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# Physiological comparison of protective clothing variations during prolonged work

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# Physiological Comparison of Protective Clothing Variations During Prolonged Work

By

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# ABSTRACT

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Physiological Comparison of Protective Clothing Variations During Prolonged Work (88 pgs.)

Director: Dr. Brian J. Sharkey

A recently-developed standard on protective clothing and equipment for wildland fire fighters (NFPA #1977, 1993) addresses outer garments and some accessories. This study describes development of a protocol for the study of clothing variations and a comparison of proposed changes. Four male and four female volunteers performed prolonged (120 minute) treadmill tests with four variations of the standard uniform: a short sleeve T-shirt (ST), a long sleeve T-shirt (LT), a shroud for face and neck protection with the short sleeve T-shirt (SH), and a no T-shirt control (NT), with test order determined by a balanced latin square design. The 120-minute tests, conducted with at least 72 hours rest, consisted of a treadmill walk at 5.65 km/hr (3.5 mph) and 4.5% grade with a 10.9 kg (24 lb) pack. The test was conducted at 32.2° C (90° F) and 30% RH, with radiant heat (radiant heat flux = 0.1 Watts/$cm^2$) during the first and third 30-minute segments. Heart rates, skin and tympanic temperatures, and perceived exertion (RPE) were recorded every 10 minutes, and weight loss and evaporative loss were determined after each trial. Male and female values were not significantly different so the data were pooled for repeated measures ANOVA. Significant order effects were found for HR and RPE ($p<0.029$ and .0001 respectively), indicating some acclimatization. Analysis of treatment effects did not reveal significant differences, although HR, RPE, weight and evaporative loss tended to be greater for the LT. Tympanic and mean body temperatures tended to be higher with the SH. Treatment differences were more pronounced at 120-minutes than 60-minutes, and the radiant heat segments were reflected in the skin temperatures. Treatment differences and heat stress indices were less for the higher fit subjects, indicating that uniform configuration may be less of a factor for those with higher fitness levels.

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## TABLE OF CONTENTS

## List of Tables and Figures

Table

Figure

# Chapter One

# THE PROBLEM

## Introduction

Fire fighting can be a strenuous physical activity, with high cardiovascular and thermoregulatory demands (Duncan, Gardner, and Barnard, 1979; Gavhed and Holmer, 1989; Romet and Frim, 1987; Skoldstrom, 1987). These stresses are a result of a competing demand for blood to the working muscles and to the periphery for cooling. Wildland fire fighters often work up to 14-24 hours in a variety of environments ranging from below freezing to above 49° Celsius (C), with relative humidities ranging from "very dry to very humid" (NFPA, 1993). Their work involves manual labor, and they face smoke inhalation, high ambient temperatures, high radiant temperatures, some convective heat, and even conductive heat in extreme circumstances. Given the changeable and extremely stressful conditions wildland fire fighters face, their protective clothing is of paramount importance.

In 1993 the National Fire Protection Association approved standards for Wildland Fire Fighting Protective Clothing and Equipment (NFPA #1977). Variations of the National Fire Protection Association wildland fire fighting uniform are sometimes worn, particularly in the undergarment T-shirt. While heavier clothing affords greater protection from radiant heat sources and increased puncture, tear, and abrasion resistance, it also impede body movement and cooling. The opposite holds true of lighter ensembles (NFPA, 1993). Given these variations, it is important to examine the physiological effects of various wildland fire fighting uniform configurations.

## **Statement of the Problem**

This study was conducted to determine the physiological effects of variations in the standard NFPA #1977 wildland fire fighting uniform. Additionally, this study attempted to establish a standard protocol for the evaluation of wildland fire fighting uniforms, and to develop baseline physiological data on the NFPA #1977 wildland fire fighting uniform.

## **Delimitations**

The delimitations of the study included the following:

1. The sample population was limited to 4 male and 4 female subjects.
2. As required for wildland fire fighting, a minimum score of 45 (ml/kg/min) on the Forest Service Step Test was required for subjects.

## Limitations

The limitations of the study included the following:

1. Subjects' motivation level was not controlled.
2. Diet, activity level, sleep, stress, lifestyle habits and outside activities of the subjects were not completely controlled.
3. The wildland fire fighting environment could not be exactly simulated in a laboratory setting.

## Hypothesis

The hypotheses are as follows:

1. There will be no difference in thermal stress of the subjects between the four uniform trials.
2. Heart rate and perceived exertion would follow the same pattern as thermal stress.
3. There would be no difference in weight loss experienced by subjects in the four trials.
4. There would be no difference in subjects' sweat evaporation proportion between the four trials.

## Definition of Terms

Conduction: transfer of heat from one object to another through direct contact.

Convection: transfer of heat through a moving fluid, such as air or water movement.

Core Temperature: A measurement taken to indicate the temperature of the body's core and vital regions.

Evaporation: heat loss from the changing of sweat from a liquid to vapor.

Sweat Evaporation Proportion: nude weight loss minus clothed weight loss, the smaller the value the greater assumed sweat evaporated from the skin and through the clothing.

Thermal Radiation: radiant energy emitted in proportion to the radiant surface temperature of a given medium.

Thermal Stress: hot environmental conditions which can result in strain or decline in physiological functions and systems.

## Basic Assumption

It was assumed that all subjects performed the tests to the best of their ability and followed the recommendations of the investigator.

## Significance of the Study

The information gathered from this study should be of value in the development of future uniform standards. This study provides information on human heat stress during prolonged work in wildland fire fighting gear, and contributes to the field of research in the areas of health, safety and work performance of wildland fire fighters.

# Chapter Two

# REVIEW OF LITERATURE

Contained in this section is a review of literature relevant to the study. The following sections comprise this review: (1) Physiological Responses to Work in a Hot Environment; (2) Effects of Work With Protective Clothing.

## Physiological Responses to Work in a Hot Environment

### Core and Skin Temperature Response

In thermal neutrality, a linear relationship exists between skin temperature and metabolic rate, as well as between sweat evaporation and metabolic rate. During exercise, metabolic rate and heat production may increase tenfold or greater over resting levels (Sawka and Wenger, 1988). As this increase occurs, the active skeletal muscles warm blood circulating through them, and other body regions are consequently warmed and core temperature is increased (Aikas, Karvonen, Piironen, Ruosteenoja, 1962; Melette, 1950). A proportional increase in core temperature during exercise occurs with increased metabolic rate. Core temperature rapidly increases initially during dynamic exercise, followed by a reduced rate of increase until a steady-state value is reached when heat loss equals heat production (Sawka and

Wenger, 1988).

This increase in core temperature occurs almost independently over a fairly wide range of environmental temperatures (Gonzalez, Berglund, Gagge, 1978; Lind, 1963; Nielsen, 1938; Nielsen, 1970). The range of environmental temperatures over which core temperature is unchanged is referred to as a "prescriptive zone" and this zone has been shown to narrow with increasing metabolic rate and increasing environmental temperature (Lind, 1963). Davies (1979) has shown that from 5° to 20° C at 65% relative max $VO_2$ intensity, core temperature response was independent of dry bulb temperature. However, it was found that core temperature was influenced by dry bulb temperature at 85% relative intensity. Lind (1963) examined core temperature responses to three metabolic intensities in "effective temperatures" (a formerly used measure combining the effects of dry bulb temperature, humidity, and air motion) between 10° and 35° C. Lind found that the upper limit of the prescriptive zone decreased with increasing exercise intensity, and that at each workload core temperature began a sharp rise between 25° and 26° C. Regardless of the prescriptive zone, individuals show higher steady-state core temperatures during exercise at higher metabolic rates (Saltin, Gagge, Stolwijk, 1970). While a good relationship exists between core temperature and metabolic rate, this relationship may vary between individuals (Sawka and Wenger, 1988).

Skin temperature changes may result from such physiological adjustments as cutaneous blood flow and sweat evaporation, or from such environmental alterations as air motion, temperature, and radiation. Physiological increases in skin temperature from work in a hot environment result from blood heated by convection in the deep body tissues when core temperature rises with increased metabolic rate. A reflex increase in skin blood flow carries this heated blood to the skin surface where heat dissipation may occur through convection, conduction, radiation, and evaporation. Skin temperature usually will show little change, as the warming of the skin from increased blood flow is usually balanced by the general cooling of the skin through sweating (Sawka and Wenger, 1988). While core temperatures have been shown to be largely independent of environmental temperature over a relatively wide range of air temperatures, skin temperature will be higher in a warmer environment, as affected by environmental conditions such as air convection, thermal radiation, and air temperature. Such external thermal influences on skin temperature trigger adjustments in skin circulation through reflex control of vasodilation and vasoconstriction as well as through direct action on the blood vessels (Brown, Hatcher, Page, 1953; Brown and Page, 1952).

While core temperature can be expected to rise with exercise in most circumstances, skin temperature response may be variable due to a combination of physiological and environmental factors.

## Physiological Cooling

Both core and skin temperatures affect thermoregulatory responses. As a result of increased heat storage, resulting from elevated metabolic heat production or environmental temperature, core and/or skin temperature will increase, evoking an increased heat loss response from the body's thermoregulatory controller. Thermoregulatory responses are more sensitive to changes in core temperature than skin temperature, as a 1° C change in core temperature elicits about nine times greater thermoregulatory response than a 1° C change in skin temperature. However, skin temperature influence is greater than the 9:1 ratio may suggest, because skin temperature typically varies over a much wider range than core temperature (Sawka and Wenger, 1988). Nadel, Bullard, and Stolwijk (1971) examined the role of skin temperature in the regulation of sweating, and concluded the following: a) sweat rate was proportional to core temperature at a constant skin temperature, b) sweat rate was proportional to mean skin temperature at a constant core temperature, and c) local sweating was dependent on local skin temperature at a given core and mean skin temperature combination. The inputs of core and skin temperature to the thermoregulatory control system evoke heat-dissipating responses and play a role in the control of sweating, vasodilation, and vasoconstriction (Gisolfi and Wenger, 1984).

A temperature gradient from core to skin is essential for body heat to be carried to the skin (Gagge and Nishi, 1983; Speckman, Allan, Sawka, Young, Muza, and Pandolf, 1988). This transfer of heat occurs through blood flow from the core and deep body tissues to the skin, where heat loss occurs (Speckman et al, 1988; Budd, 1981). When traveling from the core to the skin, some heat is lost to superficial tissues from where it may still conduct to the skin surface, and some of the lost heat is picked up by the now cooled venous blood and returned to the core. This effect diminishes the convective heat transfer efficiency of the blood, and can require increased blood flow to accomplish a given cooling.

The high sympathetic innervation of the superficial veins (Webb-Peploe and Shepherd, 1968) allows dilation in response to warming of the skin or core (Wenger and Roberts, 1980). This dilation allows the warmed blood to reach the skin surface for cooling. As warm blood flows to the skin surface, heat loss to the external environment occurs through convection, conduction, and radiation, as well as through sweat evaporation or condensation of water on the body surface (Sawka and Wenger, 1988). While some respiratory evaporative cooling occurs in humans, unlike most animals the magnitude is small in comparison to skin evaporative cooling (Gagge and Nishi, 1983; Mitchell, Nadel, Stolwijk, 1972).

The contribution of the various heat dissipation mechanisms has been shown to differ with environmental conditions. Core temperature, local skin temperature, skin wettedness, and environmental conditions all influence sweat secretion. The evaporation rate of sweat largely depends on air movement and the skin to ambient water vapor pressure gradient (Sawka and Wenger, 1988). Heat loss contribution from convection and radiation will also be greater at any given body mass with higher body surface area (Drinkwater, 1986; Shapiro, Pandolf, Avellini, Pimental, Goldman, 1980; Shapiro, Pandolf, Avellini, Pimental, Goldman, 1981). Nielsen (1938) had subjects exercise over a broad range of ambient temperatures at a variety of intensities. In the study, total heat loss, heat storage, and elevation of core temperature remained relatively constant at each exercise intensity for each environment, although the avenues for heat loss varied greatly depending on the ambient temperature. Sweating and evaporative heat loss predominated in the hotter temperatures, while convective and radiative heat loss predominated in the lower ambient temperatures (Nielsen, 1938). Further, evaporative heat loss will essentially account for all heat loss when ambient temperature is equal to skin temperature, and the body will gain heat if ambient temperature exceeds skin temperature (Sawka and Wenger, 1988).

