooling, the glove liner prototype was perceived as definitely snug; mildly heavy, stiff, damp, clingy and sticky; partially rough; and almost not scratchy at all. The glove liner prototype was effective in lowering hand temperature but questions about controlling the temperature of the cooling devices and about the practicality of the design are still to be answered.

INTRODUCTION

In agriculture the use of pesticides is necessary to protect crops against plagues and insects. Chemical protective clothing, especially handwear, is vital for those working with pesticide chemicals since the hands are the most common point of contact when performing agriculture-related activities. The hands are typically involved in the mixing, loading, spraying and cleaning operations of pesticide application. During these activities, chemical protective gloves are commonly recommended to protect the farmer from dermal exposure to pesticides. Although dermal exposure to the hands is a significant problem that is widely recognized, many of those who work with pesticides do not wear protective gloves.

Excessive perspiration on the skin due to high temperature and relative humidity can cause thermal discomfort and skin related diseases (Mansdorf, 1987; Vaughan, 1991). Heat related and dermatological problems can decrease total performance of an individual in work situations (Bernard et. al., 1991; Mansdorf, 1987). If thermal discomfort and low performance are added to poor fit and clothing discomfort, the wearability of chemical protective handwear becomes almost nil. Many studies investigated thermal and sensorial comfort of protective gloves or clothing (Branson & Sweeney, 1991; DeMartino et al., 1984; Hollies & Goldman, 1977; Fourt & Hollies, 1970; Pontrelli, 1977).

In order to increase the wearability of chemical protective gloves, the US Army and Air Force use cotton glove liners under their butyl rubber chemical protective gloves to help absorb the moisture on the skin surface. Various artificial cooling methods have been used with protective clothing to help increase workers and military personnel performance rate and productivity (Bernard et. al., 1991; Hughes, 1991; Vaughan, 1991). Artificial cooling has been shown to help prolong user working time by heat transfer by convection (Bernard et al., 1991; Vaughan, 1991). No studies were found on the development or use of artificial cooling handwear. The provision for artificial cooling in chemical protective gloves may alleviate both thermal discomfort and dermatological problems associated with the wearing of chemical protective handwear. This may help agricultural related workers keep their gloves for a longer time while protecting their hands from dermal exposure. Incorporating artificial cooling to chemical protective handwear may also increase thermal comfort and dexterity.

The purpose of this investigation was to develop and evaluate a prototype glove liner that provided improved dexterity and thermal comfort for those wearing chemical protective gloves while working in high temperature and relative humidity environments. The objectives established for this investigation were 1) to develop an artificially-cooled glove liner prototype that provides increased thermal comfort and dexterity when worn under chemical protective gloves, 2) to compare subjects' perceived liner comfort (thermal and sensorial) and skin temperature between a glove liner with and without cooling while performing tasks in a high temperature and relative humidity environment, 3) to compare subjects' dexterity between a glove liner with and without cooling while performing tasks in a high temperature and relative humidity environment, and 4) to compare pre- and post-weights of the glove liner conditions.

METHODOLOGY AND PROCEDURES

The methodolody for this research has been divided in two parts. The first part includes the development of the glove liner prototype. The second part describes the evaluation of the glove liner prototype under the specified temperature and relative humidity environmental conditions.

Prototype Development

The functional design investigation followed the systematic problem-solving approach for functional clothing design described in Watkin's (1984) book, *Clothing: The Portable Environment* . The steps of this systematic approach progress from the identification of the problem to the evaluation of the prototype developed. After the problem was identified, the investigator explored the literature available on the critical factors that affect perceived thermal comfort, skin temperature, manual dexterity, and sweat rate. During the market analysis, the designer obtained information on what chemical protective glove styles and materials are now available. Other information and gloves designed for a variety of end uses were examined for ideas and possible new features for possible adaptation and/or implementation for chemical protective glove handwear. An observational analysis was conducted by watching videos of farmers mixing, loading, spraying and cleaning pesticide contaminated equipment in real-life situations. The videos provided information on activities and movements required to prepare and apply pesticide and to clean up following application.

The videos covered various application methods. All these factors were used as inputs in the development of the prototype.

Some of the problems of protective handwear identified by other researchers (Branson & Sweeney, 1987; Tremblay, 1989) were poor fit, poor dexterity, and low thermal comfort levels. The knit fabric chosen for the prototype is a 96%/4 % nylon/spandex blend. The nylon fiber has a proprietary four-channel cross-section designed to facilitate wicking. The fabric was chosen because of its low water absorption, light weight, softness, high wicking, high air/vapor permeability, stretchability, and fast drying characteristics. The fabric is also resistant to odor and mildew and is machine washable and dryable.

The glove liner developed is a thumbless one layer prototype similar to the gloves used for cycling. Figure 1 shows the glove liner prototype including the three pockets (upper hand, palm, wrist) that hold the cooling devices in place. The cooling devices are heat-sealed plastic bags filled with a cooling gel similar to cold packs for medical purposes. The cooling devices fit inside the pockets in the glove liner. The 4.5 x 3 inch device used in the upper pocket contained two ounces of gel, the 4.5 x 2.5 inch palm device contained one ounce, and the 1.5 x 3.75 inch wrist device contained 0.5 ounce of the cooling gel. The gel-filled heat-sealed devices were cooled in a GM Frigidaire® refrigerator freezer for 24 hours prior to use.

FIGURE 1

Subjects

Ten male college students, ages 18 to 25, who answered newspaper or flyer advertisements served as volunteers. All went through a pre-screening process that included a glove system fit check, explanation of the purpose of the investigation and practice with two manual dexterity tests. Subjects signed an informed consent form and a non-disclosure agreement and were paid twenty-five dollars for their participation in both tests sessions.

VARIABLES

Controlled Variables

The evaluation process of the glove liner prototype was conducted in an environmental chamber in the Human Environmental Sciences building at Oklahoma State University. The controlled variables for this investigation were temperature, relative humidity and clothing worn by the subjects during both test sessions. During the test session, the environmental chamber was set at a temperature of 26.5±2°C and 78%±5% relative humidity. The temperature was chosen based on the average of the actual temperatures of a five year (1985-1989) data file from the National Oceanic and Atmospheric Association (NOAA) during the spring and summer seasons in Oklahoma. Subjects wore 100% denim jeans, 65/35% cotton/polyester gray workshirts, 100% combed cotton briefs, 96/4% cotton/spandex socks and a baseball cap. The clothing ensemble worn by the subjects simulated clothing typically worn by farmers for pesticide

pesticide application. The clothing ensemble was provided by the investigator. All garments were laundered and dried before and after each test session.

Independent Variables

The independent variables for this investigation were the two glove liner treatments which were the use of or absence of artificial cooling in the glove liner prototype. The glove liner used was the thumbless 96/4% nylon/spandex prototype with pockets presented in the first part of this methodology.

Dependent Variables

The dependent variables for the investigation were perceived thermal comfort, skin temperature of both hands, manual dexterity and sweat build-up within the glove system.

GLOVE SYSTEM

Since the focus of this research was to test a glove liner designed to be used under chemical protective gloves, a chemical protective glove needed to be specified. The chemical protective glove chosen was a PE/PVAE/PE laminate pancake glove. The chemical protective glove materials are polyethylene and vinyl alcohol-ethylene copolymer. These materials are recommended by the manufacturers to be an effective protection against water, amines, and wide range of alcohols. The chemical glove is also recommended for its good mechanical properties (flexibility, strength and elongation). The chemical protective glove has been shown to be an effective barrier against a wide range of chemicals. Increased breakthrough time and reduced permeation rate for four hours from the first exposure are described as features of this chemical protective glove in its US Patent (Henriksen, 1990).

Chemical protective glove manufacturers also recommend the use of a puncture resistant outer glove and a cotton liner to absorb excessive perspiration. This is the first time a three-layer glove system including a liner has been recommended as a way of providing protection against pesticides. The outer suggested glove is a soft nitrile disposable glove advertised to have extra sensitivity, abrasion resistance, elongation recovery and puncture resistance. The second layer or inner glove is the chemical protective glove chosen for this investigation. The glove liner tested with the two chemical protective gloves is the prototype developed for this investigation.

INSTRUMENTS

Perceived thermal comfort was recorded with the use of an adaptation of Hollies' (1977) subjective comfort rating chart developed for this investigation. The rating chart was adapted in order to fill the requirements for this investigation. Past research has shown that individuals may define a descriptor differently and consequently use the scale differently. For this reason, the investigator included a short definition of the descriptors used in the comfort ballots. For example, close fitting was used with the descriptor snug (See Appendix B). Hollies' subjective comfort rating chart was also adapted in the following ways. The number of descriptor terms was reduced to 9 from 15. Also, the original scale had a four-point response scale with 1 labeled totally, 2 labeled definitely, 3 labeled mildly, and 4 labeled partially. Since the scale did not accommodate a person not sensing a response, a fifth response was added to indicate not at all. The comfort ballot was completed by the subjects at the beginning and at the end of the test session and at six-minute intervals throughout the session for a total of seven times.

To record skin temperature a digital thermometer (model no. 4002; serial 3257), a switch box (model no. 4002; serial 3251), and six skin surface thermistors from Yellow Springs Instruments Co., Inc. were used. The thermistors were located on the right and left hand as shown in Figure 2. Skin temperature was recorded at three-minute intervals during the forty-minute test session. The Manipulative Aptitude Test (1967) and the Purdue Pegboard (model 32020), both from Lafayette Instruments Co., were the two tests used to assess manual dexterity. Sweat build-up within the glove liner was obtained by recording pre- and post-weights of the glove liner prototypes sealed in Ziploc bags using the Fiber Scientific XL-300 scale.

FIGURE 2

TESTING PROTOCOL

The experiment included two test sessions in which the subject wore one treatment each time. The treatment was chosen randomly. The subject came in, changed clothes, went into the chamber and was instrumented with the skin surface thermistors. After the instrumentation, the subject put on the glove system and filled out the first comfort ballot. Then, the subject completed four different exercises with the Purdue Pegboard. An exercise protocol designed to simulate pesticide mixing, loading, spraying and cleaning up was then completed. This was done to enable subjects to perform tasks similar to real life and report any discomfort noticed in the final comfort ballot. The subject then proceeded to complete the Manipulative Aptitude Test, followed by a second simulated exercise protocol and the Purdue Pegboard exercises. Lastly, the subjects repeated the exercise protocol and the final comfort ballot was completed. After the second session, the subject was asked to compare both treatments. This procedure completed the testing protocol.

RESULTS

Skin Temperature

Analysis of variance (ANOVA) for a split plot with multiple splits was used to analyze the skin temperature data. ANOVA results for hand showed there was no significant difference between left and right hand (See Table 1).

TABLE 1

Significant cooling treatment, location and cooling treatment by location effects were found. The cooling treatment was effective at lowering skin temperature. The difference in mean temperature by location and the cooling treatment by location interaction can be seen in Figure 3. Without the presence of the cooling treatment, the mean temperature for locations 1 and 2 (upper hand and wrist) was 35°C and 35.7°C for location 3 (palm). With the presence of the cooling treatment, the mean temperatures for location 1 and 3 were only 28.4°C and 29.8°C. However, for the same cooling treatment at location 2, the mean temperature was 31.2°C. Thus, the cooling device was less effective in lowering the skin temperature of location 2 (wrist) than of the other two locations.

FIGURE 3

In fact, the mean temperature of the wrist was found to be the highest of the three locations for almost the entire testing time when the cooling treatment was present. We believe that the cooling devices were in closer proximity to the skin at locations 1 (upper hand) and 3 (palm) than at location 2 (wrist). This is because the size of the cooling device (and the gel volume) was smaller at location 2.

Perceived Liner Comfort

The comfort instrument required subjects to rate the intensity of each comfort descriptor on a scale of 1 (totally) to 5 (not at all). Comfort descriptors used included: snug, heavy, stiff, sticky, cold, damp, clingy, rough and scratchy. An overall perceived liner comfort item was also assessed on a seven-point scale of 1 (very comfortable) to 7 (very uncomfortable).

ANOVA results indicated that only the descriptor cold was significantly different by cooling treatment (p>.0001). The liner with the cooling device was perceived as colder than the glove liner without the cooling device. Table 2 presents the data over time.

TABLE 2

Analysis of variance (ANOVA) results for the descriptor damp did not showed significant cooling treatment or subject differences. However, subjects often mentioned dampness when asked to compare both treatments in the open-ended question at the end of the final comfort ballot at the conclusion of each test session. Table 2 shows that the subjects wearing the liner without cooling experienced a consistent increase in the amount of dampness perceived over the time of the experiment. Subjects wearing the liner with cooling experienced an initial increased perceived dampness with the second ballot and remained at this approximate level throughout the remainder of the test session. When the cooling treatment was present, dampness outside the glove system was noticeable due to condensation of water vapor. Condensation of water vapor occurs when high temperatures and relative humidity environments are present. The combination of the low temperature of the cooling devices and the high temperature and relative humidity of the environmental chamber may have induced vapor to condense in the outer layer of the glove system.

None of the other comfort descriptors were significant by cooling treatment. Table 2 shows that, whether the cooling treatment was present or not, the glove liner was perceived as being definitely snug, mildly heavy, stiff, damp, clingy and sticky, partially rough, and not scratchy. Therefore, the presence of the cooling device did not induced more discomfort than the glove liner without the treatment. For all of the comfort descriptors except cold and damp, there was a significant subject difference. Since it has been well established that every person perceives comfort in a different way, these findings are not surprising. Individuals perceive thermal and sensorial comfort depending on a combination of various factors that influence their comfort judgment at a given point in time.

ANOVA results for overall perceived glove liner comfort showed a significant subject effect but not a treatment effect. The means for overall glove comfort were 3.1 (liner with cooling) and 2.8 (liner without cooling). Thus, the presence of the cooling treatment did not appreciably affect subjects' overall perceived glove liner comfort. The significant subject effect again reiterates the idea that human responses remain very individual. Although many studies have been done on perception of comfort by individuals under different conditions, human responses to comfort are still a fascinating topic. There is not a mathematical equation that can measure what is comfortable to an individual if the variables are given.