Thermoregulatory control inputs from core temperatures, skin temperatures, and environmental conditions through peripheral receptors evoke physiological cooling mechanisms. These mechanisms result in circulatory and body fluid shifts, with varying heat loss responses. A variety of environmental and physiological factors can influence thermoregulatory responses.

**Body Water Loss**

Individual fluid volume loss through sweat is quite variable, although it has been reported that sweating rates are frequently as high as 1 liter/$m^{-2}$/$h^{-1}$. If sufficient amounts of fluid are not consumed, total body water will be decreased from sweat loss. As core temperature rises, dehydration is an associated result of exercise-heat stress (Sawka, 1988), and this body water loss can be detrimental to performance. Dehydration adversely affects heat loss, and leads to a reduction in sweating rates during heat stress exercise at a given metabolic rate (Sawka, Francesconi, Young, and Pandolf, 1984). At a given core temperature heat loss through sweating and evaporation will be reduced with graded dehydration levels (Sawka, Young, Francesconi, Muza, and Pandolf, 1985), and if blood volume drops with dehydration, convective, conductive, and radiative heat loss will be affected from decreased skin blood flow.

A 2-4% water deficit has been shown to reduce maximal aerobic power and physical work capacity when working in a hot environment (Craig and Cummings, 1966). Even in a moderate environment, dehydration combined with hyperthermia reduces exercise time by 12% and maximal aerobic power by 6% as compared to euhydration (Sawka, Knowlton, Glaser, Wilde, and Miles, 1979). Dehydration also impairs submaximal endurance exercise by affecting the thermoregulatory and cardiovascular systems (Sawka, Knowlton, and Critz, 1979a). A 3-4% dehydration level can increase heart rate, decrease stroke volume, and decrease cardiac output compared to euhydration in moderate (Nadel, Cafarelli, Roberts, and Wenger, 1979) or severe (Sawka et al, 1979) heat stress during submaximal exercise. In these situations, the decreased stroke volume is not compensated for by the increased heart rate, resulting in a lowered cardiac output (Sawka and Wenger, 1988).

With exercise, particularly when combined with heat stress, dehydration can cause significant physiological effects. Dehydration will be detrimental to performance primarily through reduction of cardiovascular and thermoregulatory function.

## Heart Rate and Perceived Exertion

Exercising in the heat has been shown to result in greater cardiovascular stress than exercise in a neutral environment (Gisolfi and Wenger, 1984), including a higher heart rate and lower stroke volume at any given workload

(MacDougal, Reddan, Layton, and Dempsey, 1974). These cardiac responses appear to be a result of a combination of factors including increased core and skin temperature, increased skin blood flow, and dehydration (Gavhed and Holmer, 1989; White and Hodous, 1987).

With peripheral reflex vasodilation for heat dissipation at the skin surface, skin blood flow increases and blood pools in the skin. A displacement of blood from the thorax results, decreasing central blood volume and cardiac filling (Rowell, 1983a; Rowell, 1983b). Therefore, the higher cardiac output demanded by the combination of exercise and heat stress requires an increase in heart rate to sustain cardiac output. In an upright human, about 70% of the blood volume is below heart level (Rowell, 1983a), which magnifies the problem of decreased cardiac filling and reduction of stroke volume when exercising in the heat (Roberts and Wenger, 1980).

Additionally, fluid shifts rapidly occur between plasma and tissues when exercising in the heat (Harrison, 1985). These shifts can occur even before substantial fluid loss from sweating results, and the direction and magnitude of such shifts depends on factors such as temperature, hydration level, heat acclimatization, and exercise type and intensity. These effects may increase or decrease plasma volume, which would increase or decrease the effects of the skin blood pooling (Sawka and Wenger, 1988). In times of sweating, much of the sweat lost may be from extracellular fluid, including plasma, therefore reducing blood volume. Any reduction in blood volume would reduce venous filling and stroke volume, therefore requiring an increased heart rate at any given cardiac output as exercise in the heat continues.

Increased discomfort and perceived exertion is associated with an increase in heart rate (ACSM, 1991). Therefore, increased Ratings of Perceived Exertion and discomfort would be expected with most subjects exercising in a hot environment.

Exercise in the heat and dehydration will increase heart rate due to fluid shifts and fluid losses. Not only will heart rate rise, but increased discomfort can be expected as well.

## Individual Factors Affecting Heat Tolerance

Thermoregulatory differences between men and women had previously been thought to be specifically related to gender. However, with increased mean body temperature in large populations, the major sweat secretion determinant, independent of gender and age, is maximal aerobic power (Gonzalez, Berglund, and Stolwijk, 1980). Gender may influence the way heat is lost, as some evidence exists for men having a higher capacity for evaporative heat loss, possibly giving men a thermal advantage in dry heat (Gisolfi and Wenger, 1984; Shapiro et al, 1981). When skin temperature is greater than ambient temperature, women are thought to show a greater reliance on convective and radiative heat loss than men because of their generally higher surface area to mass ratio, which is also thought to be advantageous in humid heat, when evaporative potential is reduced (Shapiro et al, 1980; Shapiro et al, 1981; Drinkwater, 1986). While the female menstrual cycle can produce alterations in core temperatures, there also appears to be a parallel alteration in the core temperature threshold for heat loss response during menstruation, and work-heat tolerance appears to be only slightly or not at all affected by menstrual cycle (Drinkwater, 1984). Calendar age is a factor which has been shown to, in itself, not affect thermoregulatory capabilities independent of physical activity levels and aerobic capacity, although some small differences in various thermoregulatory responses have been noted (Smolander, Korhonen, and Ilmarinen, 1990). Heat acclimated individuals demonstrate greater physiological responses to maintain heat balance at lower core and skin temperatures, and at any given core and skin temperature demonstrate greater ability to handle heat stress (Sawka and Wenger, 1988). Fit individuals usually respond better to heat stress than unfit individuals, as the fit individual begins sweating at a lower core temperature and at any given core temperature will produce more sweat, keeping core temperature closer to normal (Henane, Flandrois, and Charbonnier, 1977). To summarize, individual fitness level and acclimatization status appear to be more important than gender or age in heat tolerance (Drinkwater, 1986).

## Effects of Work With Protective Clothing

### Protection

The National Fire Protection Association (NFPA #1977) standard wildland fire fighting uniform includes pants, overshirt, helmet and gloves, and optional shroud (NFPA, 1993). The suggested fabric weight of the pants is 8 to 12 oz/yd$^2$, while overshirt suggested weight is 5.5 to 6.5 oz/yd$^2$. The addition of a T-shirt, weighing between 3.0 and 4.0 oz/yd$^2$ produces a combined fabric weight for the upper body in the recommended 8 to 12 oz/yd$^2$ range. The NFPA report suggests this to be the best range of fabric weights to protect from radiant heat danger without excessive inhibition of body movement and cooling. This protective clothing system not only protects against tears and abrasions, particularly in the lower body where they are most likely to occur in wildland fire fighting, it increases the ensemble's thermal protective performance by increasing the air and fabric layer between the skin and the radiant heat. The increased weight of the undergarment increases the thermal radiant heat protection and decreases burn injury extent by 15%, according to the NFPA #1977 document (NFPA, 1993). The greater the area covered, such as when wearing a long sleeve undershirt, the greater the thermal protection. For prevention of serious burns, experience and analysis of wildland fire fighting protective clothing shows loose-fitting clothing to be more important than the fire resistance of the material, as tight clothes increase radiant heat danger and heat stress, and decrease performance ability (NFPA, 1993).

## Clothing Heat Stress

The increased protection afforded to wildland fire fighters by wearing undershirts also increases the probability of heat stress during physical activity (NFPA, 1993). Resistance to heat flow through fabrics is a function of temperature gradients between air layers and the thermal resistance of the clothing. Heat flux from the body depends on the temperature difference between the skin and ambient air, as well as the thermal resistance of the clothing and fabrics with the trapped air layers. A decrease in the thickness of the trapped air layer will decrease thermal resistance (Farnworth and Crow, 1983). Clothing, while offering protection from the environment, is also an added barrier to heat loss (Belding, 1967; Gagge, 1972; Gagge and Nishi, 1983).

### *Convective, Radiative, and Conductive Heat Loss*

Increased ventilation from clothing adjustments and a loose fit can allow greater convection within and between garments, and more ambient air circulation (Budd, 1981). The insulative value of clothing can be decreased with movement due to air circulation between and through the clothing layers, and this reduction of insulation is exacerbated by wetness of clothing, whether from sweat or external sources (Budd, 1981). While some convective and radiative heat loss is possible with adequate ventilation and heat movement through clothing fabrics, clothing systems inhibit heat loss. Conductive heat loss, which results from direct physical contact with another object, is not considered a significant avenue for heat loss in the context of this study.

### *Sweat and Evaporative Heat Loss*

If air and radiant temperatures are greater than skin temperatures, then evaporation through the clothing must eliminate not only the metabolic heat produced, but the heat gain from radiation and convection through the clothing (Goldman, 1990). When wearing protective clothing, evaporation potential becomes a function of not only the water vapor pressure difference of the skin and environment, but the permeability of the clothing as well (Budd, 1981; Goldman, 1990). The evaporative impedance of the protective clothing system causes sweat to soak into the clothing. This sweat movement is not as effective as evaporation for heat loss, resulting in an increased thermal burden (Budd, 1981), causing problems at high air temperatures when evaporative heat loss can be crucial (Gonzalez, 1988). Even with a complete vapor barrier layer, "effective evaporative heat loss" may occur, as sweat can evaporate off the skin and condense on the inner surface of the vapor barrier, from where heat can be lost to the environment through non-evaporative means. Further, as water vapor or condensation is absorbed on the vapor barrier layer, the moisture likely decreases the insulative value (Goldman, 1990). The wearing of underwear beneath a protective clothing ensemble has been shown to reduce evaporative heat loss compared to wearing no underwear, primarily due to the increase in insulative thickness (Winsmann, Soule, and Goldman, 1977). Wearing a cotton undershirt will rapidly wick moisture but also will absorb this moisture (Farnworth, 1986; Woodcock, 1962). The NFPA (1993) recommends that the underclothing should absorb and transport heat away from the body, and field experience shows 100% cotton, wool, PBI (polybenzimidazole), or a high-blend ratio of these materials to be most effective. Evaporative heat loss through clothing will be inhibited, to varying degrees depending on the evaporative impedance of the clothing, the water vapor pressure gradient from skin to air (through the clothing), and the wearing of undergarments.

### *Thermal Stress*

Fire fighting clothing interferes with evaporative cooling due to decreased permeability in the clothing system and increased insulation (Goldman, 1990; Budd, 1981). The reduction of insulative value from forced convection with movement does not compensate for the increased metabolic heat produced with movement and the evaporative burden of the clothing system (Gonzalez, 1988; Budd 1981). This can create problems in wildland fire fighting because the ambient environment often prohibits the removal of clothing to further reduce insulation. The Standard on Protective Clothing for Structural Fire Fighting (Goldman, 1990) concluded that the effects of materials and fabrics used for fire fighting gear probably differed little, due to a much greater thermal effect of air layers trapped in garments than the differences in the protective clothing's permeability. Ventilation and radiant heat barriers would likely be more effective than increases in permeability (Goldman, 1990). Given the environmental and physiological stresses involved in wildland fire fighting, protective clothing presents a barrier to heat loss, thereby increasing thermal stress on the fire fighter.