The subjects were asked to respond to an open-ended overall liner comfort question in order to compare both treatments. The responses for this comparison varied (See Appendix E). Some of the subjects perceived the liner with cooling to be more comfortable than the one without the cooling device. In general, comments about dampness and snugness were expressed by most of the subjects. The cooling device was perceived as comfortable by some individuals especially in terms of manual dexterity. Several subjects stated the perception that the cooling devices were thick at the palm area impeding proper functioning of the hand when grasping and grabbing objects. Two of the subjects perceived the cooling devices to be too cold at the beginning of the session. Also, excess material around the fingers especially the thumb area was perceived as a problem.

Sweat Build-Up

The liners were weighed without the cooling device both before and immediately after the experiment. The mean difference between the two weights were subjected to ANOVA analysis. Results for the analysis of variance showed that there were no significant differences by subject or treatment. Table 3 shows that there was weight gain for both treatments (with and without cooling). Although the liner with the cooling device was perceived as being significantly colder and somewhat less damp, the results did not show a significant difference in sweat build-up. Possibly, the weight gain found with the artificially cooled liner maybe due to water vapor condensation.

TABLE 3

Manual Dexterity

ANOVA results showed significant differences by subject and cooling treatment for four out of the eight exercises of both manual dexterity tests (Manipulative Aptitude and Purdue Pegboard). The Purdue Pegboard information manual required the investigator to calculate the sum of the first three exercises (right, left and both hands) and to record it as a fifth exercise (RLB). ANOVA results showed significant differences by subject (p>.0103) and cooling treatment (p>.0421) for the RLB exercise. Results for the Manipulative Aptitude Test showed significant differences for the assembly exercise by subject (p>.0107) and by cooling treatment (p>.0053), and for the left hand exercises by subject (p>.0582) and by cooling treatment (p>.0528). Significant differences were found for subject and cooling treatment for two of the four exercises (assembly and right hand) of the Purdue Pegboard. The results were significantly different for the assembly exercises by subject (p>.0006) and cooling treatment (p>.0029), and for the right hand exercise by subject (p>.0284) and cooling treatment (p>.0181). A significant subject effect was found for the both hands exercise (p>.0122) of the Purdue Pegboard. Although the results were not significantly different for four of the exercises, Table 4 shows that in all the tests the subjects had a better performance when wearing the cooling treatment.

TABLE 4

DISCUSSION

Heat related problems are a source of thermal and sensorial discomfort in handwear. Adding artificial cooling to handwear was the way used by the investigator of improving thermal and sensorial comfort as well as to improve manual dexterity. The use of artificial means for lowering the overall skin temperature was effective. Overall mean skin temperature was significantly lowered when the cooling devices were present.

Subjects' comfort perceptions were significant by subject for seven out the nine comfort descriptors of the ballot reinforcing the idea that perceptions of comfort are indeed very individual. In general, the subjects perceived the glove liner prototype as definitely snug; mildly heavy, stiff, damp, clingy and sticky; partially rough; and almost not scratchy at all.

When the subjects were asked to compare both treatments (cooling and no cooling) in an open-ended question, dampness and snugness were often expressed as important points. Dampness in the form of condensed water vapor was noticed in the outside of the glove when the cooling device was present. This may have influenced subjects' perceptions when responding to the descriptor damp. Also, this situation may have affected the results when weighting the glove liner prototypes for sweat build-up. The researcher believes that the weight gain recorded when the cooling device was present was not only due to sweat build-up but to moisture take-up.

The subjects commented that the glove system was snugger when the cooling device was present. The cooling device helped the glove system to be closer to the fingertips enabling the subjects to have higher scores for all of the manual dexterity tests.

Adding artificial cooling to the glove liner had been shown to be effective at lowering skin temperature and at increasing manual dexterity performance. Also, comparable ANOVA results were found for perceived thermal and sensorial comfort, overall perceived comfort and overall moisture take-up regardless of the presence of the cooling device.

The researcher recommends further investigation in to the possibility of a different kind of cooling solution to enable a less bulky design and a different cooling device design to accomplish more cooling coverage. ALso, the possibility of developing different design features for the glove liner prototype as well as in the use of different materials warrants further investigation. Also, it would be interesting to test the artificially cooled glove liner prototype against the 100% cotton liner recommended by the chemical protective glove manufacturer.

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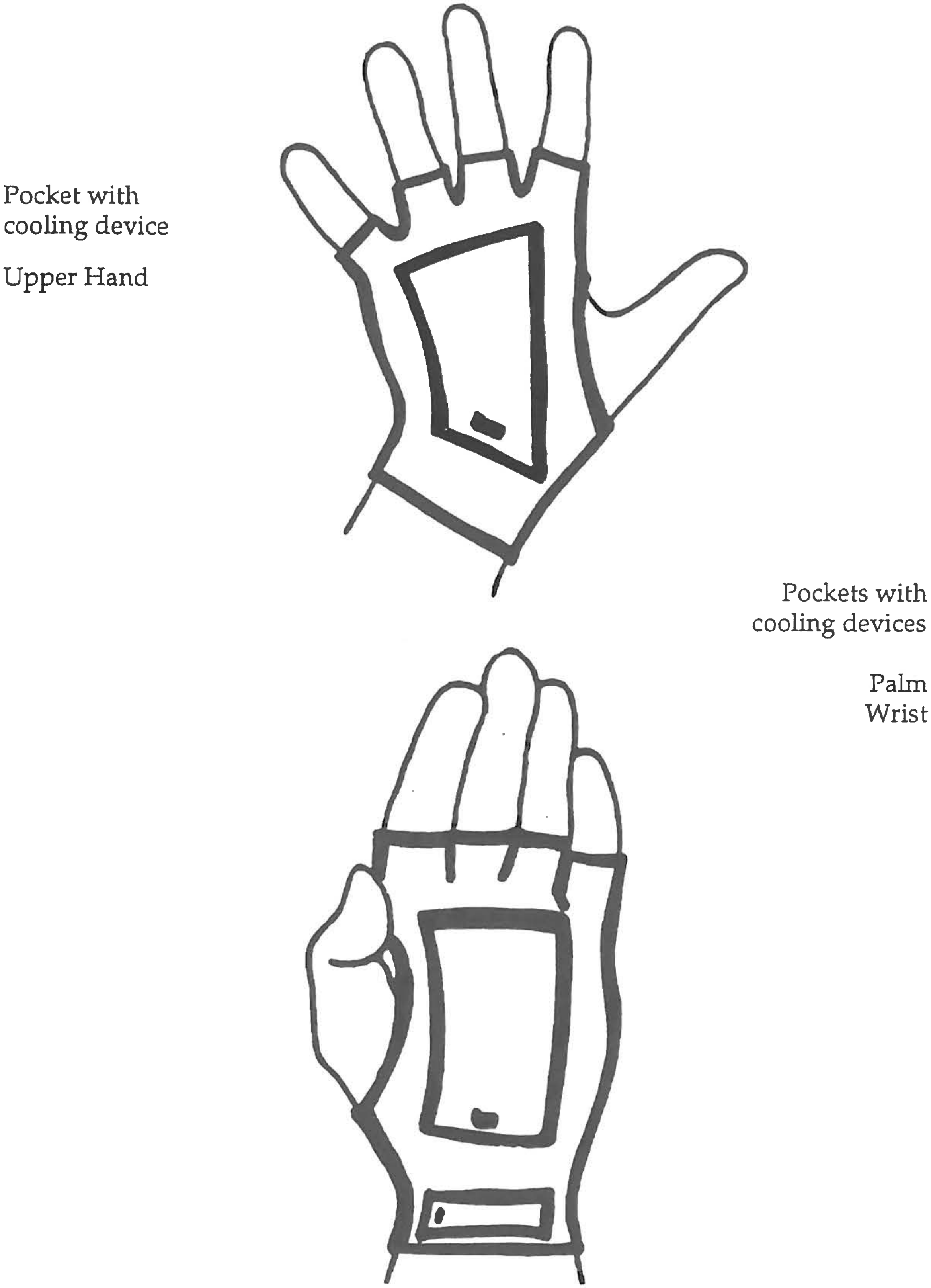