## Stress From Clothing Weight and Bulk

Not only do clothes decrease heat dissipation ability, the increased weight of protective clothing increases workload and the bulk and weight can decrease movement efficiency, as has been supported by at least one study (Smith, Petruzzello, Kramer, Warner, Bone, and Misner, 1993). Heavy and bulky clothing ensembles can decrease the efficiency of body movement due to "friction drag" between layers, increasing the metabolic heat generated by the wearer (Teitlebaum and Goldman, 1972). The weight (Berglund, Fashena, Su, and Gwosdow, 1987; Teitlebaum and Goldman, 1972) and bulk (Belding, Russell, Darling, and Folk, 1947; Haisman and Goldman, 1974) of clothing systems can be a burden to performance. The weight, stiffness, and extra bulk at body joints will increase heat production (Goldman, 1990). In summary, the weight and bulk of protective clothing systems can be expected to increase heat and exercise stress.

# Chapter Three

# METHODS AND PROCEDURES

## Subjects

This study used four male and four female volunteer subjects, all with a minimum score of 45 (ml/kg/min) on the Forest Service Step Test. Subjects were required to complete an informed consent form (Appendix A) and a medical history questionnaire (Appendix B) prior to participating in this study.

## Testing

All testing was completed in the Human Performance Laboratory on The University of Montana Campus, following approval from the Institutional Review Board.

Pilot studies, using non-subject volunteers, were conducted to help establish the protocol and familiarize the investigator with the testing procedures. Data were not analyzed in these pilot studies.

Testing consisted of four trials, each spaced at least 72 hours apart. Each trial consisted of the subjects walking on a Quinton Q 4000 treadmill for 120-minutes at 5.65 km/hr (3.5 mph) and a 4.5% grade. The ambient temperature was held at 32.2° C (90° F), with approximately 30% relative humidity, and air speed of 8.1 km/hr (5 mph) with a chest-level fan placed five feet away. The subjects walked between equally spaced light bars (18 inches apart) positioned on the subject's left side, each holding three 250 Watt radiant heat lamps 18 inches from the subject, evenly spaced from knees to shoulder. The radiant heat flux was calculated to be 0.1 Watts/cm$^2$. These lamps were turned on from the start until minute 30, and from minute 60 until minute 90 of each trial. This protocol was chosen to simulate wildland fire fighting conditions, including the estimated average workload (Sharkey, 1977) and environmental conditions, including radiant heat stress from sun and flame. The 120-minute protocol was selected to represent changes that occur with prolonged exercise.

Beginning with minute zero, the following data were recorded every 10 minutes: heart rate, Rating of Perceived Exertion (RPE 0-10), tympanic temperature, right thigh skin temperature, right arm skin temperature, left chest skin temperature, left back skin temperature, ambient air temperature. Heart rate was measured using a UniqCic Heart Watch (Polar Equipment). Tympanic temperature was measured on the right (non-radiant) side of the body using a Exergen OTOTEMP 3000 Infrared Tympanic Temperature Scanner. Tympanic temperature was chosen for the applicability and comparison to field work data, and because problems with the rectal probe thermometer were encountered during pilot trials. The arm and thigh skin thermistors (YSI Equipment) were placed on each subject's right (non-radiant) side, and the chest and back thermistors, although close to the center of the body, where to the left (radiant side) of the midline. Before and after each trial, the subject's body weight nude and fully clothed in uniform was recorded on a calibrated Toledo Weight Plate electronic scale. Every 30 minutes the subject was given a one minute break and allowed to consume up to 300 ml of cool water. Fluid intake was measured and weight loss was corrected for fluid intake by adding the fluid weight to the weight loss value. Weight loss, for analysis, was calculated as corrected nude weight change. Evaporation proportion was calculated as corrected nude weight change minus corrected clothed weight change.

In each trial, the subject wore NFPA standard wildland fire fighting (Nomex) overshirt and pants, hard hat, leather gloves, and 10.9 kg backpack. Subjects provided their own socks, underwear, and bra, consisting of no less than 50% cotton. Subjects wore their own shoes during each trial; running shoes or comfortable walking shoes were recommended. In addition to the above-mentioned uniform, the four treatments consisted of the following clothing: (ST) short sleeve T-shirt, (LT) long sleeve T-shirt, (NT) no T-shirt, (SH) short sleeve T-shirt with protective face and neck shroud (hanging from helmet). All T-shirts were 100% cotton, and were provided.

Balanced Latin Square experimental designs were used, with four subjects (of each gender) and four uniform configurations.

Subjects were advised not to exercise the day of the test, to avoid strenuous exercise the previous day, to be well hydrated and well nourished, and to abstain from caffeine or other drugs the day of the test.

## Analysis of Data

Data was analyzed on a Zenith computer with the program Statistics with Finesse. The $p<0.05$ level was considered significant. Mean skin temperature, tympanic temperature, mean body temperature, heart rate, RPE, sweat loss, and evaporation proportion were computed for each treatment. Repeated Measures Analysis of Variance (ANOVA) was used to determine if any order effects of testing occurred. Differences within subjects for treatment means were analyzed with repeated measures ANOVA, and significant differences were further analyzed by Sheffe comparison for differences between treatments. Data was analyzed for men, women, and combined (men and women). The mean value for minute 110 and 120 was used for analysis of each variable.

This end value was analyzed as the most obvious possibility for statistical significance. If significance was found, other time points would also have been analyzed.

# Chapter Four

# RESULTS AND DISCUSSION

This chapter contains an analysis of the data collected in tests of four wildland fire fighting uniforms, as well as an analysis of the order effects of the testing. The chapter concludes with a discussion of the findings.

## Demographic Data

Table 1 contains descriptive data for the subjects, with means and standard deviations for age, height, weight, body mass index (wt[kg]/ht$^2$[meters]), and fitness levels for men, women, and men and women combined. The group had a mean score of 54.6 (ml/kg/min) on the Forest Service Step Test. The mean score for the men was 57.9 (ml/kg/min), and 51.5 (ml/kg/min) for the women. A predicted max $VO_2$ of 45 ml/kg/min on the Forest Service Step Test is required for fire fighters in the U.S. Forest Service. While fitness levels of the subjects participating in this study met the requirement for wildland fire fighters, none of the subjects were fire fighters. Appendix C contains individual data for the physical characteristics of the subjects.

Table 1

DESCRIPTIVE DATA FOR THE EIGHT SUBJECTS

| Variable | Mean +/- Standard Deviation | | |
|---|---|---|---|
| | MEN | WOMEN | COMBINED |
| Age (yrs) | 23.5 (1.7)* | 24.3 (2.8) | 23.9 (2.2) |
| range | 22 - 25 | 21 - 27 | 21 - 27 |
| Height (cm) | 171.5 (7.6) | 167.3 (6.9) | 169.4 (7.1) |
| range | 167.6 - 182.9 | 157.5 - 172.7 | 157.5 - 182.9 |
| Weight (kg) | 72 (5.4) | 58.3 (6.5) | 65.2 (9.2) |
| range | 65.1 - 78.1 | 48.8 - 63.2 | 48.8 - 78.1 |
| Body Mass Index | 24.6 (2.6) | 20.8 (1.0) | 22.7 (2.7) |
| range | 21.9 - 27.8 | 19.7 - 21.9 | 19.7 - 27.8 |
| Fitness ($VO_2$ max) | 57.9 (9.4) | 51.5 (7.4) | 54.6 (8.7) |
| range | 48 - 68 | 45.8 - 62 | 45.8 - 68 |

* ( ) denotes +/- 1 Standard Deviation

Individual data is included in APPENDIX C

Statistical analysis revealed no significant differences between men and women for any measures, so data was pooled for all eight subjects; this was also done to represent the wildland fire fighter workforce, which includes men and women.

## Order Effects

Data was analyzed for order effects, regardless of treatment. Each variable was analyzed using the average value for minute 110 and 120. The data summary for order effects (men and women pooled) is presented in Table 2. Analysis revealed a significant ($p=0.0285$) order effect for heart rate.

Sheffe comparisons for treatments showed significant heart rate effects for test 1 with test 3 (p=0.0061), test 1 with test 4 (p=0.0014), test 2 with test 3 (p=0.0328), test 2 with test 4 (p=0.0079). Test 1 with test 2 and test 3 with test 4 were not statistically significant. The mean heart rate for tests 1 through 4 were: 151.5, 149.8, 143, 141.6. Order effects for RPE were also significant (p=0.0001). Sheffe comparison showed significant interaction for test 1 with test 2 (p=0.0075), test 1 with test 3 (p=0.0001), test 1 with test 4 (p=0.0001), test 2 with test 3 (p=0.0003), test 2 with test 4 (p=0.036). Test 3 with test 4 was not statistically significant (p=0.1967). The mean RPE for tests 1 through 4 were: 5.31, 4.66, 3.75, 4.13. The statistical analysis summary is shown in Table 3. Appendix D displays the complete statistical analysis. No other variables showed significant order effects.

Table 2

DATA SUMMARY FOR ORDER EFFECTS

ORDER EFFECTS

| minute | hr | tymp | mskin | mbody | rpe | correct wt loss | evap prop |
|---|---|---|---|---|---|---|---|
| | | | Test 1 | | | | |
| 30 | 133.13 | 37.18 | 35.27 | 36.79 | 2.72 | | |
| 60 | 137.25 | 37.05 | 34.83 | 36.61 | 3.47 | | |
| 90 | 146.38 | 37.35 | 35.06 | 36.89 | 4.31 | | |
| 120 | 151.50 | 37.40 | 34.86 | 36.89 | 5.31 | 1.93 | 0.35 |
| | | | Test 2 | | | | |
| 30 | 133.00 | 37.26 | 35.26 | 36.86 | 2.13 | | |
| 60 | 139.69 | 37.36 | 35.05 | 36.90 | 2.91 | | |
| 90 | 146.25 | 37.46 | 35.25 | 37.02 | 3.94 | | |
| 120 | 149.81 | 37.53 | 34.95 | 37.02 | 4.66 | 1.77 | 0.32 |
| | | | Test 3 | | | | |
| 30 | 132.94 | 37.15 | 35.28 | 36.78 | 2.06 | | |
| 60 | 133.81 | 37.24 | 34.83 | 36.76 | 2.66 | | |
| 90 | 140.19 | 37.34 | 34.76 | 36.82 | 3.34 | | |
| 120 | 143.00 | 37.41 | 35.18 | 36.96 | 3.75 | 1.93 | 0.35 |
| | | | Test 4 | | | | |
| 30 | 129.13 | 37.19 | 35.35 | 36.82 | 1.81 | | |
| 60 | 131.31 | 37.21 | 35.01 | 36.77 | 2.72 | | |
| 90 | 137.00 | 37.26 | 34.93 | 36.79 | 3.50 | | |
| 120 | 141.56 | 37.26 | 34.87 | 36.78 | 4.13 | 1.92 | 0.27 |

Table 3

STATISTICAL ANALYSIS SUMMARY FOR ORDER EFFECTS

Repeated Measures Anova for Order Effects

| Variable | F-Value | P-Value |
|---|---|---|
| HR | 3.674 | 0.029* |
| Sheffe Comparison: | | |
| Test 1 with 2 | 0.216 | 0.884 |
| Test 1 with 3 | 5.484 | 0.006* |
| Test 1 with 4 | 7.496 | 0.001* |
| Test 2 with 3 | 3.523 | 0.033* |
| Test 2 with 4 | 5.165 | 0.008* |
| Test 3 with 4 | 0.157 | 0.924 |
| RPE | 11.162 | 0.0001* |
| Sheffe Comparison: | | |
| Test 1 with 2 | 5.219 | 0.008* |
| Test 1 with 3 | 29.586 | 0.0001* |
| Test 1 with 4 | 17.089 | 0.0001* |
| Test 2 with 3 | 9.953 | 0.0003* |
| Test 2 with 4 | 3.420 | 0.036* |
| Test 3 with 4 | 1.704 | 0.197 |
| Tympanic Temp | 2.018 | 0.142 |
| Mean Skin Temp | 1.308913 | 0.298 |

* denotes values which are statistically significant ($p<0.05$)

Complete statistical analysis is included in Appendix D.

## Uniform Tests

Four wildland fire fighting uniform configurations were tested: short sleeve T-shirt (ST), long sleeve T-shirt (LT), no T-shirt (NT), short sleeve T-shirt with shroud (SH). The rest of the uniform was identical for all trials, and is fully described in **METHODS** (Chapter 3). Data was analyzed for all eight subjects across the four trials using a Repeated Measures ANOVA. The following variables were analyzed using the average value for minutes 110 and 120: heart rate, tympanic temperature, mean skin temperature, mean body temperature, Rating of Perceived Exertion (RPE), nude weight loss, evaporation proportion. The data summary for the treatment effects (men and women pooled) is displayed in Table 4. Repeated Measures ANOVA revealed no significant difference ($p>0.05$) for any of these measures across the four treatments. The statistical analysis summary is shown in Table 5. The complete statistical analysis is shown in Appendix E.

Table 4

DATA SUMMARY FOR TREATMENT EFFECTS

| TREATMENT EFFECTS | | | | | | | |
|---|---|---|---|---|---|---|---|
| minute | hr | tymp | mskin | mbody | rpe | correct wt loss | evap prop |
| | | | Short T | | | | |
| 30 | 131.31 | 37.14 | 35.36 | 36.78 | 2.19 | | |
| 60 | 134.88 | 37.16 | 35.04 | 36.73 | 2.97 | | |
| 90 | 140.94 | 37.29 | 35.24 | 36.88 | 3.72 | | |
| 120 | 144.06 | 37.33 | 35.07 | 36.88 | 4.28 | 1.88 | 0.43 |
| | | | Long T | | | | |
| 30 | 133.50 | 37.14 | 35.24 | 36.76 | 2.13 | | |
| 60 | 138.88 | 37.14 | 34.91 | 36.70 | 2.84 | | |
| 90 | 147.00 | 37.29 | 35.08 | 36.85 | 3.72 | | |
| 120 | 152.00 | 37.40 | 34.89 | 36.90 | 4.59 | 2.01 | 0.37 |
| | | | No T | | | | |
| 30 | 130.75 | 37.20 | 35.24 | 36.81 | 2.13 | | |
| 60 | 133.50 | 37.22 | 34.82 | 36.74 | 2.78 | | |
| 90 | 140.38 | 37.32 | 34.93 | 36.84 | 3.66 | | |
| 120 | 143.63 | 37.31 | 34.84 | 36.82 | 4.47 | 1.84 | 0.26 |
| | | | Shroud | | | | |
| 30 | 132.63 | 37.29 | 35.31 | 36.89 | 2.28 | | |
| 60 | 134.81 | 37.34 | 34.95 | 36.87 | 3.16 | | |
| 90 | 141.50 | 37.51 | 35.28 | 37.07 | 4.00 | | |
| 120 | 146.19 | 37.55 | 35.11 | 37.06 | 4.50 | 1.89 | 0.30 |
| | | | All 4 Uniforms Combined | | | | |
| 30 | 132.05 | 37.19 | 35.29 | 36.81 | 2.18 | | |
| 60 | 135.52 | 37.22 | 34.93 | 36.76 | 2.94 | | |
| 90 | 142.45 | 37.35 | 35.13 | 36.91 | 3.77 | | |
| 120 | 146.47 | 37.40 | 34.98 | 36.91 | 4.46 | 1.90 | 0.34 |

Table 5

STATISTICAL ANALYSIS SUMMARY OF TREATMENT EFFECTS

Repeated Measures ANOVA for Treatments

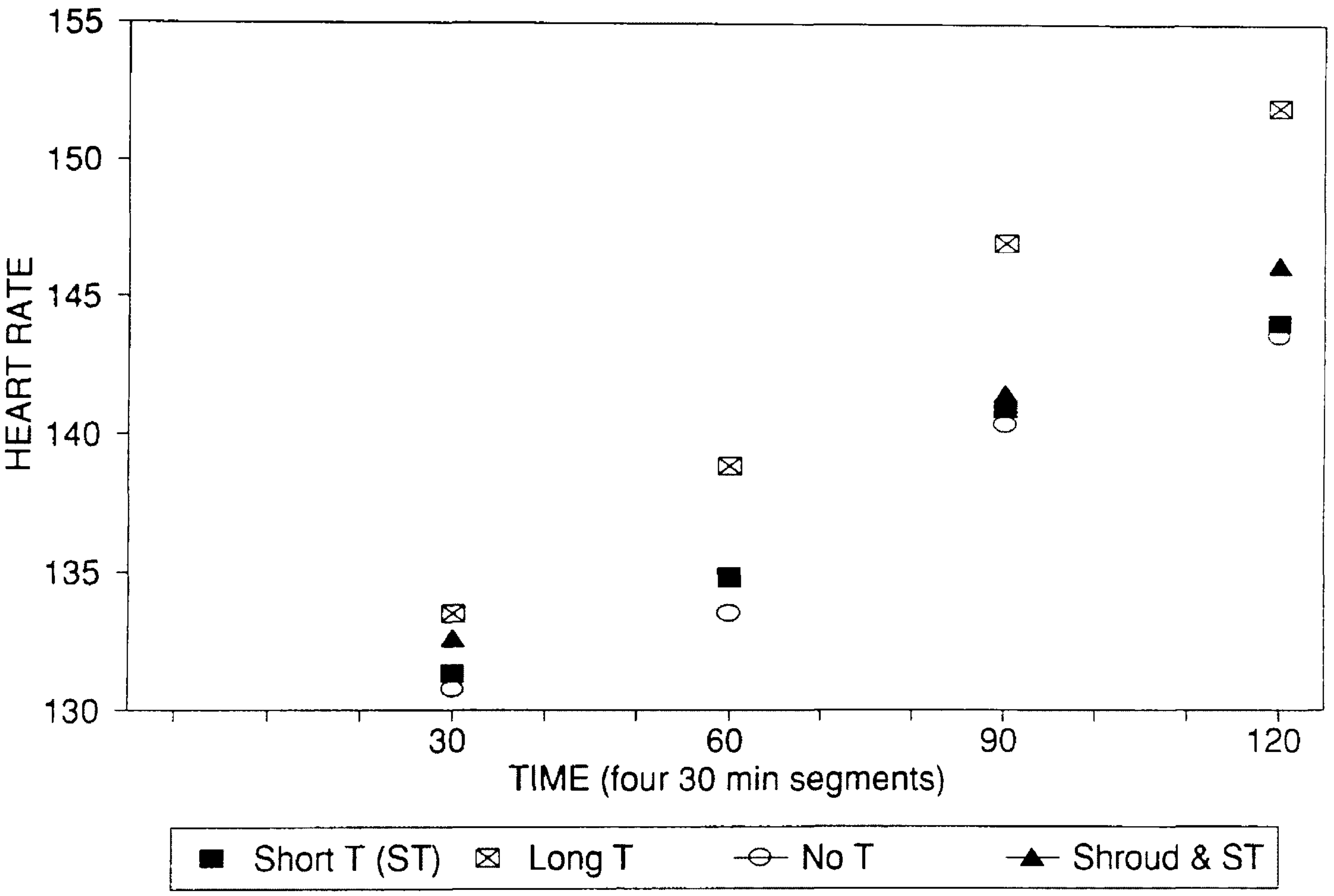
| Variable | F-Value | p-Value |
|---|---|---|
| HR | 1.874 | 0.165 |
| Tympanic Temp | 1.814 | 0.176 |
| Mean Skin Temp | 0.903 | 0.457 |
| Mean Body Temp | 2.063 | 0.136 |
| RPE | 0.164 | 0.919 |
| Weight Loss | 2.159 | 0.123 |
| Evaporation Prop | 0.574 | 0.638 |

Complete statistical analysis is included in Appendix E.

Graphs for the four tests over time for heart rate, tympanic temperature, mean skin temperature, mean body temperature, and RPE are presented in Figures 1-5. Time was divided into four 30-minute segments, with each value equalling the mean of the given variable for minute 20 and 30, 50 and 60, 80 and 90, 110 and 120. Figure 6 displays the variables for heart rate, tympanic temperature, mean skin temperature, and mean body temperature across time, with all four treatments averaged together.