* Figure 1. Glove Liner Prototype

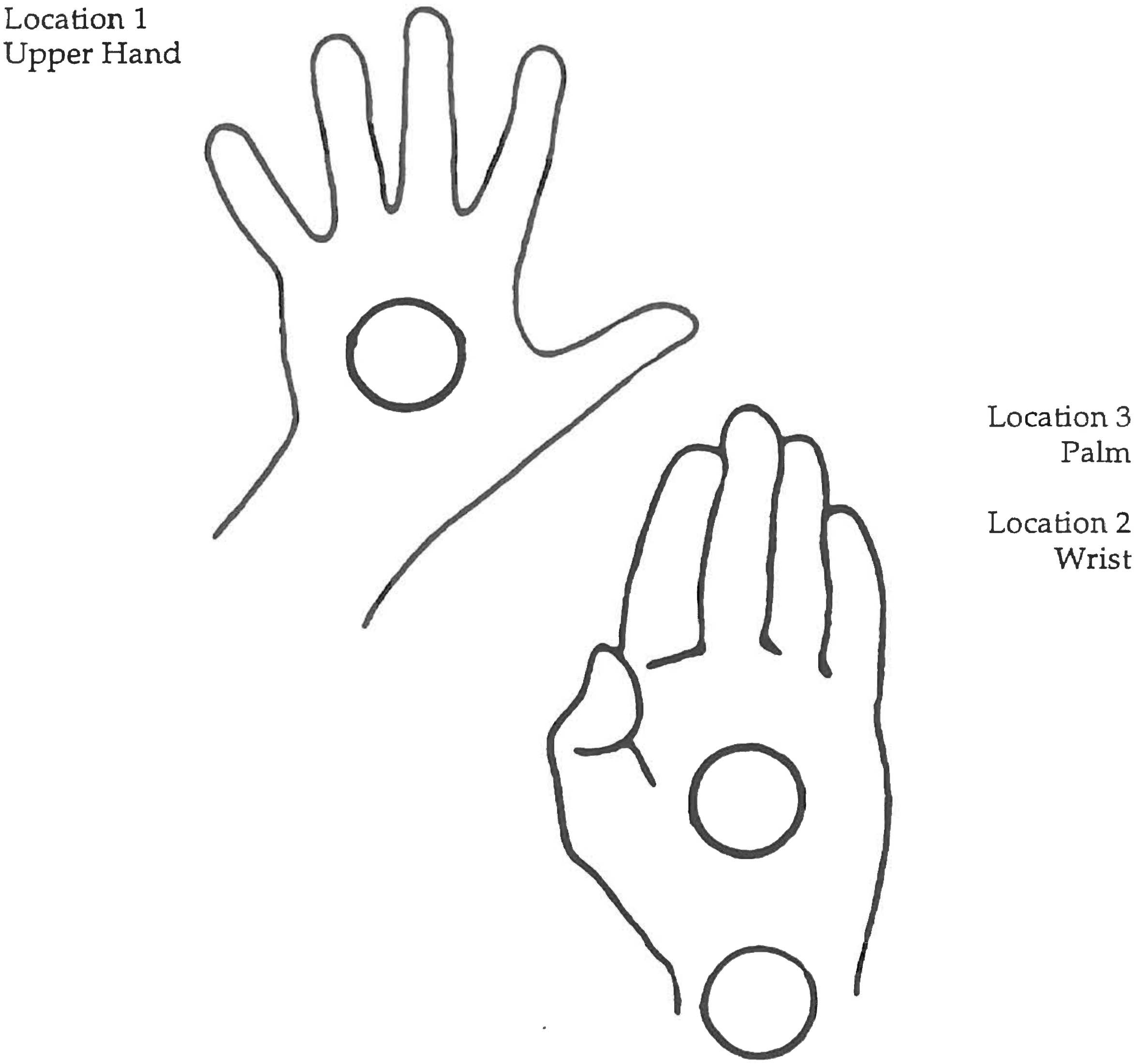

*Figure 2: Placement of Thermistors

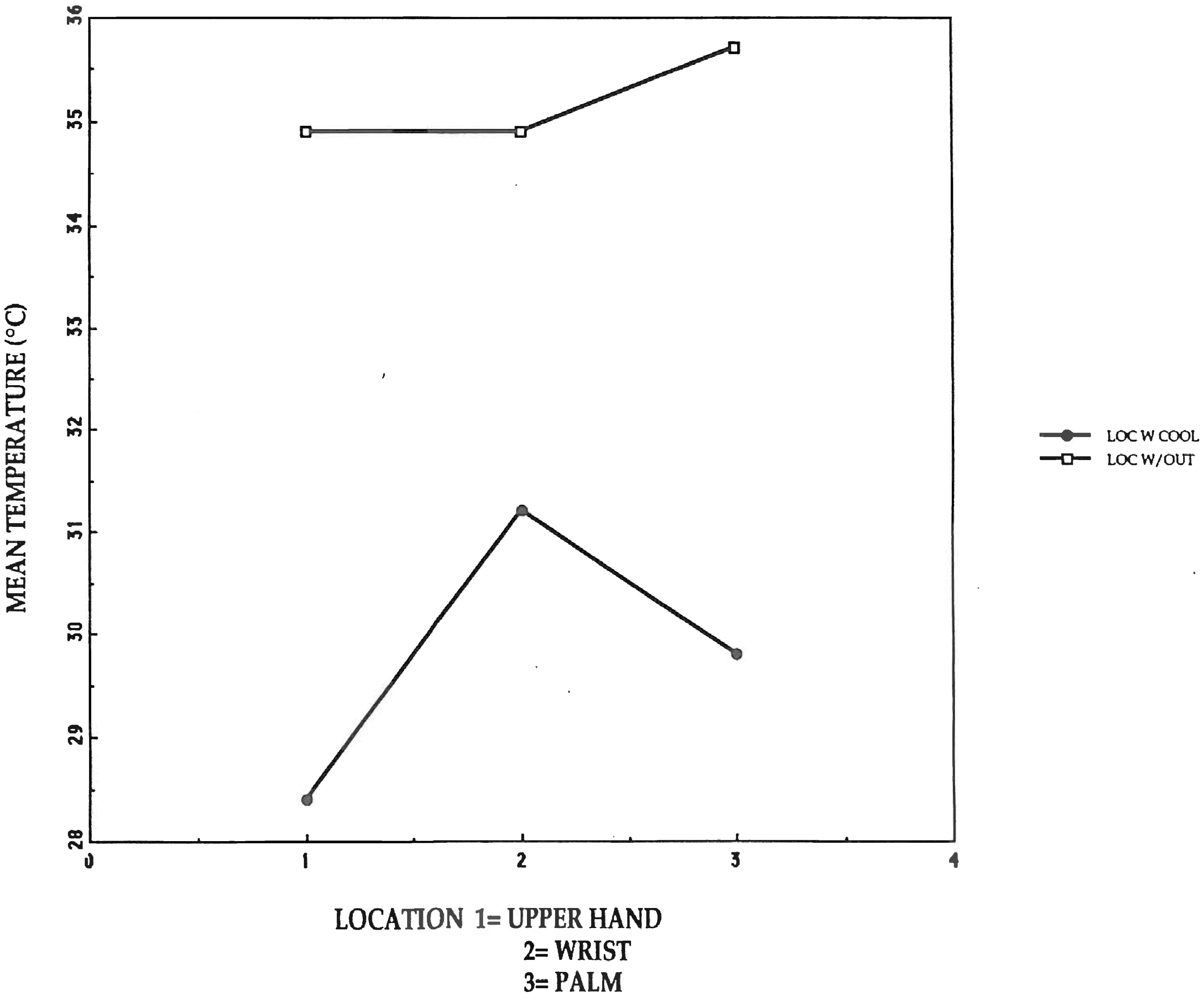

Figure 3. Mean Temperature Over Location

TABLE 1

ANALYSIS OF VARIANCE OF TEMPERATURE OVER TIME

SOURCE	DF	MEAN SQUARES	F VALUE	PR>F
Model	119	394.307	20.8	0.0001
Hand	1	0.03434	0	0.9636
Cool	1	36167.6403	287.98	0.0001
Hand*Cool	1	0.0215	0	0.9897
Location	2	926.3829	36.31	0.0001
Hand*Location	2	6.1943	0.24	0.7851
Cool*Location	2	933.1883	36.58	0.0001
Hand*Cool*Location	2	14.2571	0.56	0.5744
Sampling Error (Time)	1410	18.9602		
Error (a)*	9	15.6112		
Error (b)**	18	125.5917		
Error (c)***	72	25.5139		

* Subject x Hand

**Subject x Hand x Cool

***Subject x Hand x Cool x Location

TABLE 2

OVERALL MEANS AND STANDARD DEVIATIONS FOR COMFORT DESCRIPTORS OVER TIME

					TIME					
DESCRIPTOR	TREATMENT	1	2	3	4	5	6	7	MEAN	SD
SNUG**	WITH COOLING	1.90	2.30	2.20	2.10	2.20	2.20	2.20	2.16	1.41
	WITHOUT COOLING	2.10	2.00	2.00	2.20	2.30	2.40	2.20	2.17	1.24
HEAVY**	WITH COOLING	2.70	3.10	3.10	3.30	3.20	3.20	3.50	3.16	1.19
	WITHOUT COOLING	3.80	2.80	3.40	3.20	3.30	3.30	3.40	3.31	1.00
STICKY**	WITH COOLING	3.50	3.80	3.70	3.40	3.80	3.30	3.30	3.54	1.35
	WITHOUT COOLING	3.90	3.50	3.60	3.70	3.40	3.30	3.40	3.54	1.20
COLD***	WITH COOLING	2.20	2.80	3.40	3.90	4.10	4.10	4.60	3.59	1.45
	WITHOUT COOLING	4.30	5.00	5.00	5.00	5.00	4.90	5.00	4.89	0.63
ROUGH**	WITH COOLING	4.00	4.00	4.20	4.10	3.90	4.00	4.10	4.04	1.27
	WITHOUT COOLING	4.50	4.20	4.20	4.10	4.20	4.20	4.20	4.23	0.94
SCRATCHY**	WITH COOLING	4.80	4.50	4.50	4.50	4.40	4.40	4.40	4.50	1.14
	WITHOUT COOLING	4.60	4.50	4.60	4.60	4.70	4.70	4.60	4.61	0.73
STIFF**	WITH COOLING	2.78	3.20	3.30	3.20	3.50	3.60	3.50	3.30	1.05
	WITHOUT COOLING	3.30	3.00	3.00	3.10	3.20	3.10	3.40	3.16	0.77
DAMP	WITH COOLING	4.00	3.20	3.30	3.11	3.30	3.20	3.50	3.38	1.14
	WITHOUT COOLING	4.20	3.70	3.10	3.00	2.90	2.70	2.70	3.19	1.03
CLINGY**	WITH COOLING	3.33	3.33	3.50	3.10	3.50	3.50	3.40	3.38	1.23
	WITHOUT COOLING	2.90	3.00	3.00	3.33	3.10	3.10	3.30	3.10	1.11

*1=TOTALLY, 2=DEFINITELY, 3=MILDLY, 4=PARTIALLY, 5=NOT AT ALL

**Indicates $p<.05$ for subject

*** Indicates $p<.005$ for treatment

TABLE 3

SWEAT BUID-UP WITHIN THE GLOVE LINER PRE AND POST WEIGHT (GRAMS)

TREATMENT	PREWEIGHT (gr)	POSTWEIGHT (gr)	DIFFERENCE (gr)
WITH COOLING	38.9	40.5	1.6
WITHOUT COOLING	39.4	41.3	1.9

*Weight of the liner was taken without the cooling device

TABLE 4

OVERALL MEANS AND STANDARD DEVIATIONS OF MANUAL DEXTERITY BY COOLING TREATMENT

	WITH COOLING	SD	WITHOUT COOLING	SD
PURDUE PEGBOARD				
PREF. 1*	27.2	5.67	22.4	4.67
BOTH	13.2	1.93	11.7	1.89
LEFT*	11.7	2.71	10.1	1.73
RIGHT	11.5	1.9	11.4	2.99
MANIPULATIVE APTITUDE TEST				
RIGHT*	12.3	2.34	10.4	2.3
LEFT	10.8	2.28	9.9	2.44
BOTH**	15.9	3.01	14.6	3.36
RLB*	38.6	7.07	34.2	7.68
ASSEMBLY*	22.2	4.02	19.5	4.14

*Indicates p<.05 for subject and treatment

**Indicates p<.01 for subject

CHAPTER V

SUMMARY AND RECOMMENDATIONS

The environment influences people's decision making process for clothing and the clothing they choose to wear influences their performance in a given job situation. People's clothing preferences do not always match their clothing needs for a specific environment. Therefore, there has to be a compromise between their clothing preferences and their clothing needs. Protective handwear in environments that involve some kind of chemical manipulation is a necessity because from 20% to 97% of the total chemical exposure can be on the hands (Bonsall, 1985; Popendorf, 1988; Grover et al., 1988). However, chemical protective handwear is not used by many of those that work with chemicals. Some of the problems described by glove users as reasons for not wearing chemical protective gloves are poor fit, poor manual dexterity, and low thermal comfort levels (Branson & Sweeney, 1991; Tremblay, 1989).

During the past decade, some chemical protective clothing companies (LC Dover, Exotemp, Ltd. and KT Corporation) have introduced and tested clothing that will prolong the worker's working time in high temperature environments by supplementing artificial cooling to certain garments (especially vests). Bernard et al., (1991) stated that productivity and efficiency of workers while wearing artificially cooled garments has increased from 30% to 200% in potential heat stress environments. The three types of artificial cooling available in the market are air cooling, liquid cooling, and ice cooling (Bernard et al., 1991). This cooling equipment influences the user's thermoregulation process by lowering skin temperature through the heat transfer processes of convection and conduction. Artificial cooling has been added to different types of garments (vests and body suits) but none artificially cooled glove or glove liner was found.

The purpose of this investigation was to develop and evaluate a prototype glove liner that provided improved manual dexterity and perceived thermal and sensorial comfort properties for those wearing chemical protective gloves while working in high temperature and relative humidity environments. By incorporating a cooling device into handwear, the investigator tried to increase the users' perceived thermal and sensorial comfort and their manual dexterity performance; and, therefore to positively influence the user's decision to wear protective handwear when manipulating chemicals. Four objectives were established for the investigation: to develop an artificially cooled glove liner, to compare subjects' perceived thermal and sensorial comfort and skin temperature between the two glove liner treatments (cooling and no cooling), to compare subject's manual dexterity between the two glove liner treatments (cooling and no cooling), and to compare sweat build-up within the glove liner between the two glove liner treatments (cooling and no cooling).

This investigation was divided into two parts: the development and evaluation of the artificially-cooled glove liner prototype. In order to develop an artificially-cooled glove liner, a systematic problem-solving approach for functional clothing design described in Watkin's 1984 book *Clothing: The Portable Environment* was used. The glove liner developed for the investigation was a thumbless, fingerless, one-layer cycling type liner with three pockets (upper hand, palm and under wrist) that hold the gel-filled, heat sealed plastic bags used as the cooling device. In order to evaluate the glove liner prototype a testing protocol was developed for this investigation.

TESTING PROTOCOL

The test was performed in the environmental chamber at the College of Human Environmental Sciences in Oklahoma State University during the Summer and Fall semesters. The environmental chamber was set up at the temperature of 26.5±2°C and relative humidity of 78±5%. Ten male college students from the ages of 18 to 25 that answered newspaper and flyer advertisements served as subjects. The subjects went through a pre-screening process; and, if selected, were paid the amount of $25.00 for their participation in the orientation session and the two test sessions. The test sessions consisted in a series of exercises of two manual dexterity tests (Manipulative Aptitude Test and The Purdue Pegboard) and an exercise protocol developed for this experiment (See Appendix A). In order to record perceived thermal and sensorial comfort, an adaptation of Hollies' (1977) perceived comfort ballots were filled out by the subjects at the beginning and at the end of the test and at intervals of six minutes throughout the experiment. Also, skin temperature was taken at three minutes intervals throughout the experiment. Sweat build-up was recorded by weighting the glove liners without the cooling device before and immediately after each test session.

CONCLUSIONS

This study tried to incorporate the use of artificial cooling in handwear to help increase perceived thermal and sensorial comfort levels and manual dexterity performances by lowering the skin temperature of the hand by the heat transfer processes of conduction and convection. When using chemical protective handwear, there has to be a compromise between comfort, dexterity and protection because there is nothing similar yet invented to the bare hand that will have high protection against chemicals and that will be thermally comfortable to the majority of the glove user population while permitting high levels of manual dexterity.

The use of artificial means in handwear for lowering skin temperature gave interesting results for the environmental conditions set for the experiment. As hypothesized the presence of the cooling device made a difference in the subjects' mean temperature and in the subjects' perception when responding to the descriptor cold. Whether the presence or not of the cooling treatment, the glove liner was perceived as definitely snug; mildly heavy, stiff, damp, clingy and sticky; partially rough; and almost not scratchy at all.

Two major points were often expressed by subjects in the open-ended glove comfort question: dampness and snugness. Dampness outside the glove system (condensed water vapor) was observed by the researcher in every test session that involved the cooling device. The researcher believes that the presence of condensed water vapor on the outside of the glove system when the cooling device was present may have negatively influenced the damp descriptor results. Perhaps, the presence of dampness in the outside of the glove system when the cooling device was present may have made it difficult for the subjects to respond to the descriptor damp. The researcher also believes that the presence of this condensation outside the glove system influenced the results when weighting the liners to record sweat build-up. Perhaps, when weighting the glove liners the amount of weight gain noticed when the cooling treatment was present was not only due to sweat build-up but to moisture take-up caused by the condensation rate that may have occurred inside the glove. Open ended comments by subjects also suggest that the cooling devices made the glove system fit more snugly at the fingertips.

In order to record skin temperature over time, the researcher used skin surface thermistors at three positions of the hand described as the upper hand, the wrist and the palm. The mean temperature of the wrist location over time was the highest of the three locations when the cooling treatment was present. The cooling devices for the upper hand and the palm locations included larger volumes of cooling gel than the wrist device. Therefore, the cooling devices for these two (upper hand and palm) were closer to the skin than the one for the wrist location. Perhaps, this situation helped to lower the temperature more efficiently at the upper hand and palm locations than at the wrist location.

Although only five out of nine dexterity test results were significantly different by treatment, there was a trend for higher manual dexterity scores when the cooling devices were present. Perhaps the perception that the glove system was snugger in the presence of the cooling device described by the subjects in the open-ended question gave them better precision when manipulating the small objects of the manual dexterity tests.

The bulkiness in the palm area due to the volume occupied by the cooling devices had positive as well as negative aspects concerning the overall glove comfort. The bulkiness helped to improve the fit of the glove at the finger tips making manual tasks easier. Tremblay's (1989) stated that "a tight fitting glove will increase cutaneous sensations and thus favor a worker's level of performance." (p. 85) At the same time, the bulkiness decreased the sense of touch in the palm area during grasping and grabbing situations.

The use of better designed gloves providing better fit, better perceived thermal and sensorial comfort properties and better manual dexterity performance can help increase the wearability of protective gloves and decrease hand fatigue in tasks related to pesticide use. Artificial cooling added into glove liners could also help increase the wearability of chemical protective gloves by allowing workers to increase the time spent in pesticide related tasks.

There are a number of serious questions to be answered. How cold is comfortably cold? How can the length of time for effective cooling be increased? How practical is the cooling device for farmers?

RECOMMENDATIONS FOR FUTURE RESEARCH

The following recommendations for future research were stated:

1. Continue to investigate the possibility of a different kind of cooling solution to enable a less bulky design.

2. Continue to investigate the possibility of a different design for the cooling device itself. More cooling coverage could be accomplished if a steady flow of cool air or liquid can be achieved through flexible tubing.

3. Conduct similar investigation with the glove liner prototypes using different types of materials, different design features and at different controlled temperatures and relative humidity environments.