# FIG 1. HR vs Time

for Four WFF Uniform Configurations



# FIG 2. Tympanic Temp vs Time

## for Four WFF Uniform Configurations

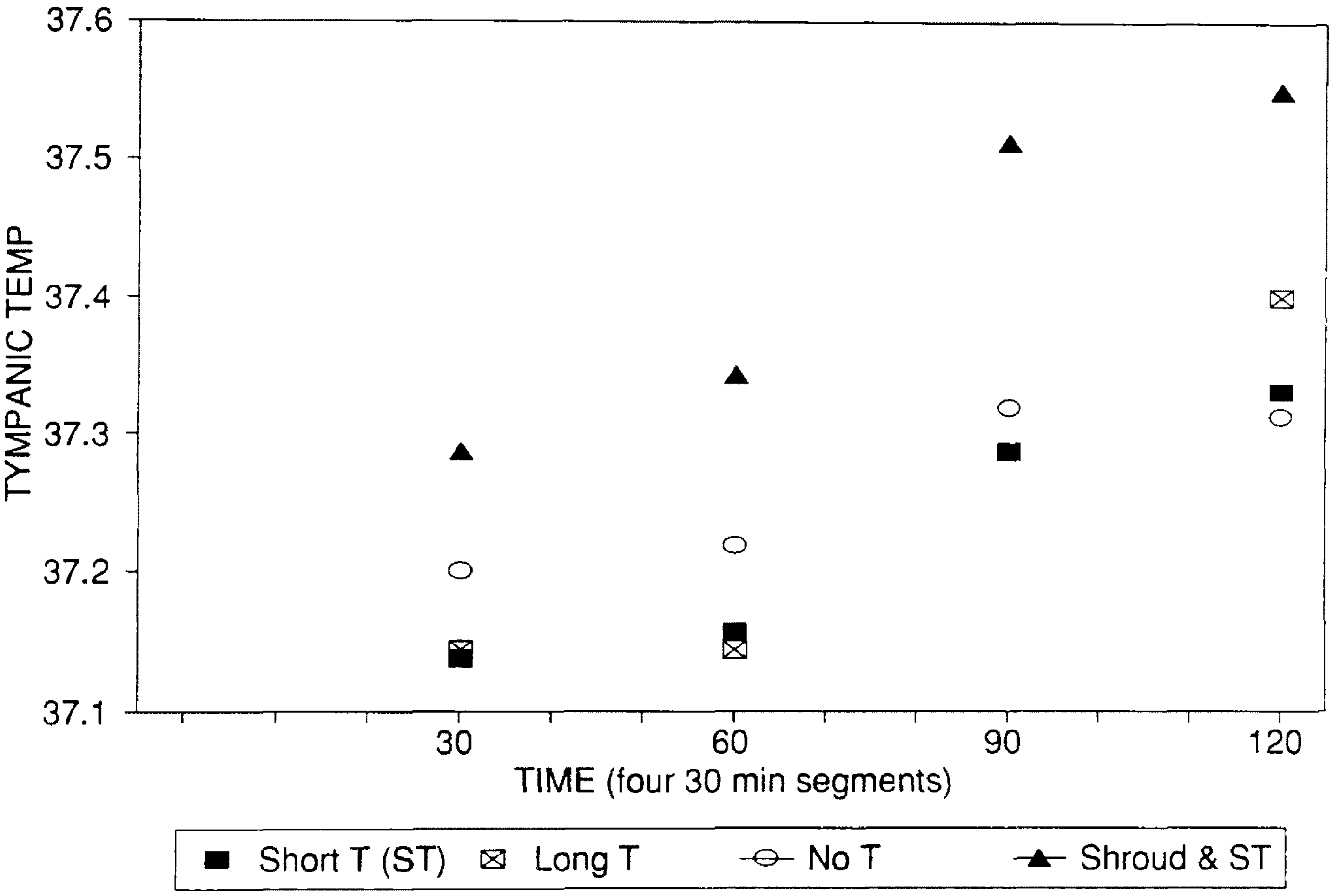
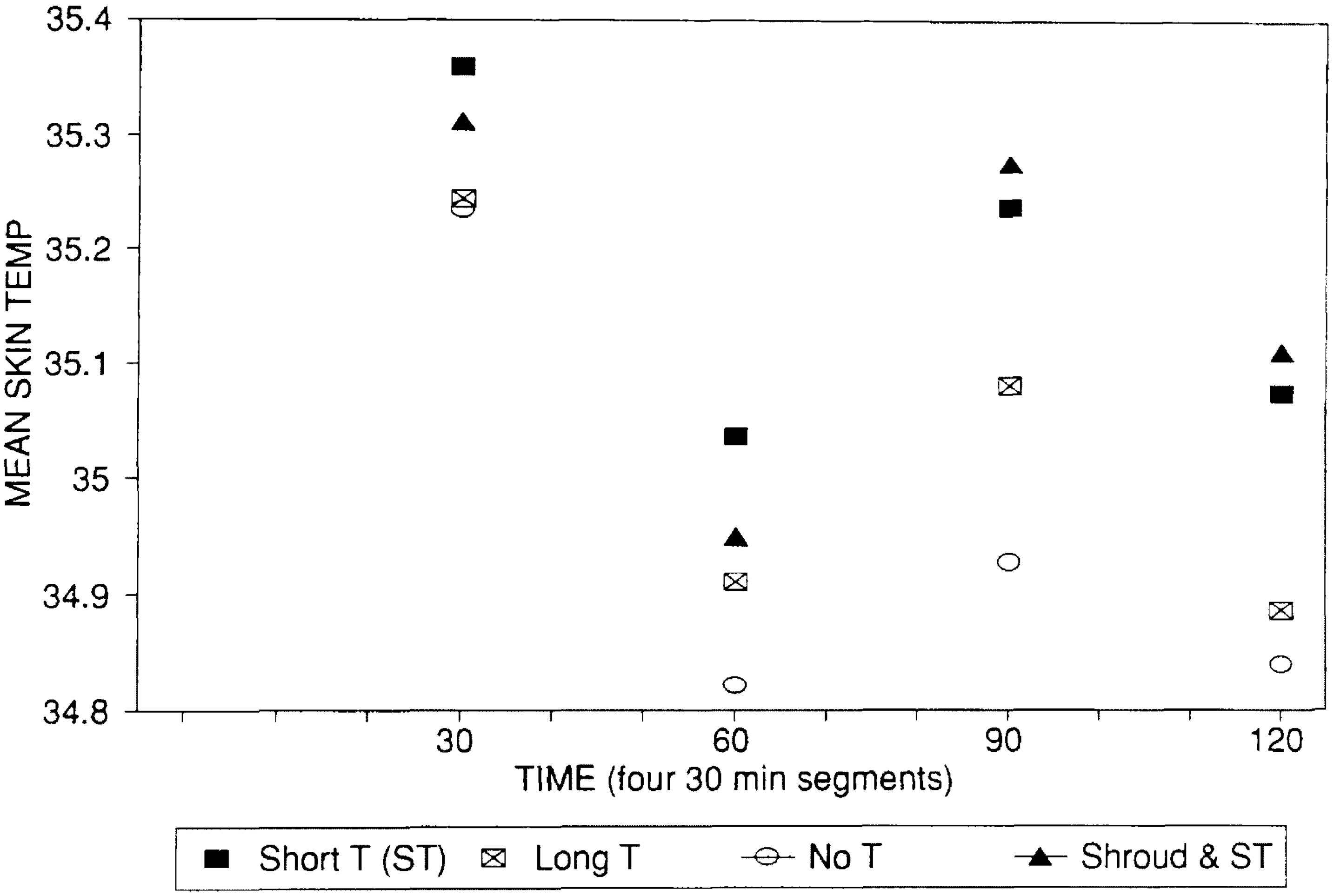


FIG 3. Mean Skin Temp vs Time

for Four WFF Uniform Configurations



# FIG 4. Mean Body Temp vs Time

## for Four WFF Uniform Configurations

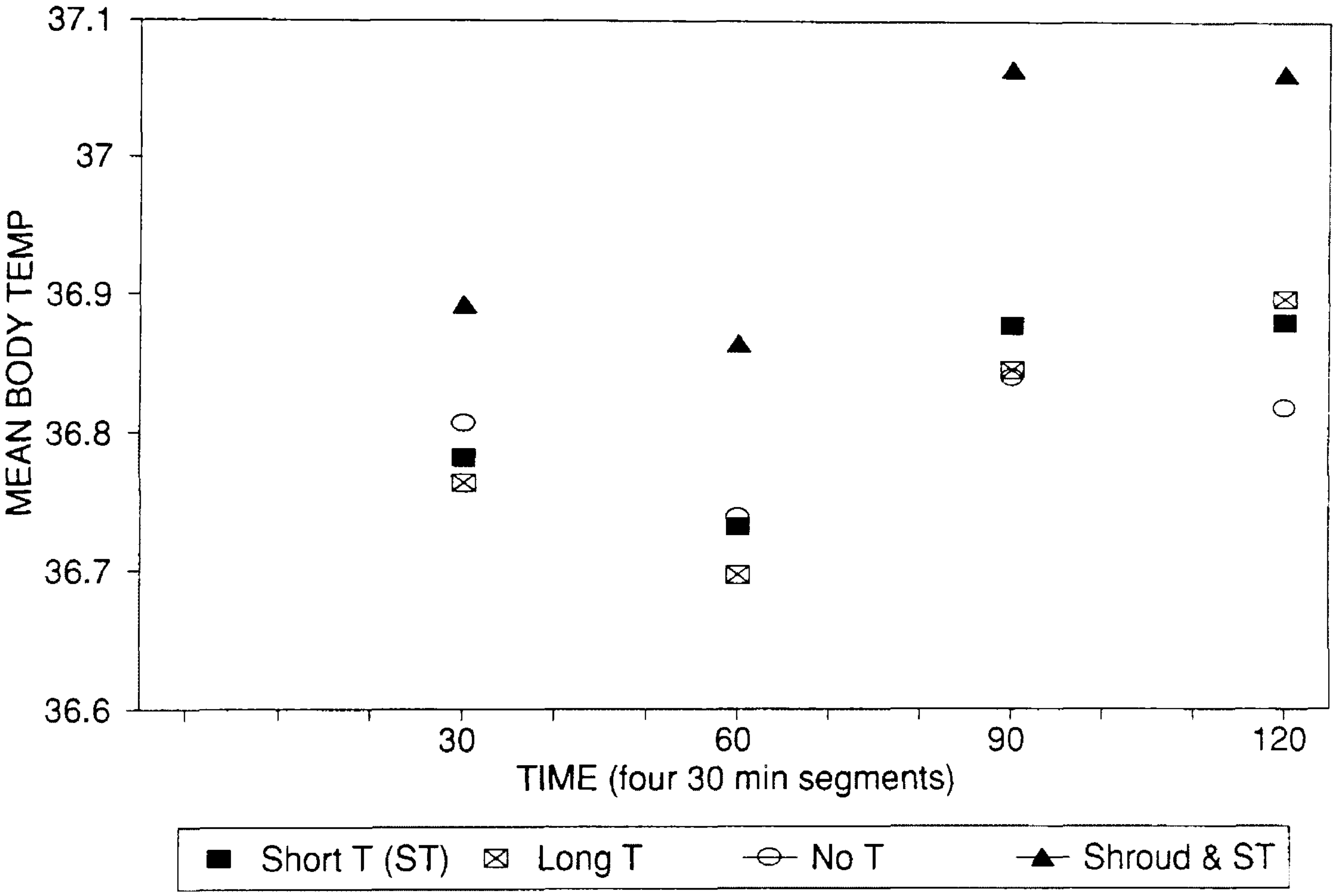
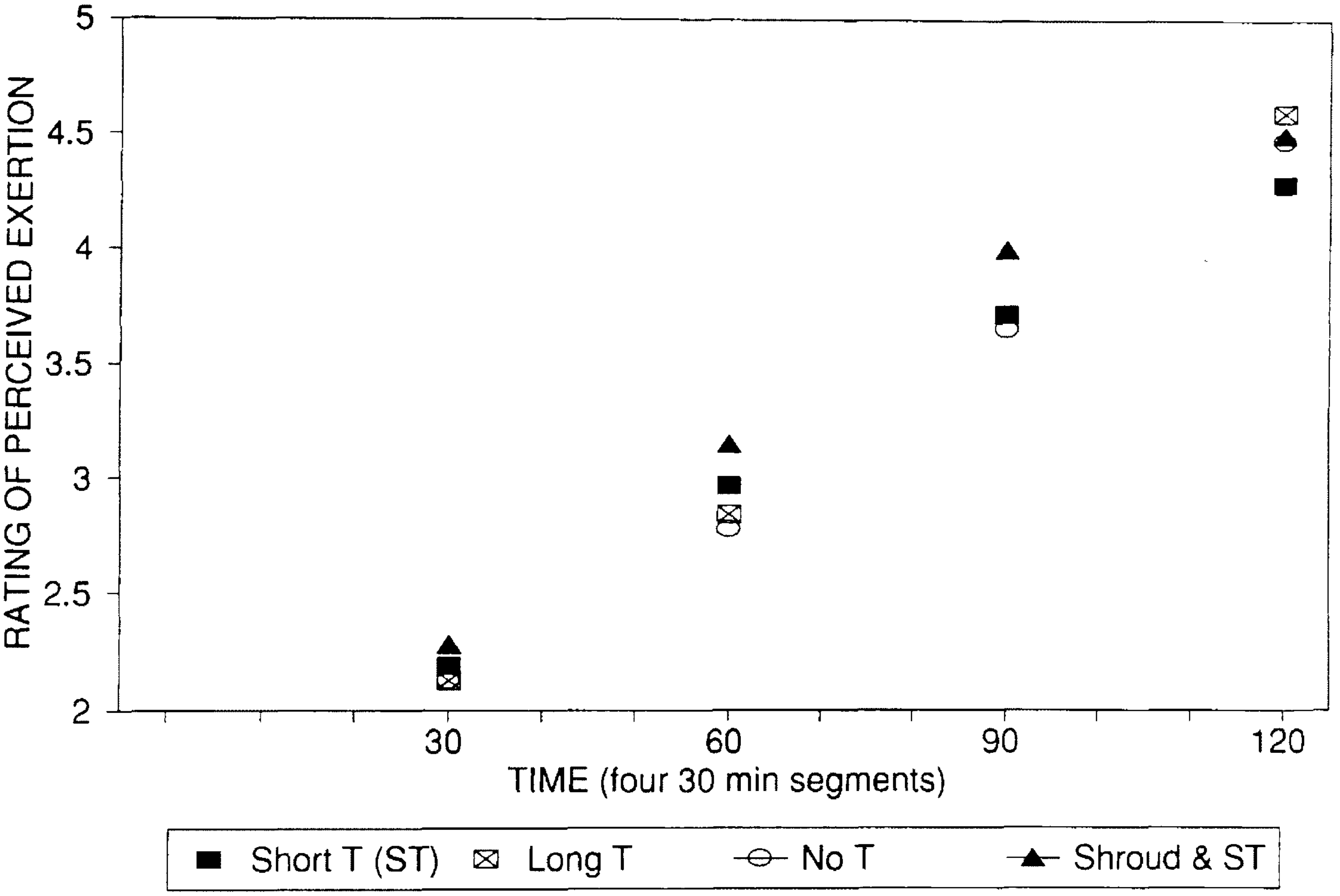