4. It would be interesting to test the cooling prototype with the 100% cotton ARMY glove liner recommended by the chemical protective glove manufacturer.

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APPENDIXES

APPENDIX A

EXERCISE PROTOCOL

EXERCISE PROTOCOL

The following exercise protocol has been developed for this investigation in order to record skin temperature during simulated farmer's tasks. The exercise protocol will simulate farmers' tasks while mixing, loading and cleaning pesticides.

INSTRUMENTS

* Small tanks similar to the use for pesticide application
* 2 Buckets

PROCEDURE

The steps to be followed for the protocol were posted in the wall of the environmental chamber to ensure accuracy.

ENSEMBLE

* Remove small nozzle
* Replace with long nozzle
* Screw on top
* Simulate pouring bucket contents into sprayer
* Replace top
* Release handle (Push down and turn left)
* Pump 10 times
* Lock it
* Squeeze and Spray (Count until 10)

CLEANING

* Remove top
* Empty contents into bucket
* Simulate filling with cleaning solution
* Replace lid
* Shake 5 times
* Squeeze and spray (count until 10)
* Remove lid
* Empty contents back into bucket
* Replace top
* Replace small nozzle

APPENDIX B

SUBJECTIVE COMFORT RATING CHART

Subjective Comfort Rating Chart (Hollies, 1977)

If you note any of the comfort sensations listed below, put a rating in the appropriate box when requested by the operator. Use the scale: 4-partially, 3-mildly, 2-definitely, 1-totally, according to the intensity of the sensation.

	Rating Periods				
	1	2	3	4	5
Snug (Close fitting)	___	___	___	___	___
Heavy (Bulky, Thick)	___	___	___	___	___
Stiff (Rigid, Not Flexible)	___	___	___	___	___
Sticky (Viscous)	___	___	___	___	___
Cold	___	___	___	___	___
Damp (Moist,Somewhat Wet)	___	___	___	___	___
Clingy (Adhere)	___	___	___	___	___
Rough (Coarse, Not Smooth)	___	___	___	___	___
Scratchy (To Rub, Itching)	___	___	___	___	___

Please indicate how comfortable the glove was:

	Very						Very	
Comfortable	1	2	3	4	5	6	7	Uncomfortable

Comments on the parts of the glove that feel uncomfortable:

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

APPENDIX C

NON-DISCLOSURE AGREEMENT

NON-DISCLOSURE AGREEMENT

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

Dear Subject:

We have developed a novel glove liner design that is to be worn under protective and sports gloves. 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 clothing.

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) or **use or cause to be used** (in whole or in part) **all or any portion of my clothing 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 set clothing design.

If the foregoing accurately sets forth our entire agreement with respect to the disclosure of our clothing design, please so indicate by signing below.

Very truly yours,

AGREED:

(Signature of the Individual)

Dr. Donna H. Branson
Professor

Date

Brenda Melissa Velez-Torres
Graduate Student

APPENDIX D

INFORMED CONSENT

INFORMED CONSENT

I, ____________________________, voluntarily agree to participate in this study entitled "Development and Evaluation of a Glove Liner Design for High Temperatures & High Humidity Environments" through the department of Design, Housing and Merchandising, Oklahoma State University.

I understand that the purpose of this study is to develop and test a glove liner that is to be worn under chemical protective gloves.

I understand that I will be participating in two controlled laboratory tests with environmental conditions specified at 80±2°F and 78±5% RH. I understand that the procedure will include wearing jeans, long-sleeved shirt, baseball cap, briefs, socks and the test glove. I understand that I will be instrumented with six surface skin temperature thermistors (3 on each hand) and asked to complete seven comfort ballots through out each 40-minute test session. I understand that I will also participate in various activities including simulating mixing chemicals, cleaning equipment and completing several manual dexterity tests to the best of my ability.

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

1) experience in a research comfort study
2) knowledge that my input helped improve the acceptability of chemical protective gloves
3) $25.00 for my participation in <u>both</u> test sessions

I understand that there are <u>no risks</u> anticipated by the investigators for participants in the study and that records of this study will be <u>kept confidential</u> 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 anytime 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 E

COMMENTS MADE BY SUBJECTS WHEN ASKED TO COMPARE BOTH TREATMENTS

COMMENTS MADE BY SUBJECTS WHEN ASKED TO COMPARE BOTH TREATMENTS

SUBJECT #1

LINER FIT-Some bulk at the metacarphalangeal joints.
WITH COOLING-"They are a bit sticky, a bit thick to handle small parts."
WITHOUT COOLING-"The glove is bit thick to handle small objects. It causes bit damp but not uncomfortability."
COMPARISON- "The one without is comfortable than the one with the pads."

SUBJECT #2

LINER FIT-Short at the middle finger at the MC joint. Kind of big around the thumb, make it a little bit difficult to grab things.
Comments- Had problems when screwing the rods due to excess of fabric in the thumb. The rod will roll and get caught in the nitrile glove. We stopped the first time and started all over again.
WITH COOLING- "Dampness within the glove was slightly noticeable. Palm pack was a little cumbersome."
WITHOUT COOLING- "Thumbs tend to be loose at times. A little tight across back of hands."

SUBJECT #3

LINER FIT-A little bit long at the small finger.
Comments- He had the best readings yet for the second readings of the Purdue test, maybe due to the fact that he is use to work with his hands, he's a musician.
It seems he did not like the idea of the cooling, I could see it in his face. He had a juice while doing the tests, he was grabbing it with his left hand. He kept pushing glove down for better fit at the finger tips. The probe #1 (left 1) did not record temperature until the 8th reading when cooling was part of the liner.
WITH COOLING-"The bulky part where the cold packs are (where uncomfortable). At first the cold pack was very uncomfortable. Snug , bulky, impedes movement, sticky, warms up with time, dampness on outside of gloves, rough on inside, scratchy, YES!."
WITHOUT COOLING-"Impedes feeling in fingertips"
COMPARISON-"At the end of the experiment, the cold packs warm-up and make my hands even more uncomfortable than the 1st pair (no cooling). The first pair is much easier to work with."

SUBJECT #4

LINER FIT-Very Good
Comments-He talked about the liner being too cold at the beginning. This was shown at the readings for probes 4 and 6 where temp could not be recorded. The cold packs are stiff making dexterity harder. The bulk at the palm make the wearer feel that he cannot grasp things properly. As soon as the cold packs become warmer movement is easier and dexterity is better.
WITH COOLING-"(1)The portion of the palm of the glove is thick and gaudy. (2)AT the onset the glove is extremely cold (3) Mildly sticky as the time passes."

WITHOUT COOLING-"(1)The glove (rubber) tends to hinder in finger dexterity (2) The sweat makes the gloves mildly clammy. Very close fit to hand a bit gaudy but really uncomfortable, fingers are slightly inflexible, sticks to the fingers, the texture is not smooth to the touch (fingers)."
COMPARISON- "In comparing the comfort of the Glove A= Ice Pack and Glove B=Regular glove unit I came to my overall conclusion about their comfort.
1.Glove A is a bit bulky in the palm area. Glove A is very moist at times. Glove A is moderately rigid at the onset of any operation overall. Glove A would get a "B-" rating. Scale A-F.
2. Glove B is a bit more flexible than Glove A. Glove B is not cold compared to Glove A. Glove B has more range of motion than Glove A. Overall: Glove B would get an "A-" rating. Scale A-F."

SUBJECT #5

LINER FIT-Very Good
WITH COOLING-"This glove allowed for more dexterity and control."
WITHOUT COOLING-"Fingertips feel a bit awkward due to inability to grab accurately."

SUBJECT #6

LINER FIT-Good
WITH COOLING-"La parte mas incomoda es la del dedo pulgar, el movimiento se hace un poco dificil pero no mucho."
WITHOUT COOLING-"Senti que el guante se me iba de los dedos lo que me impedia el movimiento entre los dedos y las puntas no me permitian un trabajo preciso con el material pequeno."
COMPARISON-"En comparacion con el guante de ayer (WOC), este segundo resulto mucho mas comodo (WC). El problema con el de ayer era principalmente que el guante se corria a los dedos, impidiendome sujetar cosas pequenas. Ahora, con las ice-packs, parece que estas ayudan a sujetar el guante y evitar que se vaya a los dedos. Aparte de la extrana sensacion que es para mi usar guantes, (porque nunca los he usado) no encuentro ningun problema en su uso. Si acaso, el poco en el movimiento en el dedo pulgar. El material exterior es bastante elastico y algunas veces se prensaba entre mi dedo y la barra donde se ensartaban las tuercas."
TRANSLATION-
WITH COOLING-"The most uncomfortable part was the part of the thumb, movement was a little bit difficult but not a lot."
WITHOUT COOLING-"I felt that the glove was running away from my fingers so the movement between my fingers was hampered and the fingertips did not permit me to work precisely with small objects"
COMPARISON-"In comparison with glove used yesterday (WOC), the second one resulted more comfortable (WC). The problem with the one yesterday was that the glove was "running" away from my fingers impeding hold small things. Now, with the "ice packs", it seems that these help to hold the glove in place without leaving material to run to the fingers. Besides the point that I have never used gloves before, I don't find any problem in its use. The exterior material has enough elasticity and sometimes it will be in the way of my fingers and the nuts."

SUBJECT #7

LINER FIT-Good. Long but skinny fingers. This subject has worked with gloves before
WITH COOLING-"The fingertips make it difficult to grasp small objects.
WITHOUT COOLING-"My fingers were to short and the part of the glove that hung over made manual tasks difficult"
COMPARISON-"The second glove (WC) did not fill with perspiration as rapidly making it more comfortable and easier to use. The cooling units also made the glove fit more snugly, which helped make use of the fingers easier."

SUBJECT #8

LINER FIT-Very Good
WITH COOLING-"The coolant had some initial effect on comfort but once the temperature had reached a certain point there was little noticeably change in dampness or overall dexterity. The area between the fingers still seemed to want to "roll up" and cause some tightness."
WITHOUT COOLING-"The area between the fingers at the base of the fingertips a little tight when picking up very small items." He said that he was sweating at the MC area.
COMPARISON-"The "cooled" gloves provided extra comfort as far as preventing dampness but did little to change my perceptual ability to use my fingers once the glove were at body temperature I felt dampness occurring but that was the only discomfort I noticed. The "uncooled" gloves caused perspiration almost instantly but there seemed to be little difference in mobility of the two sets."

SUBJECT #9

LINER FIT-Very Good
WITH COOLING-Between Fingers: tightness
Around wrists: tightness
Tight on small finger
WITHOUT COOLING-Areas are tight between the fingers
COMPARISON-"The addition of the ice packs did increase the tightness of the gloves, enhancing grip in the fingertips, however the other increased tightness hindered movement of the fingers. The bulkiness of the ice packs increased fatigue of my small finger."

SUBJECT #10

LINER FIT-
WITH COOLING-"Thumbs don't fit snugly enough. Glove is kind of hot".
WITHOUT COOLING-"Gloves are hot and make hand sweat. Hard to pick up washers and little things. Gloves are a little stiff"
COMPARISON-"Cooling glove fit snugger. Hand didn't sweat as much in cooling glove. Heating glove was less restrictive. Overall-Cooling is more comfortable"

APPENDIX F

TABLES AND FIGURES

TABLE 5

OVERALL MEANS AND STANDARD DEVIATIONS OF HAND BY TREATMENT BY LOCATION

Level of HAND	Level of COOL	Level of LOCATION	N	TEMPERATURE(°C) Mean	SD
L	WC	1	122	28.27	7.73
L	WC	2	130	31.22	4.84
L	WC	3	130	29.9	6.79
L	WOC	1	130	35.02	1.29
L	WOC	2	127	34.85	1.42
L	WOC	3	130	35.71	0.96
R	WC	1	120	28.58	8.02
R	WC	2	130	30.8	5.43
R	WC	3	129	29.72	6.76
R	WOC	1	130	34.93	1.3
R	WOC	2	124	35.04	1.32
R	WOC	3	128	35.65	0.9

*Overall Mean Temperature with cooling = 29.83°C
Overall Mean Temperature without cooling = 35.20°C

TABLE 6

ANALYSIS OF VARIANCE FOR PRE AND POST-WEIGHT FOR SWEAT BUILD-UP

SOURCE	DF	MEAN SQUARE	F VALUE	PR>F
Subject	9	4.65	1.24	0.3853
Cool	1	5.03	1.34	0.2804
Error (a)	8	3.75		