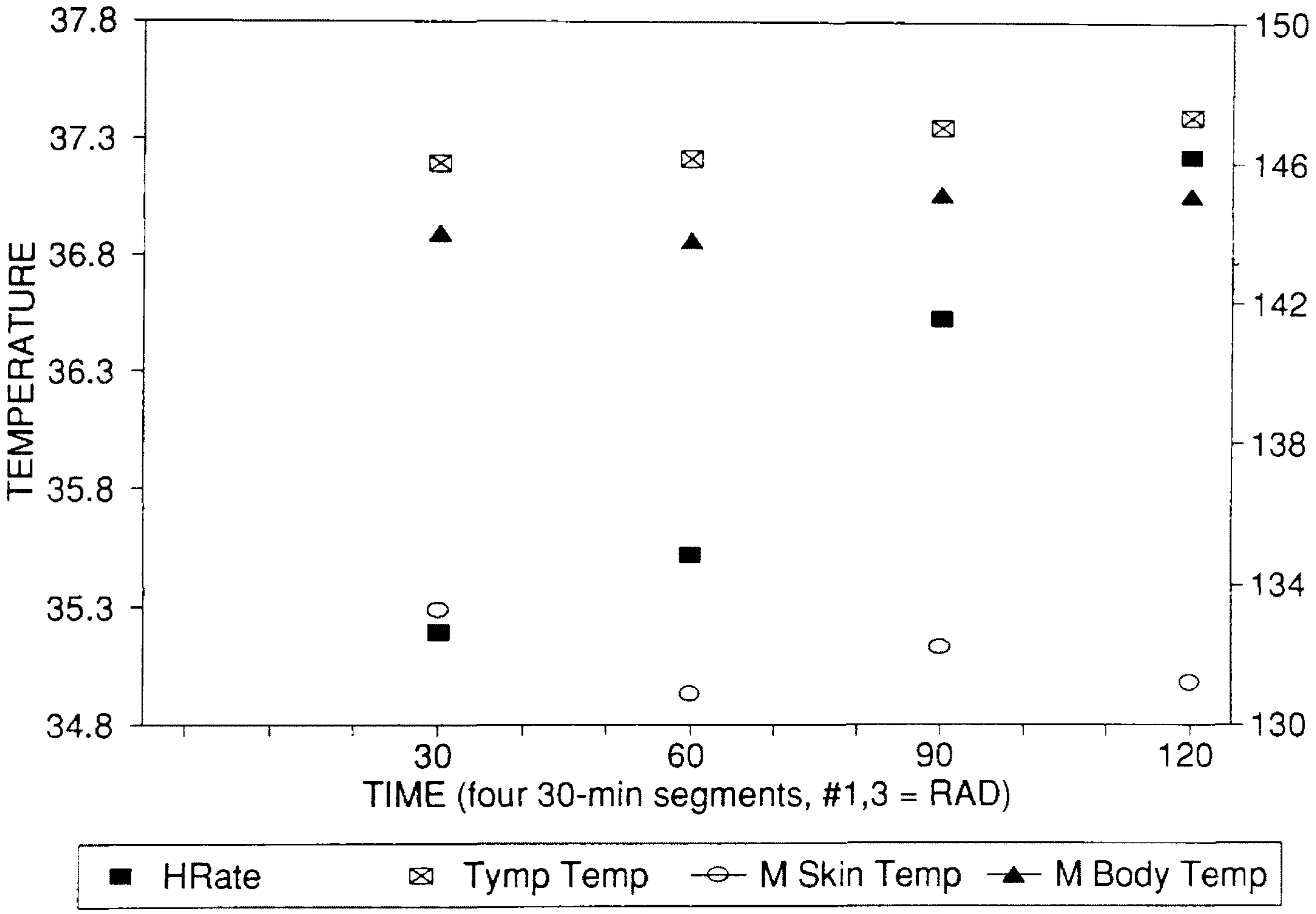
FIG 5. RPE vs Time

for Four WFF Uniform Configurations



# FIG 6. Four Measures vs Time

All Uniforms Grouped



## Discussion

### Order Effects

Analysis revealed significant order effects of testing for heart rate (p=0.0285) and RPE (p=0.0001), indicating some heat acclimatization. No other values showed significant order effects. Human heat acclimatization is produced by exposure to heat stress during rest and/or exercise. The term acclimation refers to changes produced in a controlled setting, such as a laboratory. Acclimatization refers to changes resulting in a natural environment, such as with seasonal and weather changes. Because the two terms frequently overlap in this study, acclimatization will be the preferred usage in such instances. With acclimatization, heart rate, core temperature, and skin temperature decrease, and sweat output, rate, and evaporation increase. With one week of daily exercise in a hot environment, most of the decreases in heart rate, core and skin temperatures occur (Adolph, 1947). The most rapid reduction occurs in heart rate, much of which results in four to five days (Machle and Hatch, 1947). The heart rate changes are nearly complete after seven days, with much of the core and skin temperature changes then complete as well. It may take longer, up to one month, for the increase in sweating (Horvath and Shelley, 1946). Given that heart rate shows the most rapid change with exposure to heat stress acclimatization, and RPE is associated with heart rate (ACSM, 1991), these results were not surprising. Four trials of exercise heat stress in subjects who may have already been partially acclimatized may have been enough to produce these changes. Because changes in sweating, core and skin temperature occur more slowly, the non-significance of order effects with these variables is understandable. The Latin square testing design was intended to reduce the effect of order of testing, although the effects of repeated heat stress, regardless of treatment, proved to be significant for heart rate and RPE. Sheffe comparisons for treatments revealed significant ($p<0.05$) differences for heart rate in test 1 with test 3 and 4, and test 2 with test 3 and 4. Test 1 with 2, and test 3 with 4 were not significantly different. Therefore, it appears that some degree of acclimatization occurred between the second and third trials. RPE showed significant interaction for all trials except test 3 with 4. Future studies could perhaps be preceded with a period of heat acclimation, as testing strategies such as the Latin square design may not be relied upon to reliably compensate for acclimation throughout the multiple test trials.

## Uniform Tests

Comparison of the physiological effects of the four variations of the NFPA #1977 wildland fire fighting uniform was one of the major purposes of this study. Although statistical analysis revealed no significant differences in any of the variables, several trends were observed.

While mean end heart rate for the LT trial (heart rate = 152) was 5.8 to 8.4 beats per minute higher than the other three trials, this difference was not statistically significant (p=0.1649). This higher LT value is expected, considering that the LT uniform covered the greatest surface area. Increased clothing weight can increase exercise and heat stress through decreased efficiency of movement and increased weight and bulk (Belding et al, 1947; Berglund et al, 1987; Goldman, 1990; Haisman and Goldman, 1974; Smith et al, 1992; Teitlebaum and Goldman, 1972). The other three trials followed an expected pattern, with the SH trial second highest (heart rate = 146.2), probably due to the possibility of added heat stress if the shroud trapped heat around the head and neck, as indicated by tympanic temperature. The ST (heart rate = 144.1) and NT (heart rate = 143.6) trials resulted in the lowest heart rates, likely a function of the lower weight, bulk, and thermal resistance.

No significant difference was found for tympanic temperature (p=0.1755), although the SH trial (37.55° C) was 0.15° to 0.24° C higher than the other three trials. The use of tympanic temperature as a measure of core body temperature has been reported to be inconsistent and unreliable (Greenleaf and Castle, 1972; McCaffrey, McCook, Wurster, 1975), and increased head skin temperature has been shown to bias tympanic temperature (McCaffrey et al, 1975). This could result in an artificially elevated tympanic temperature while wearing the shroud. Despite the reported problems with tympanic temperature, Greenleaf and Castle (1972) found tympanic temperature to be highly correlated with rectal temperature, but consistently lower. The researchers concluded that although tympanic temperature did not provide an accurate estimate of core temperature compared to rectal temperature, tympanic temperature gave an adequate estimate of mean body temperature (compared to mean body temperature formulas using rectal and skin temperatures). Furthermore, problems with rectal measurements during the prolonged tests were encountered when walking on the treadmill in pilot trials. Also, the usefulness of the tympanic temperature device for field data collection during wildland fire fighting was considered an important application to allow future comparisons of field work to this study. The LT trial resulted in a tympanic temperature of 37.4° C, followed by the ST and NT trials (37.33° C and 37.31° C, respectively). These values are likely a result of the thermal stress associated with the respective surface area covered increasing thermal resistance, with the possible exception of the SH, as previously noted. Clothing weight and bulk of each uniform may also be a factor, but differences in weight between the four treatments is probably negligible.

No pattern was evident with the non-significant (p=0.5261) mean skin temperatures, with a relatively narrow range (0.23° C) considering that skin temperature typically varies over a much wider range than core temperature (Sawka and Wenger, 1988). Mean skin temperature was computed from a modification of Nadel, Mitchell, and Stolwijk's (1973) formula: Mean skin temperature = (arm temperature * .25) + (thigh temperature * .31) + (chest temperature * .22) + (back temperature * .22). Mean skin temperature might be expected to parallel core temperature, as heated blood from a high core temperature is carried to the skin surface, warming the skin with the increased blood flow (although this effect is usually balanced by cooling of the skin from sweating [Sawka and Wenger, 1988]). SH was highest (35.11° C), followed by ST (35.07° C), LT (34.9° C), NT (34.84° C). Figure 3 and Figure 6 display the effects of the radiant heat periods (the first and third 30-minute segments) on the mean skin temperature. Mean skin temperature was higher during the radiant time periods, and of all the variables (see Figures 1-6), mean skin temperature appeared to be most affected by the radiant heat. Mean skin temperature followed a declining pattern over time, probably due to increased sweating in response to the increasing tympanic temperature and heart rate.

Mean body temperature was derived from the formula: (.8 * tympanic temperature) + (.2 * mean skin temperature). This formula is recommended for use with core temperature by

Greenleaf and Castle (1972). Based on the formula, mean body temperature is heavily influenced by tympanic temperature, and the differences between treatments were not significant (p=0.1558). The SH trial resulted in the highest mean body temperature (37.06° C), followed by LT (36.9° C), ST (36.88° C), NT (36.82° C). Given the influence of the tympanic temperature with the SH trial and the thermal resistance (including clothing weight and bulk) of each ensemble, these results were not surprising.

Although differences in RPE did not approach significance (p=0.9193) the LT trial was highest (4.59). Increased discomfort and perceived exertion is associated with an increase in heart rate (ACSM, 1991), and the LT trial also resulted in the highest heart rate, followed by the SH. The SH trial was second highest (4.5 RPE), followed by NT (4.47 RPE) and ST (4.28 RPE). Although NT and ST did not follow the heart rate order, the differences in this subjective variable are so slight that they could be considered negligible. The LT trial was not the highest until the final time period (Figure 5). The SH trial appeared consistently highest until this final period, with LT RPE remaining low through the first three time periods. It is possible that the LT trial provided protection against the radiant heat, and absorbed more sweat, allowing for a cooler feeling against the skin. As fatigue and heart rate increased with time, this effect may have been negated by the increased weight and thermal resistance of the

LT shirt soaked with sweat. Apparently the shroud did not increase comfort by shielding the radiant heat, and this may support the use of the tympanic temperature measure, as covering the neck and head resulted in greater discomfort for most of the testing. The absence of an undershirt in the NT trial allowed for greater evaporation of sweat, likely the reason for it's low RPE score, at least for the first three time periods. Radiant heat stress during the first and third time periods did not appear to increase discomfort in the ST and NT trials, nor did LT and SH appear to offer greater comfort by blocking the radiant heat. This is probably due to the intensity of the radiant heat source.