Figure 4. Comfort- Clingy Over Time

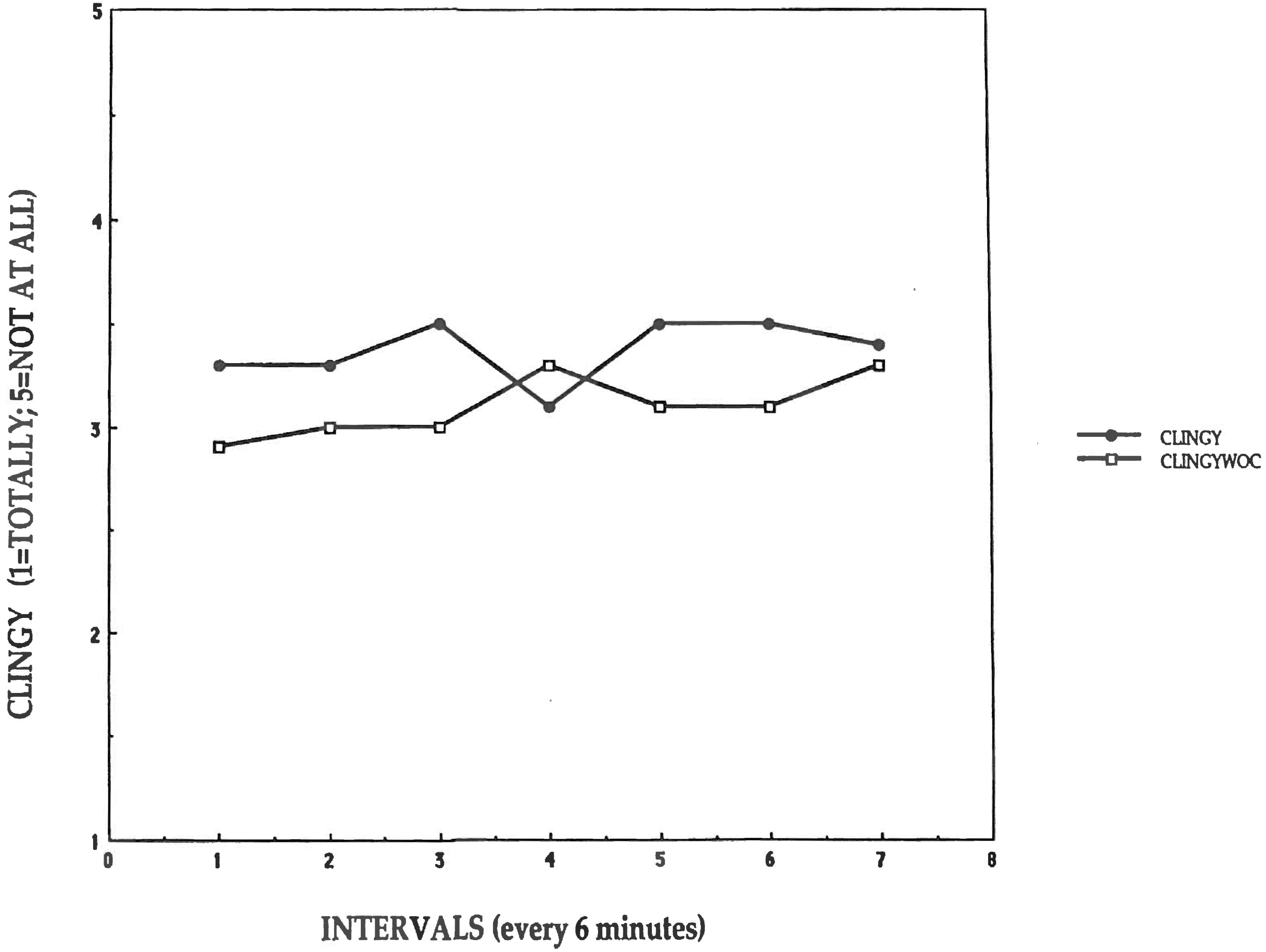


Figure 5. Comfort-Cold Over Time

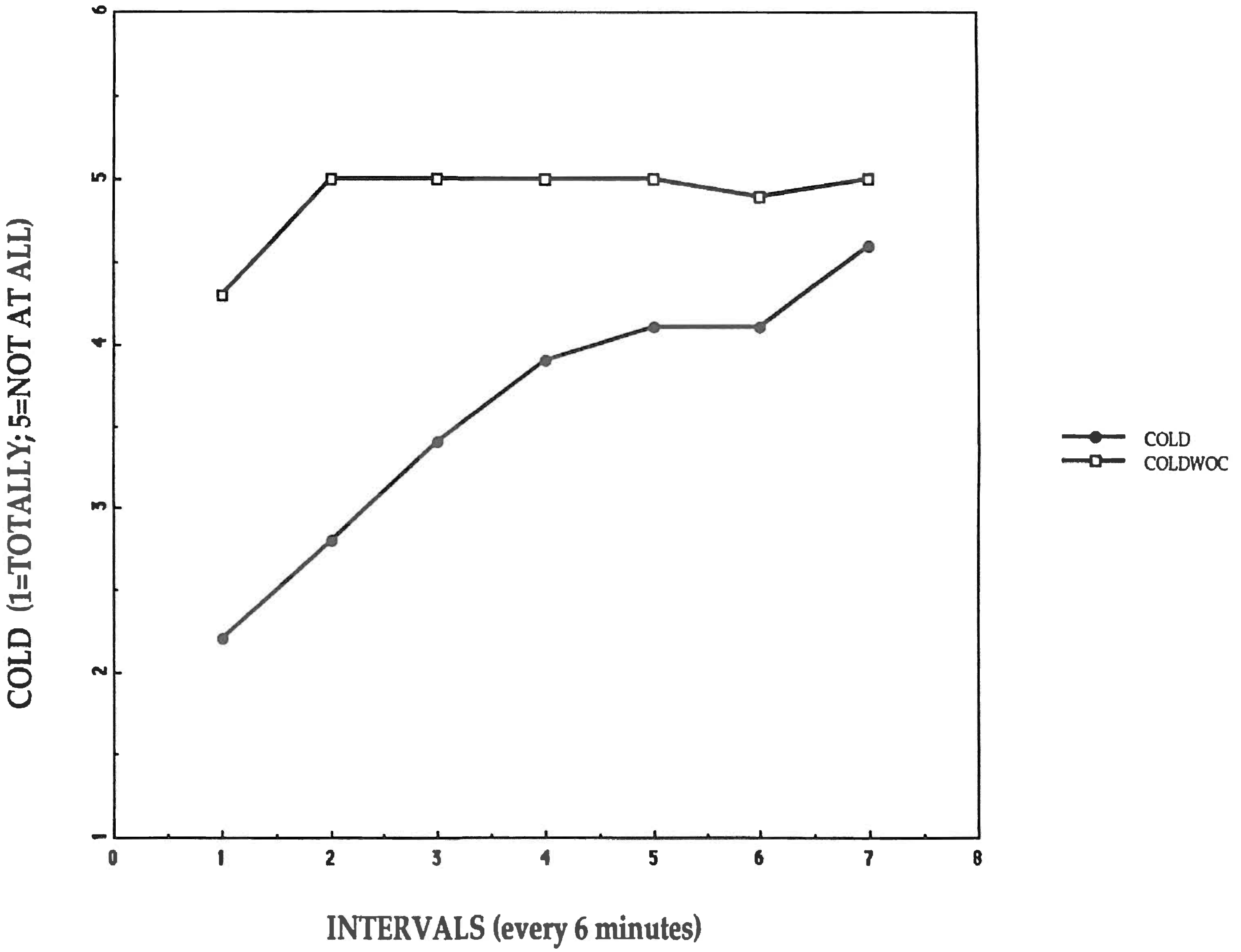


Figure 6. Comfort-Damp Over Time

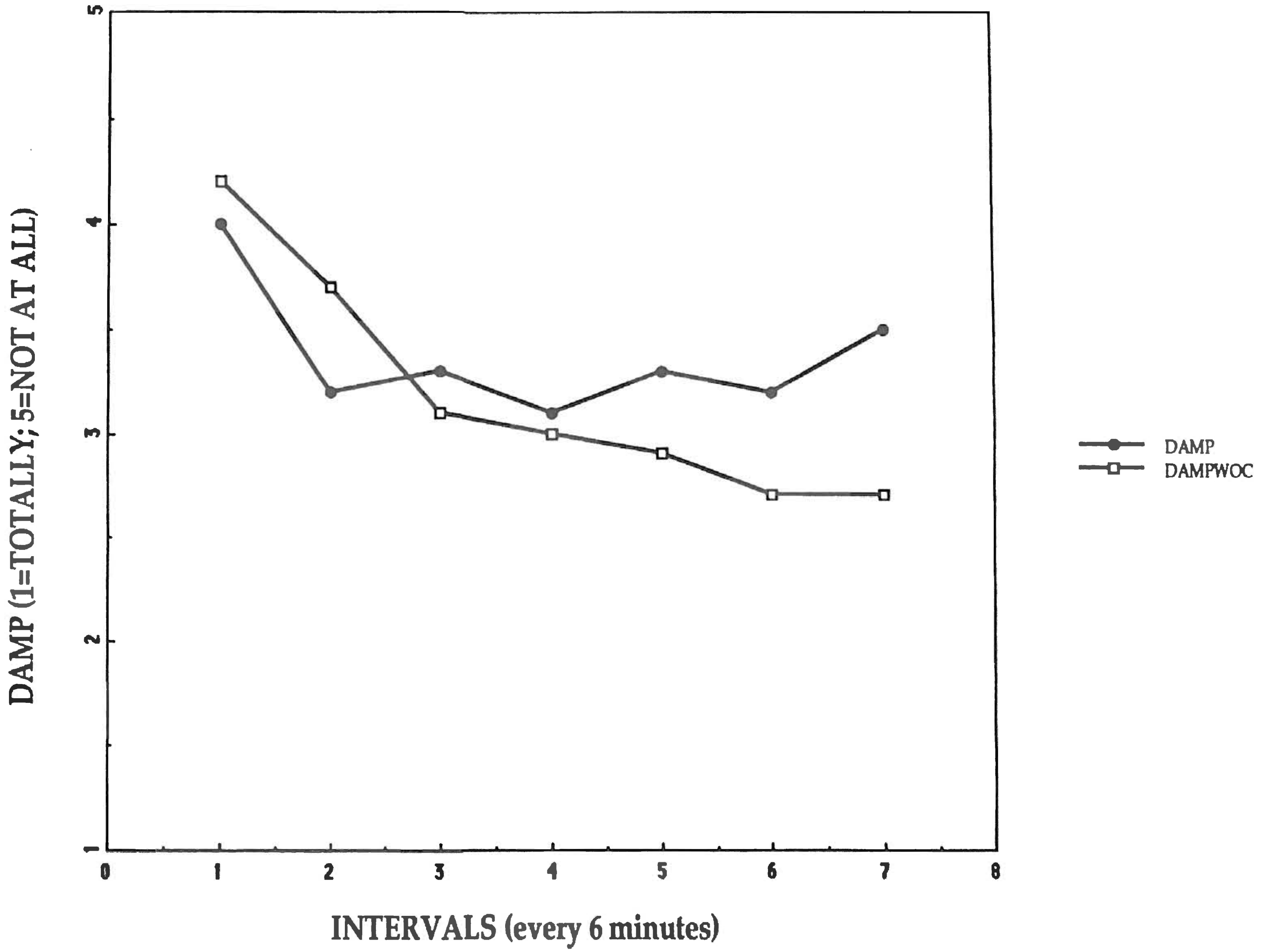


Figure 7. Comfort-Heavy Over Time

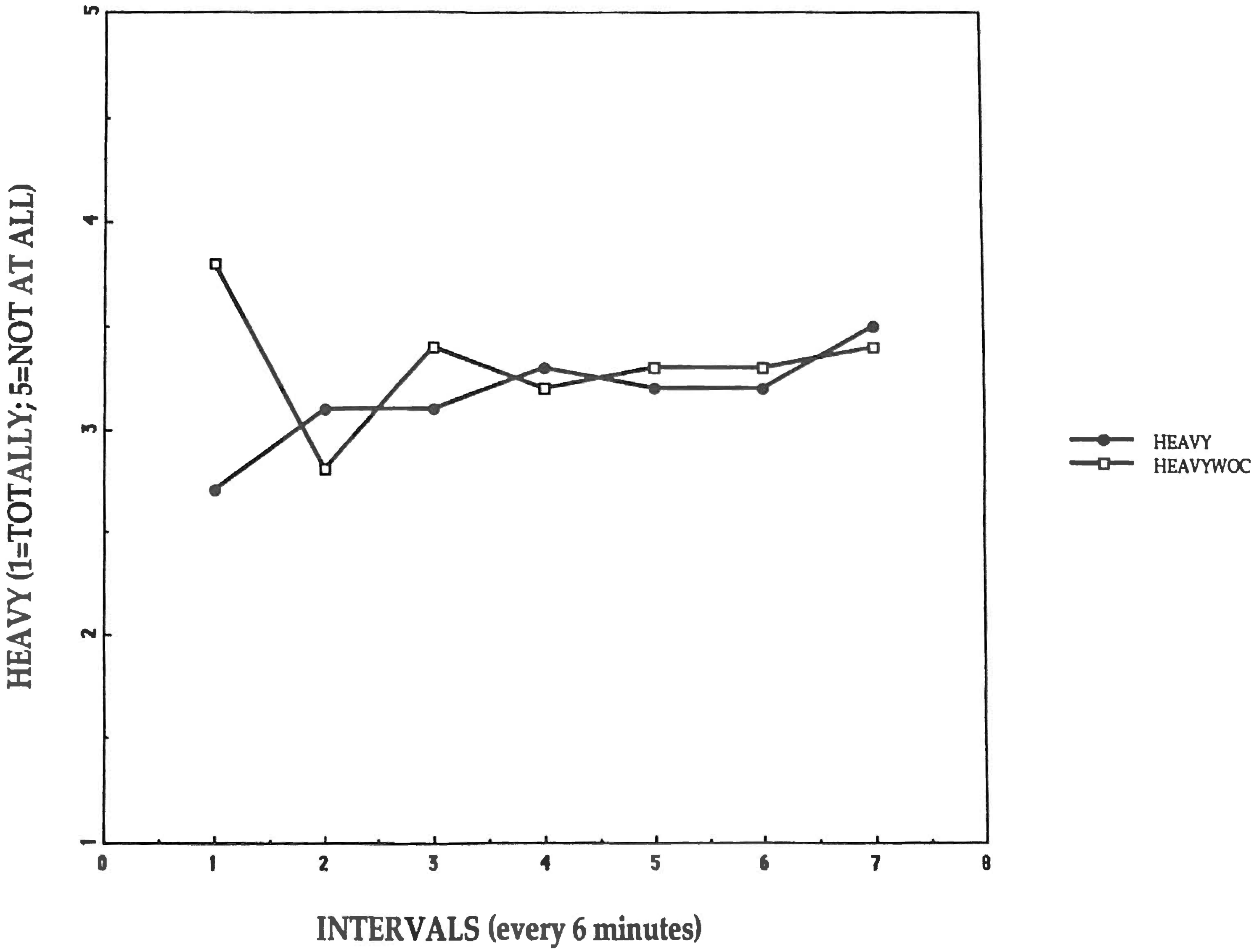


Figure 8. Comfort-Rough Over Time

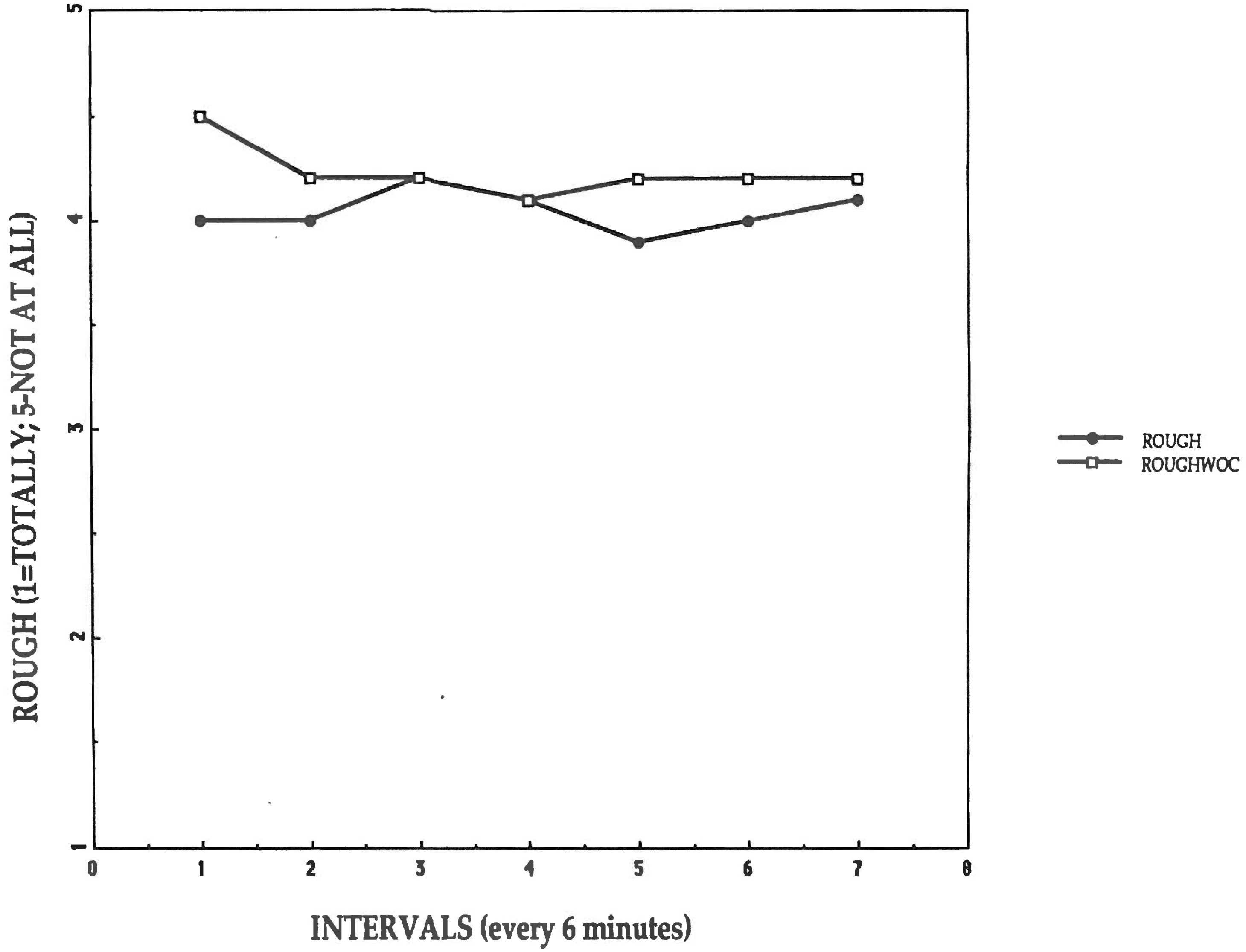


Figure 9. Comfort-Scratchy Over Time

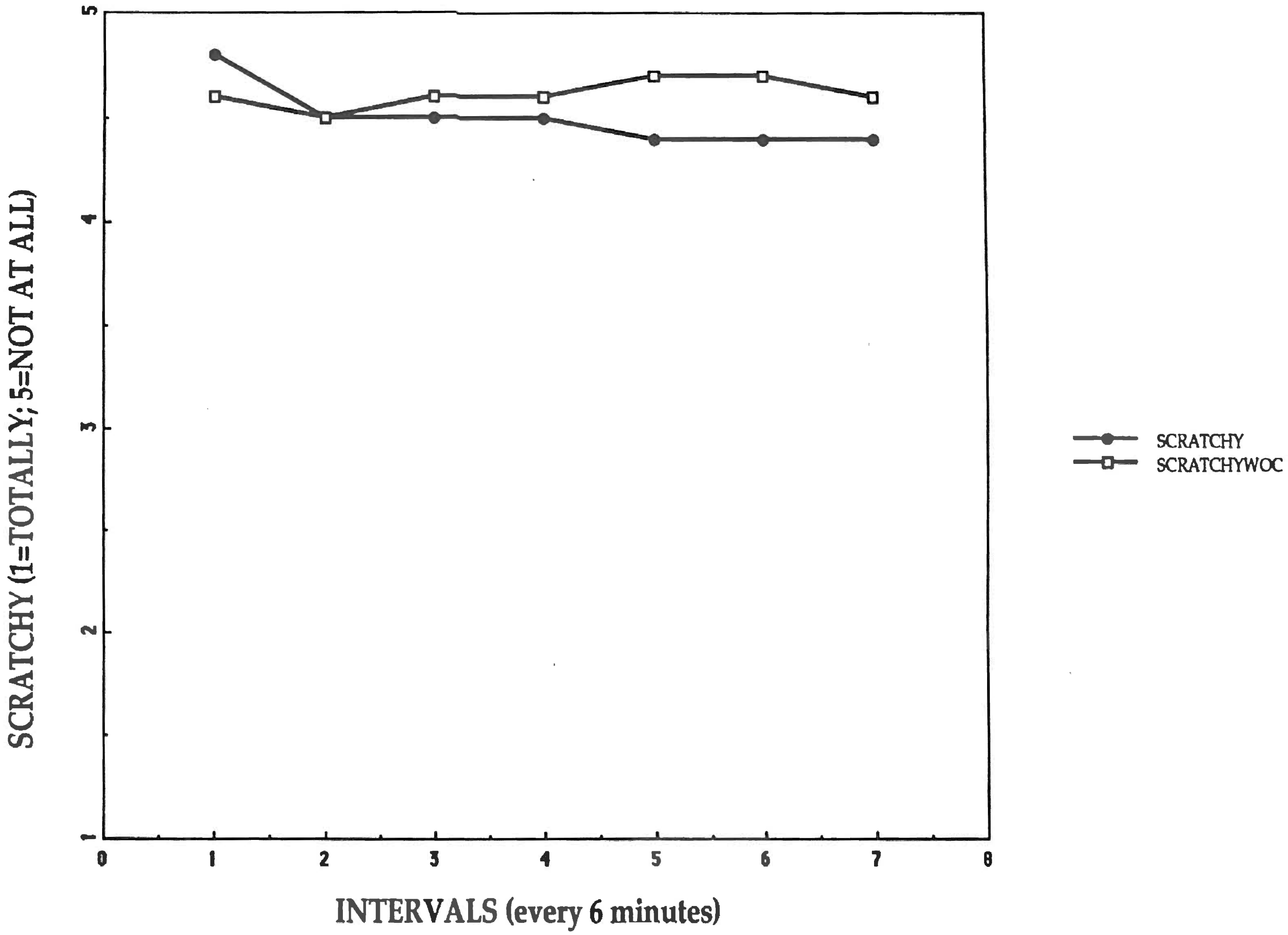


Figure 10. Comfort-Snug Over Time

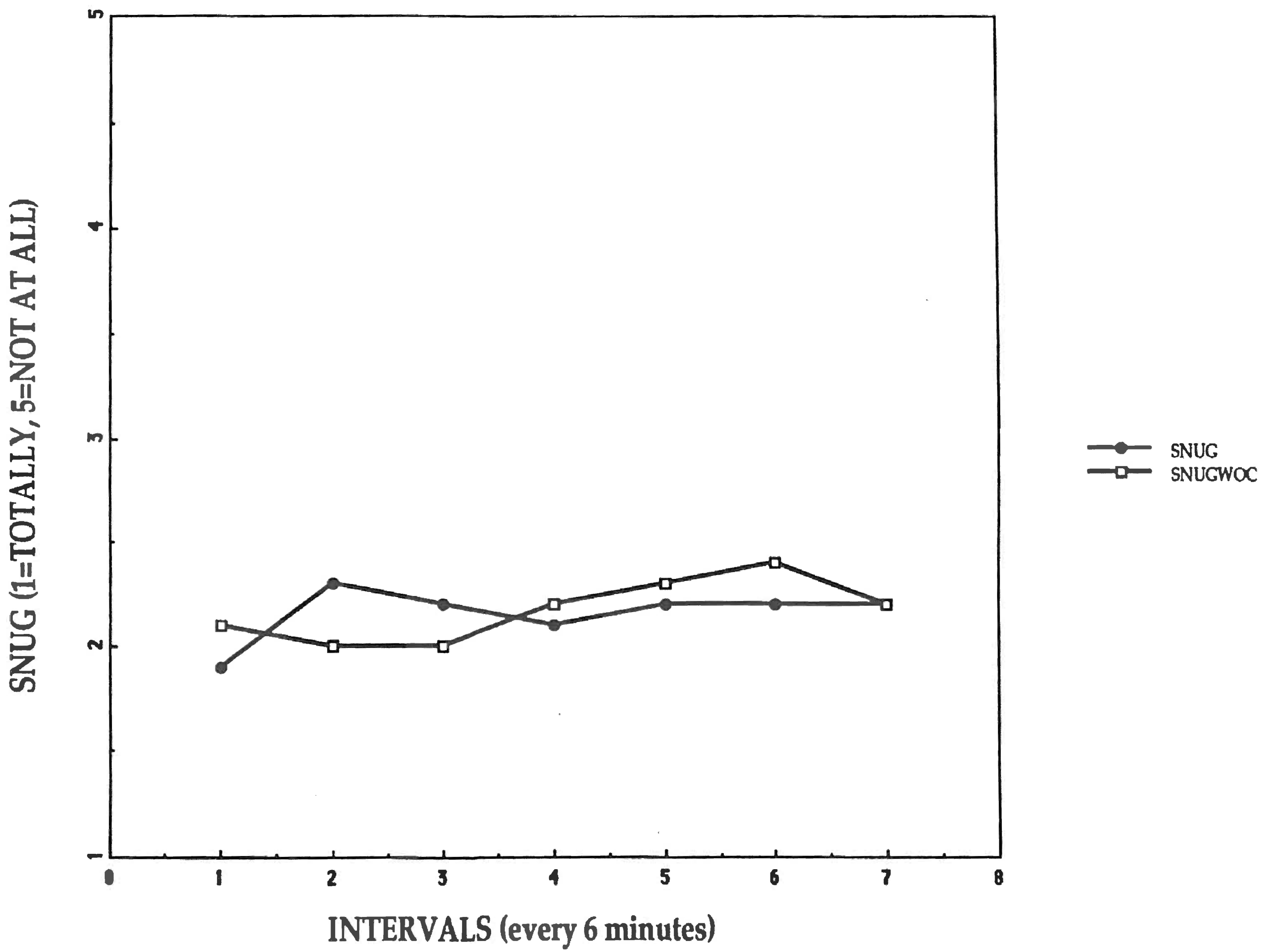


Figure 11. Comfort-Sticky Over Time

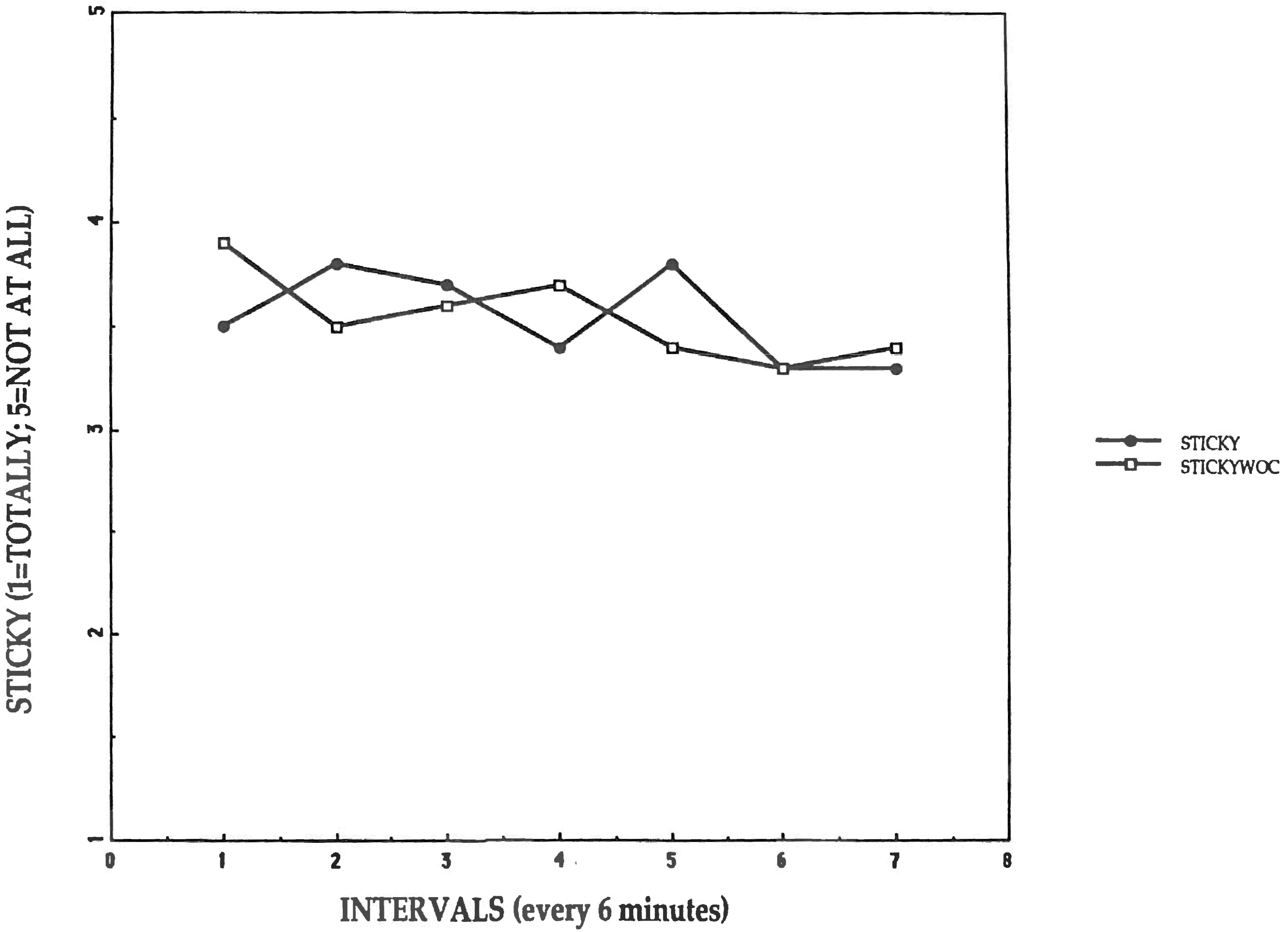


Figure 12. Comfort-Stiff Over Time

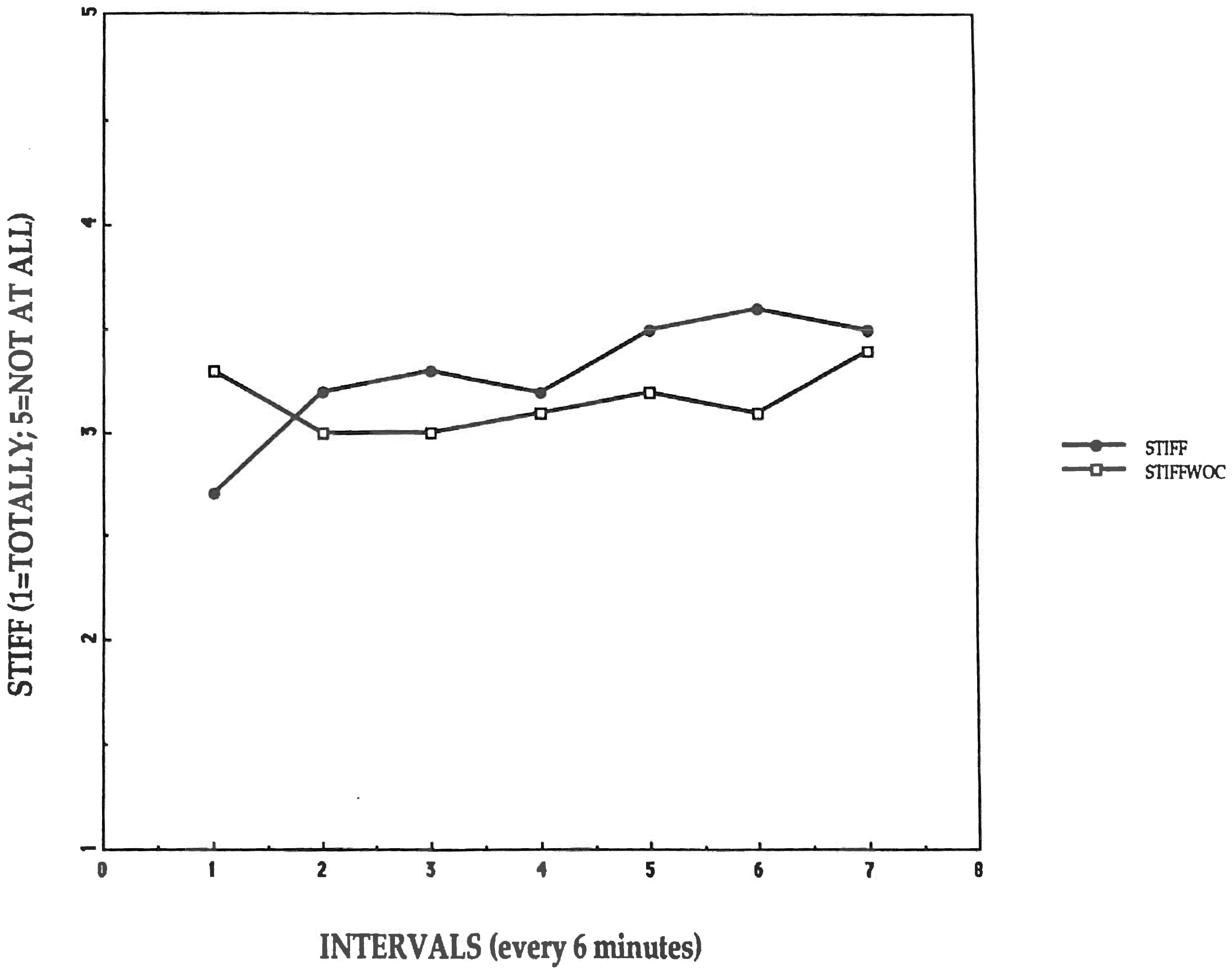