Changes in weight loss (pretest nude weight minus posttest nude weight, adjusted for fluid intake) across treatments were not significant (p=0.1232), and followed the same pattern as RPE. LT resulted in the greatest mean weight loss (2.01 kg), followed by SH (1.89 kg), NT (1.84 kg), ST (1.77 kg). Given the afore-mentioned increase in work and heat stress with heavier and bulkier clothing, LT and SH could be expected to result in greater body water loss from sweating and, to a lesser degree, respiratory losses. Additionally, LT and SH displayed higher tympanic and mean body temperatures, and higher heart rates, further drive for increased sweating. However, ST would be expected to result in greater sweat loss than NT due to the additional undergarment worn (short sleeve T-shirt), unless sweat absorbed in the cotton shirt in the ST trial provided cooling without sufficient weight to increase work and heat stress. However, this possibility is not supported by any measure except RPE, and ST actually displayed the highest mean skin temperature. The difference between the NT and ST nude weight loss was slight (0.07 kg), and could be considered negligible.

Evaporation proportion, an estimate of sweat evaporation (nude weight loss minus clothed weight loss), did not approach significance (p=0.6383). The greater the value (weight), the more sweat was assumed trapped in the clothing. The lesser the weight value, the more sweat was assumed evaporated, allowing for greater cooling. Although differences were not statistically significant, the LT trial resulted in the lowest evaporation (weight difference = .37 kg), as supported by LT's high values for heart rate, tympanic and mean body temperatures, RPE, and sweat loss. This is probably due to the increased barrier for sweat evaporation. SH (.3 kg) would be expected to follow LT, as indicated by the previous measures of heat stress and (compared to ST and NT) barrier to evaporation of sweat. However, ST (.32 kg) was the second highest. No explanation is offered for this order. As expected, the NT (.25 kg) trial resulted in the greatest sweat evaporation, due to the absence of a barrier between the skin and the outergarment. The absence of this barrier allowed reduced impedance for sweat evaporation. This is consistent with NT's low indices of heat stress, reflected in heart rate, tympanic, skin, and mean body temperatures.

It is interesting to note that while order effects displayed the only statistically significant differences, examination of individual data for the eight subjects revealed some interesting trends. When examining differences between the fit and less fit subjects (see Table 1), differences between subjects, regardless of treatment, became apparent. Examination of the individual data (Appendix F), particularly for heart rate, tympanic temperature, and RPE, may indicate that fitness level is the most important "treatment variable" for reducing physiological strain in wildland fire fighting. For example, male subject K.C. (predicted max $VO_2$ = 68 ml/kg/min) had the following end value ranges across the four treatments: heart rate, 115.5 - 123; tympanic temperature, 36.9 - 37.15; RPE, 1.75 - 2.25. Male subject T.R. (predicted max VO2 = 48 ml/kg/min) had the following end value ranges across the four treatments: heart rate, 143 - 176; tympanic temperature, 37.15 - 37.6; RPE, 4.25 - 7.5. A Pearson Correlation score of - 0.9 revealed the relationship of fitness score to mean end heart rate (mean of the four treatments) for the eight subjects. Not only were the absolute indices of heat stress lower for the higher fit, but the ranges were lower as well, indicating that uniform configuration may be less of a factor for those with higher fitness levels. These patterns appeared evident throughout the eight subjects, and may warrant future studies on this topic. While analyzation of fitness level interaction with the variables and treatments of wildland fire fighting is beyond the scope of this study, this may be worth consideration in future studies.

## Radiant Heat Stress

In the first and third 30-minute segments (the first 30 minutes of each hour) subjects were exposed to radiant heat. These radiant heat segments were included in the protocol to simulate field conditions of intermittent exposure to fire. Figure 6 displays heart rate, tympanic, mean skin, and mean body temperature for all treatments grouped together plotted against time. This allows graphical representation of the effects of the radiant heat periods on these four variables. The radiant heat stress was reflected strongly on mean skin temperature, with higher mean skin temperatures for the radiant heat segments than the non-radiant heat segments. This pattern was also displayed, to a lesser magnitude, in mean body temperature. Heart rate and tympanic temperature patterns also appeared to show less dramatic increases with time during the non-radiant heat segments. While ambient room temperature was held constant at 32.2° C, the subjects were only 18 inches from the radiant heat lamps, which apparently increased heat stress. The magnitude of the influence of the radiant heat is difficult to determine, however, as the continuing effect of exercise duration likely had some effect as well.

## Protocol Evaluation

One purpose of this study was to establish a standard protocol for the evaluation of wildland fire fighting uniforms. This 120-minute protocol was deemed to be important, since some changes were noticed at 120 minutes that were not apparent at 60 minutes. Differences in the order of values for treatments changed from 60 minutes to 120 minutes for heart rate, tympanic, mean skin, and mean body temperature, and RPE. This provides justification for the second hour of testing. While it would be interesting to note if measures continued to differ for a third hour, a three hour test may not be practical. Two hours of testing should be adequate for the differentiation of treatments.

While the treatments showed no significant effects for the variables examined, several patterns and differences were noted. It is quite likely that statistical significance was not achieved due to the small sample size (N=8). Furthermore, the effect of high subject variability (a wide range of fitness levels was evident in the subject pool, see Table 1) decreases the chances for significance. The significant order effects for heart rate and RPE underline the high variability, particularly for these two variables, further decreasing the chances for significance. In addition to a larger sample, the heat acclimatization status of the subjects could be controlled (ie. use acclimatized subjects).

In this protocol design, it is difficult to determine if the use of radiant heat is warranted. Examination of the data did not appear to show any blocking of radiant heat in the LT and SH trials, and perhaps a study comparing radiant and non-radiant heat tests could determine the usefulness of radiant heat testing. Also, the fact that the arm and leg skin thermistors were located on the side of the body furthest from the radiant heat lamps may be a factor. From the limited determinations that could be made of radiant heat in this study, no recommendations can be made. However, this study could provide adequate baseline data for comparison to other studies conducted at the same ambient temperature, with and without radiant heat stress.

The treadmill speed and grade used in this protocol elicit an energy expenditure that is likely to be encountered while working in wildland fire fighting. The estimated VO2 of work at 8.1 km/hr (3.5 mph), 4.5% grade, while wearing a 10.9 kg backpack, is approximately 22.75 ml/kg/min, which is the estimated average workload for wildland fire fighting (Sharkey, 1977). No problems with calf and leg cramps from the treadmill grade were reported by the subjects. While this speed and grade appear justified, a more practical protocol, in regards to application to actual field work performance, could involve maintenance of a given heart rate (e.g., 150 BPM), with work load adjusted throughout the test to maintain this heart rate. It is likely that workers control their work rate in response to physiological stresses (heart rate, RPE), and that the decline in workload would represent the effect of the clothing treatment (Mead and Sharkey, 1993).

## Baseline Data

Another purpose of this study was to develop baseline data on the NFPA #1977 wildland fire fighting uniform. Notable heat stress data was obtained in this study, which may be useful for comparison to future wildland fire fighting uniform studies.

# Chapter Five

# SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This chapter includes a summary, conclusions and recommendations for future research. This study compared the physiological effects of various wildland fire fighting uniforms.

## Summary

A major purpose of this study was to determine the physiological effects of variations in the NFPA #1977 wildland fire fighting uniform. Four male and four female volunteers performed four prolonged (2 hour) treadmill tests with different variations of the standard NFPA #1977 uniform: ST, LT, NT, SH, in a balanced latin square design. A 10.9 kg pack was worn in each trial, with ambient conditions of 32.2° C and 30% relative humidity, with 0.1 watts/cm$^2$ radiant heat for the first half of each hour.

Despite the latin square design, significant order effects resulted for heart rate and RPE ($p<0.029$ and 0.001), indicating possible heat acclimatization. Results of treatment (uniform) analysis did not reveal significant differences, although heart rate, RPE, and weight loss were greater for LT, and LT had the lowest proportion of sweat evaporation. Tympanic and mean body temperatures were higher in the SH trial. The trials with the greatest clothing weight and bulk tended to result in the greatest heat stress, and the influence of a shroud on tympanic temperature illustrates the effect of that garment.

Another purpose of this study was to develop a standard protocol for wildland fire fighting uniform evaluation. The workload seemed appropriate, equalling the estimated average workload needed for wildland fire fighting. The second hour of testing produced treatment differences not seen after one hour. The value of radiant heat segments was unclear, although radiant heat segments tended to influence skin temperatures.

The final objective of this study was to develop baseline data on the NFPA #1977 wildland fire fighting uniform. Important heat stress data was obtained to help guide the evolution of the wildland fire fighting uniform. The data may be useful for comparison in future wildland fire fighting uniform studies.

## Conclusions

Based on analysis of data collected from four male and four female subjects, with a minimum estimated max $VO_2$ of 45 ml/kg/min, and within the limitations of this study, the following conclusions were drawn:

1. Wearing a LT undergarment during prolonged exercise-

heat stress can result in a higher heart rate, RPE, weight loss, and increased evaporative impedance compared to the SH, ST, or NT uniforms.

2. Wearing the shroud accessory during prolonged exercise-heat stress can result in higher tympanic and mean body temperatures compared to the LT, ST, NT uniforms.

3. Wearing the LT or SH uniforms during 0.1 watts/cm$^2$ radiant heat flux provided no apparent benefit. Further analysis is necessary to determine if the LT and SH uniforms are beneficial in conditions of greater radiant heat.

4. Wearing the LT or SH during prolonged exercise-heat stress can result in slightly greater heat stress compared to ST and NT.

5. The higher fit subjects experienced lower indices for heat stress than the lesser fit subjects, across all treatments.

## Recommendations for Further Research

The following suggestions for further research were prompted by this study:

1. A similar study using a larger pool of subjects who are heat acclimatized.

2. A study examining the effects of radiant vs. non-radiant heat, independent of duration, to analyze the effects of radiant heat stress.

3. A study with greater radiant heat stress to determine any benefit from the LT or SH uniforms.

4. A wildland fire fighting uniform study using a protocol in which heart rate is held constant, examining the effects of heat stress on work rate over time.

5. A wildland fire fighting uniform study measuring skin temperature on the radiant heat side of the body.

6. A wildland fire fighting uniform study comparing physiological effects across treatments in subjects grouped for fitness level.

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## APPENDIX A

## HUMAN INFORMED CONSENT FORM

1. *Objective of the Study*: You are volunteering to participate in a study entitled "Thermoregulatory, cardiovascular, metabolic, and perceived comfort responses to prolonged, submaximal work while wearing four styles of wildland firefighting uniforms." This project is designed to evaluate the physiologic responses of your body to treadmill walking while wearing four styles of USDA-FS uniforms.

2. *Testing Procedures*: All testing will be conducted in the University of Montana Human Performance Laboratory (121 McGill Hall). The subjects will be asked to complete the following:

   a. Perform a maximal graded exercise test on the treadmill.

   b. Perform four, 120-min, constant-rate walking trials with the treadmill set at 3.5 miles per hour and a 4.5 % grade. The four testing trials will be conducted while you are wearing: 1) USDA-FS standard uniform with a short-sleeve T-shirt, 2) USDA-FS standard uniform with a long-sleeve T-shirt, 3) USDA-FS standard uniform with no T-shirt, and 4) USDA-FS standard uniform with a short-sleeve T-shirt and a shroud. All tests will be performed between four and seven days apart with the order of trials conducted in random order. All trials will be conducted while wearing a 25 pound (11.3 kg) USDA-FS back pack. The trials will be conducted in a completely-enclosed environmental chamber with a controlled ambient temperature of 90 degrees Fahrenheit, 20% humidity, wind speed of 5 mph, and radiant heat flux of 0.1 $\text{Watts}^{\bullet}\text{cm}^{-3}$.

   *Prolonged Walking Test Procedures*: Immediately prior to and after exercise you will be weighed without clothes. At regular intervals during the 120-min test, several thermoregulatory, cardiovascular, metabolic, and perceived comfort measurements will be taken. Metabolic parameters will be assessed by having you breathe periodically through a mouthpiece, heart rate and skin temperature will be monitored by electrodes taped to your skin, and blood pressure will be assessed by a cuff wrapped around your upper arm. Internal temperature will be monitored via the ear canal. Perceived comfort will be monitored by a 1-10 scale RPE chart. All procedures are standardized laboratory techniques which are routinely used during exercise testing with minimal associated discomfort.