Figure 13. Manipulative Aptitude Test

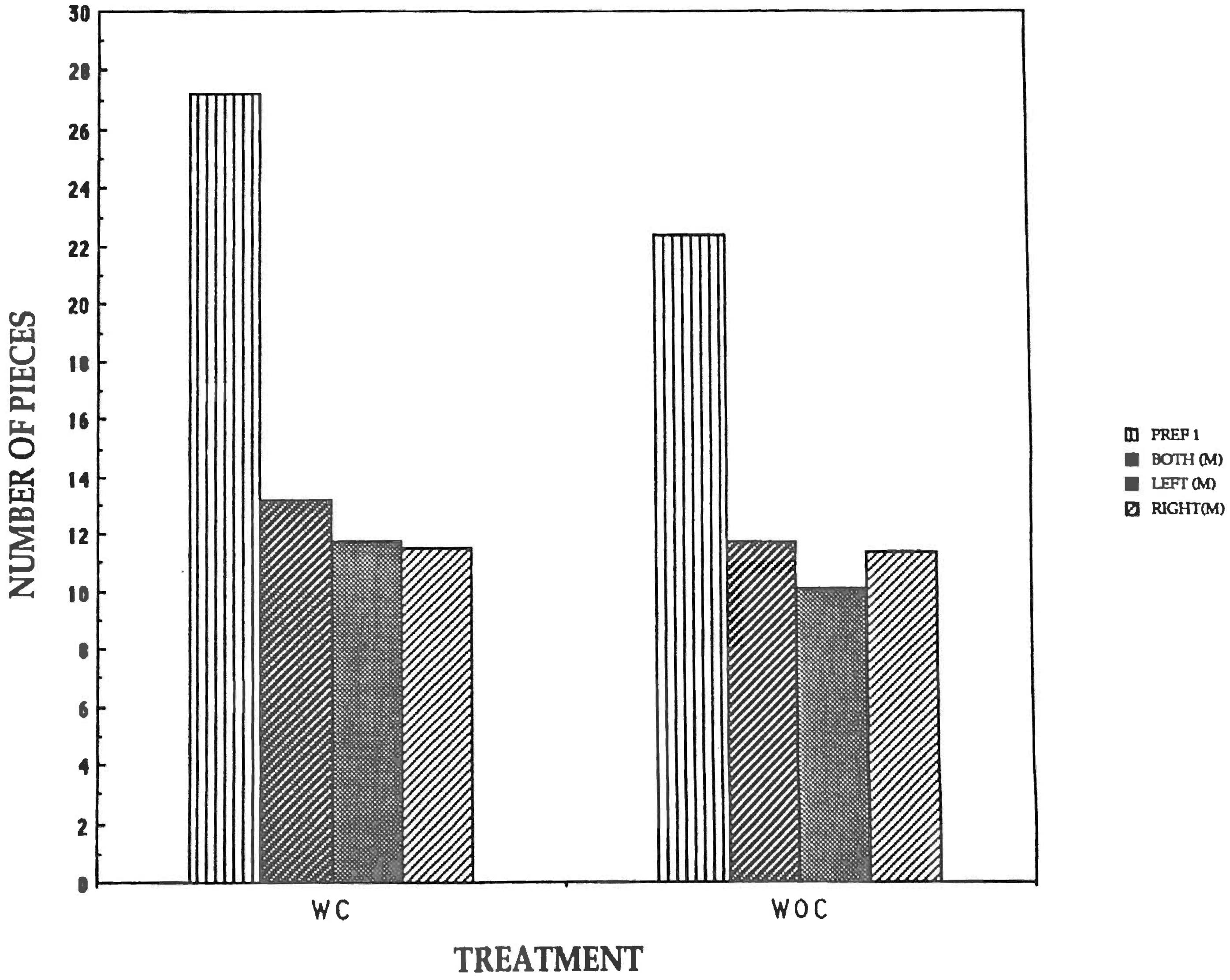


Figure 14. Purdue Pegboard Test

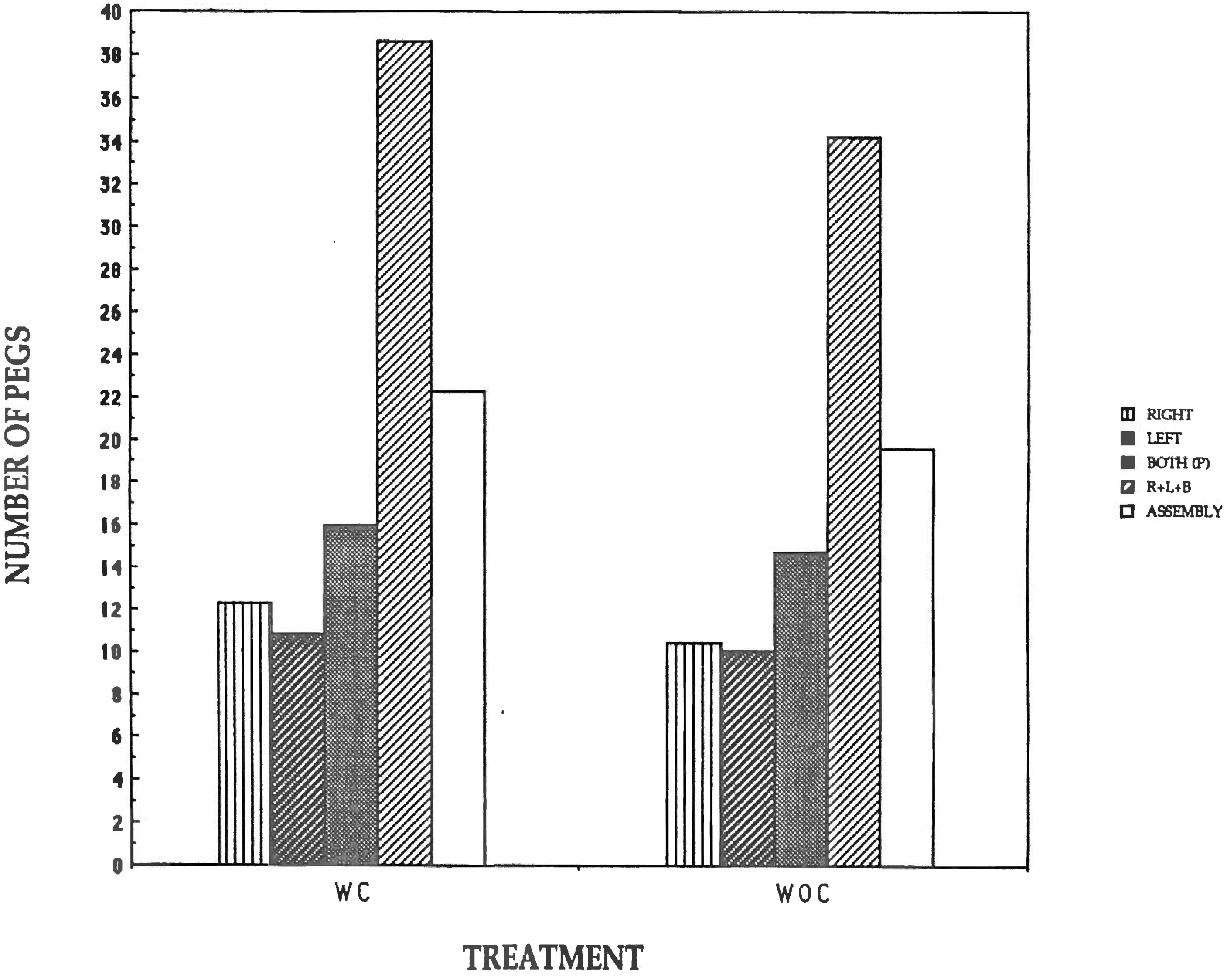


Figure 15. Mean Temperature by Treatment Over Time

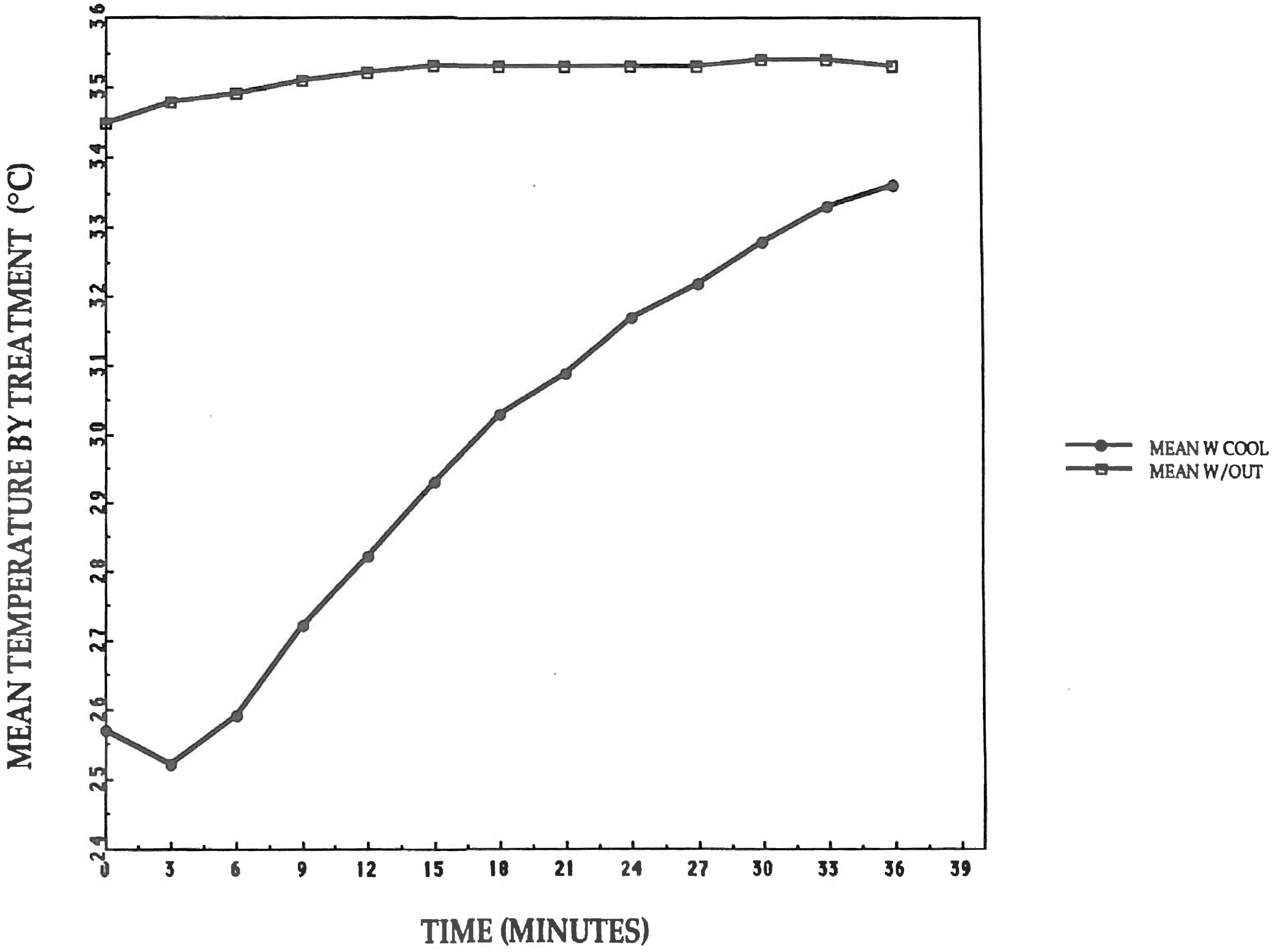


Figure 16. Mean Temperature by Left and Right Hand Over Time

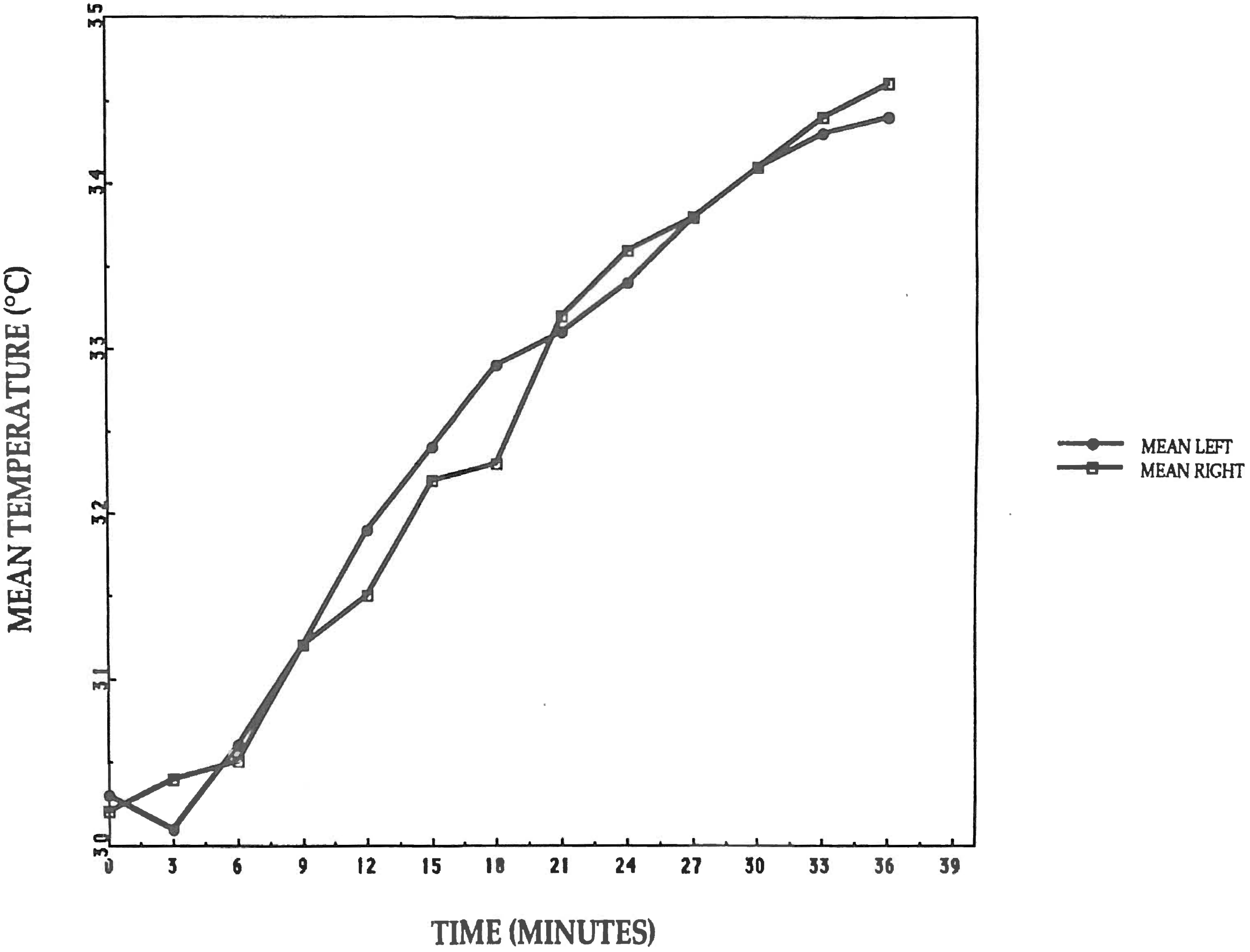


Figure 17. Mean Temperature With Cooling Over Time

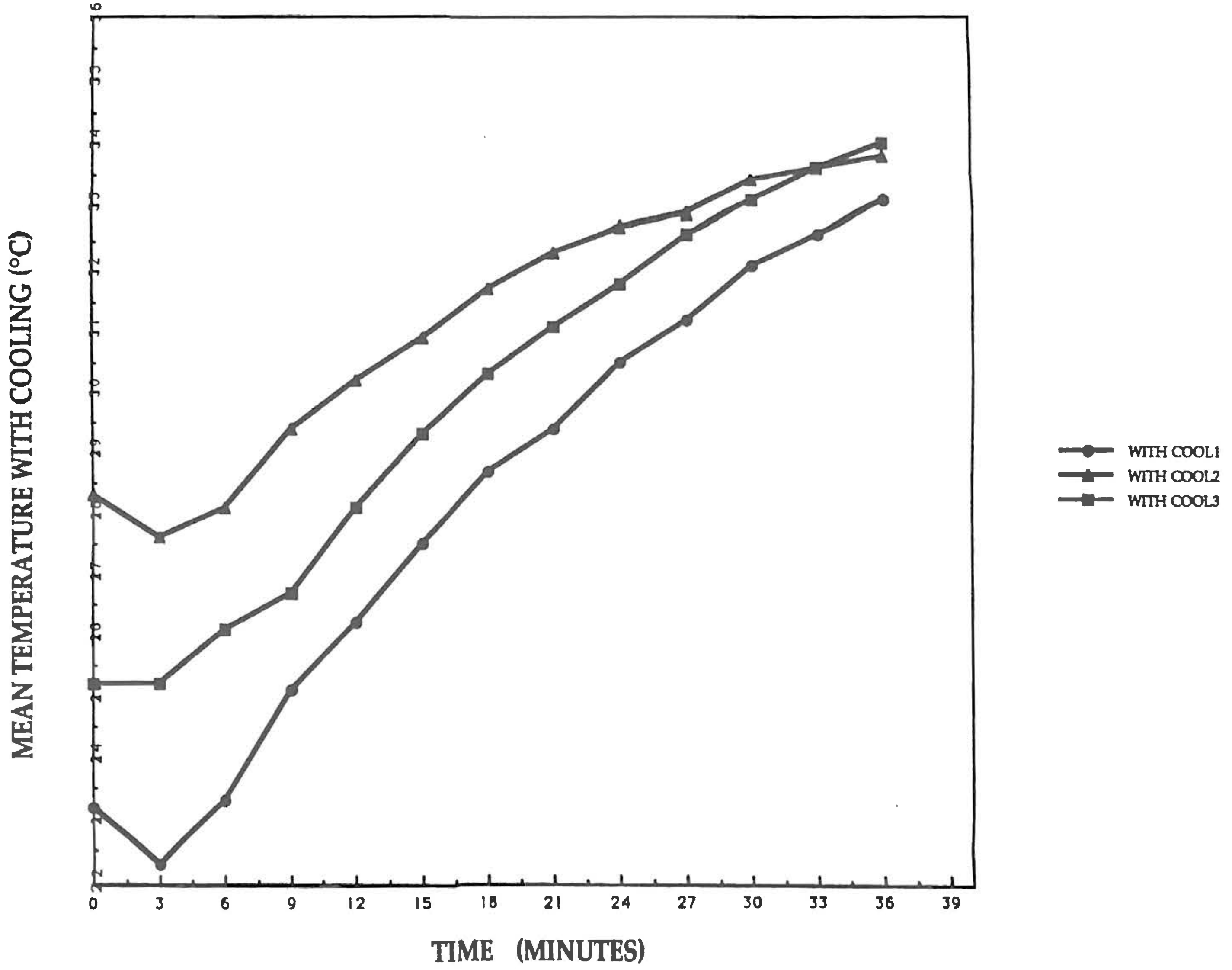
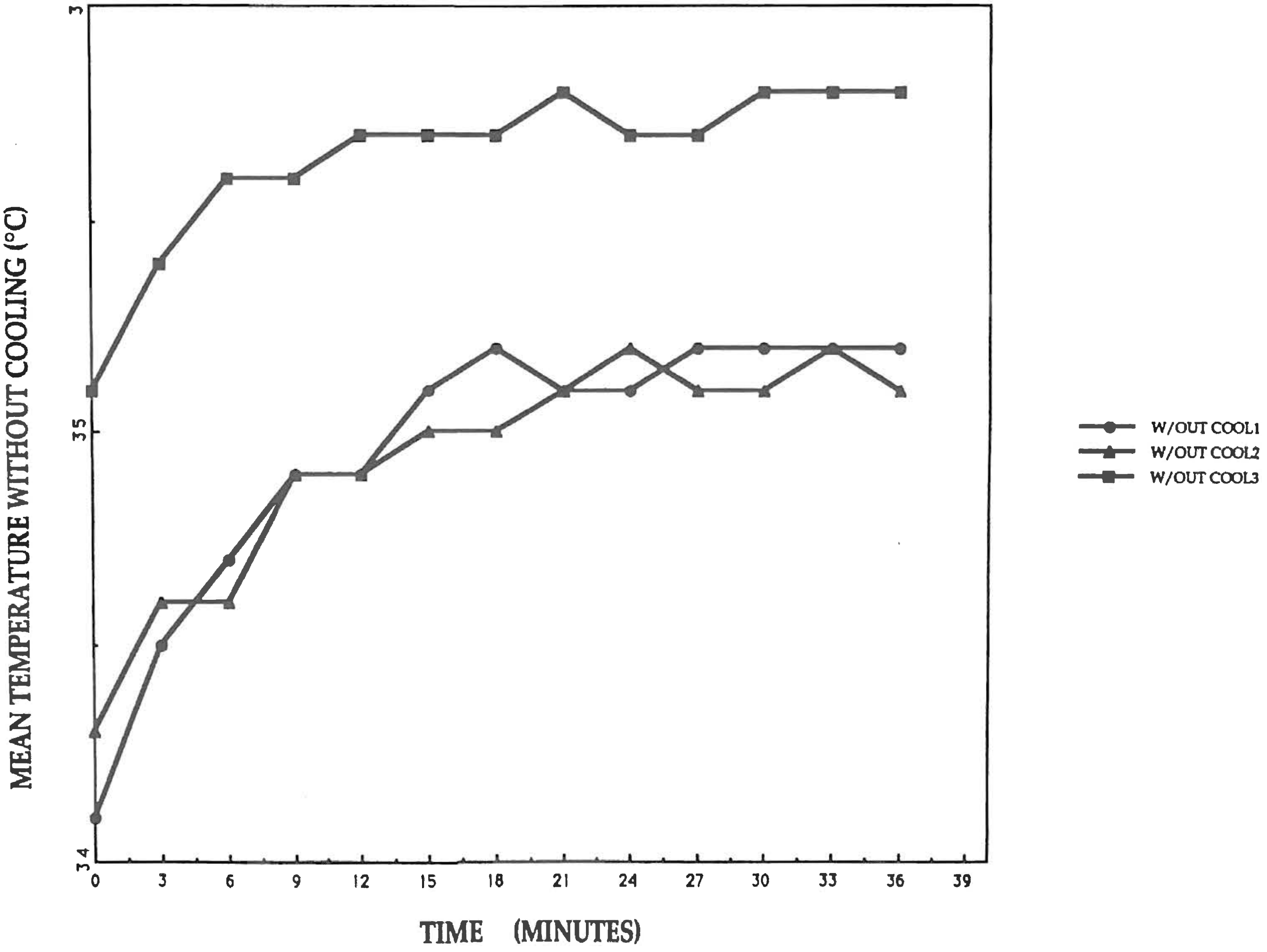


Figure 18. Mean Temperature Without Cooling Over Time



VITA

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Master of Science

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