   Subjects will be asked to consume 4 quarts of water during the day prior to each exercise session to ensure adequate hydration status. You will be asked to consume a cup of water every 30 minutes during the two hour test. Water will be given ad libatum if the subject desires more water intake during the test.

3. *Duration of Testing*: The subject's time commitment will be 45 minutes for the initial maxVO2 treadmill test and body composition check and 2.5 hours each for each of the four exercise trials.

4. *Potential Benefits*: Participation in this study will provide the subjects with an accurate assessment of their maximal aerobic capacity and information regarding their personal responses to prolonged exercise. Subjects will receive a copy of their test results and a brief consultation session with a health and fitness specialist to explain their results to them.

5. *Risks and Discomforts*: The overall risks associated with participation in this study are minimal. Possible risks and discomforts include: muscle soreness, nausea, dizziness, fatigue, shortness of breath, abnormal blood pressure responses, irregular heart beats, and in rare instances, heart attack. Prolonged physical work in a hot environment causes a rise in heat storage, resulting in elevated body temperatures. This may result in cool, clammy skin, a lower than normal blood pressure, a rapid heart rate, dehydration, and possible dizziness. Subjects will be continually monitored throughout all testing. Subjects may terminate any of the tests at any time if they feel unduly stressed or uncomfortable.

6. *Confidentiality*: The subjects will be given an identification number which will only be known by the principle investigators. Personal information on all participants will be used only for research purposes, including publication. Information used in presenting or publishing data will in no way include information which could personally identify an individual subject. Personal data will only be released after obtainment of the subject's written consent.

7. *Medical Treatment or Compensation for Physical Injury*: In the event that a subject is physically injured as a result of this research, he/she should individually seek appropriate medical treatment. If the injury is caused by the negligence of the University or any of its employees, the subject may be entitled to reimbursement or compensation pursuant to the Comprehensive State Insurance Plan established by the Department of Administration under the authority of M.C.A., Title 2, Chapter 9. In the event of a claim for such physical injury, further information may be obtained from the University Legal Council. If a subject believes that they have suffered an injury as a result of participation in this research project, they should contact the

Office of the Vice President for Research Administration, phone number (406) 243-6670 during regular business hours.

8. *Person to Contact for More Information*: Although several persons will be involved in data collection, the person listed below is the principal researcher in this study. Please feel free to contact him if more information is desired.

Daniel G. Graetzer, Ph.D.
Human Performance Laboratory, HHP Department
121 McGill Hall - University of Montana
Missoula, MT 59812-1055 Phone: (406) 243-2117

I have read this informed consent form and have been given a copy of it for my personal records. The experimental procedures that I will perform have been explained to me in a manner in which I fully understand. I consent to participate in this study.

| | |
|---|---|
| ______________ | ______________________________ |
| Date | Subject |
| ______________ | ______________________________ |
| Date | Witness |

## APPENDIX B

# MEDICAL HISTORY QUESTIONNAIRE

Name: ____________________ Address: ____________________________
City & State: __________________ Zip: _________ Phone: __________

Name of your physician: ______________________ Phone: __________

List the date of your last:
Physical Exam: ______ Surgery: ______ EKG: _____

1. Have you been told by a doctor that you have or have had any of the following? (Please check each response.)

| YES | NO | | YES | NO | |
|---|---|---|---|---|---|
| ☐ | ☐ | Rheumatic fever | ☐ | ☐ | High blood pressure |
| ☐ | ☐ | An enlarged heart | ☐ | ☐ | Abnormal EKG pattern |
| ☐ | ☐ | Epilepsy | ☐ | ☐ | Diabetes |
| ☐ | ☐ | Heart of vascular disease | ☐ | ☐ | Hyperuricemia (high uric acid levels) |
| ☐ | ☐ | Metabolic disorders | ☐ | ☐ | Varicose veins |
| ☐ | ☐ | Heart murmur | ☐ | ☐ | Stroke |
| ☐ | ☐ | Lung or pulmonary disorders | ☐ | ☐ | Allergies<br>Specify: ______________ |
| ☐ | ☐ | Thrombophlebitis (blood clots) | ☐ | ☐ | Abnormally high blood cholesterol or triglycerides |

2. Please list any drugs, medication, or dietary supplements *prescribed* by a physician that you are currently taking:

Drug: ________________ for: ________________ dosage: ____
Reactions: ______________________________________________
Drug: ________________ for: ________________ dosage: ____
Reactions: ______________________________________________

3. Please list any *self-prescribed* drugs, medications, or dietary supplements that you are currently taking:

Drug: ________________ for: ________________ dosage: ____
Reactions: ______________________________________________
Drug: ________________ for: ________________ dosage: ____
Reactions: ______________________________________________

4. Is there a history of heart disease, heart attack, elevated cholesterol levels, high blood pressure, or stroke in your immediate family (grandparents, parents, brothers, and sisters) *before the age of 60*?

☐ YES ☐ NO Number: ______________

5. Do you smoke now? ( ) YES ( ) NO
   a. If yes, how many cigarettes do you smoke per day? ________
   b. If no, have you ever smoked? ( ) YES ( ) NO
      A. If yes, how many cigarettes per day? ____________
      B. How long ago did you quit? _____yr _____ mo

6. Are you currently under a great deal of stress either at work, school, or personally? ( ) YES ( ) NO
7. Do you actively relieve stress through exercise, meditation, or other methods? ( ) YES ( ) NO

8. Are you currently on a regular exercise program?
( ) YES ( ) NO If yes, check the following:
Type of exercise: ( ) walking ( ) bicycling ( ) tennis
( ) aerobics ( ) swimming ( ) racquetball ( ) other __________
Frequency per week: ( ) 1-2 times per week
( ) 3-4 times per week
( ) 5 or more times per week
Duration (each day): ( ) < 15 minutes
( ) 15-30 minutes
( ) 30-45 minutes
( ) > 45 minutes

9. While exercising do you ever feel limited by (if yes, state type or activity you are performing when this arises):

| | | YES | NO | |
|---|---|---|---|---|
| a. | breathing | ( ) | ( ) | Activity: ______________ |
| b. | chest, arm or neck pain | ( ) | ( ) | Activity: ______________ |
| c. | low back pain | ( ) | ( ) | Activity: ______________ |
| d. | pain in leg, relieved by rest | ( ) | ( ) | Activity: ______________ |
| e. | side aches | ( ) | ( ) | Activity: ______________ |
| f. | lower leg pain, front shin pain back achilles | ( ) | ( ) | Activity: ______________ |
| g. | extreme long-lasting fatigue | ( ) | ( ) | Activity: ______________ |

10. Do you have a history of problems while exercising in the heat (fainting, extreme dehydration, etc.)? If yes, please explain.

I hereby certify that my answers to this questionnaire are true and complete and to the best of my knowledge I am in good health.

Signature: ____________________ Date: ______________

# APPENDIX C

## PHYSICAL CHARACTERISTICS OF THE EIGHT SUBJECTS

| SUBJECT | AGE(YRS) | HT(CM) | WT(KG) | BMI | EST VO2max |
|---|---|---|---|---|---|
| MEN | | | | | |
| MC | 25 | 182.9 | 73.4 | 21.9 | 52 |
| TR | 22 | 167.6 | 78.1 | 27.8 | 48 |
| DB | 22 | 167.6 | 71.5 | 25.4 | 63.6 |
| KC | 25 | 167.6 | 65.1 | 23.2 | 68 |
| WOMEN | | | | | |
| RL | 21 | 172.7 | 63.2 | 21.2 | 45.8 |
| AK | 23 | 167.6 | 61.5 | 21.9 | 46 |
| DH | 26 | 171.5 | 59.6 | 20.3 | 51.2 |
| DB | 27 | 157.5 | 48.8 | 19.7 | 62 |

## APPENDIX D

## STATISTICAL ANALYSIS FOR ORDER EFFECTS

```
------------------------------------------------------------------

                    File Name:    order hr

                    REPEATED MEASURES ANOVA

------------------------------------------------------------------
Source           Sum of Sqr.    DF   Var. Est.    F-Ratio    Prob
------------------------------------------------------------------

Between Subj      8287.094       7    1183.870     16.839     0.0

Within Subj.      1687.375      24      70.307

  Treatments       580.781       3     193.594      3.674     0.0

  Error           1106.594      21      52.695

Total             9974.469      31     321.757

------------------------------------------------------------------

       Treatment           N          Mean          Std. Dev.

     test 1 hr             8        151.500         20.329

     test 2 hr             8        149.813         21.127

     test 3 hr             8        143.000         15.825

     test 4 hr             8        141.563         15.228


------------------------------------------------------------------
Scheffe Comparisons for Treatments

test 1 hr with test 2 hr:    F=        0.2162           P= 0.9841
test 1 hr with test 3 hr:    F=        5.4844           P= 0.0061
test 1 hr with test 4 hr:    F=        7.4963           P= 0.0014
test 2 hr with test 3 hr:    F=        3.5229           P= 0.0328
test 2 hr with test 4 hr:    F=        5.1665           P= 0.0079
test 3 hr with test 4 hr:    F=        0.1569           P= 0.9241
```

```
---------------------------------------------------------------------

                    File Name:   order ear

                    REPEATED MEASURES ANOVA

---------------------------------------------------------------------
Source              Sum of Sqr.    DF   Var. Est.    F-Ratio   Prob. F
---------------------------------------------------------------------

Between Subj          3.2168        7    0.4595      8.1359    0.0001

Within Subj.          1.3556       24    0.0565

  Treatments          0.3034        3    0.1011      2.0181    0.1422

  Error               1.0522       21    0.0501

Total                 4.5724       31    0.1475

---------------------------------------------------------------------

       Treatment              N          Mean        Std. Dev.

     test 1 ear               8        37.4000        0.3586

     test 2 ear               8        37.5313        0.3731

     test 3 ear               8        37.4063        0.4004

     test 4 ear               8        37.2562        0.4263


---------------------------------------------------------------------
```

```
--------------------------------------------------------------------------

                      File Name:    msk order

                      REPEATED MEASURES ANOVA

--------------------------------------------------------------------------
Source           Sum of Sqr.    DF    Var. Est.    F-Ratio    Prob. F
--------------------------------------------------------------------------

Between Subj       7.924277      7    1.132040    7.989167    0.0001

Within Subj.       3.400724     24    0.141697

  Treatments       0.535720      3    0.178573    1.308913    0.2978

  Error            2.865004     21    0.136429

Total             11.325001     31    0.365323

--------------------------------------------------------------------------

        Treatment            N          Mean        Std. Dev.

     test 1 msk              8       34.856174     0.583360

     test 2 msk              8       34.952175     0.465157

     test 3 msk              8       35.178925     0.591094

     test 4 msk              8       34.869099     0.797028


--------------------------------------------------------------------------
```

```
------------------------------------------------------------------------

                    File Name:   RPE order

                    REPEATED MEASURES ANOVA

-------------------------------------------------------------------------
Source             Sum of Sqr.     DF    Var. Est.    F-Ratio    Prob. F
-------------------------------------------------------------------------

Between Subj          94.4043       7      13.4663    17.9974     0.0001

Within Subj.          17.9844      24       0.7493

  Treatments          11.0527       3       3.6842    11.1617     0.0001

  Error                6.9316      21       0.3301

Total                112.3887      31       3.6254

-------------------------------------------------------------------------

      Treatment            N           Mean        Std. Dev.

    test 1 RPE             8          5.3125         1.8744

    test 2 RPE             8          4.6563         2.1042

    test 3 RPE             8          3.7500         1.8274

    test 4 RPE             8          4.1250         1.7879


-------------------------------------------------------------------------
Scheffe Comparisons for Treatments

test 1 RPE with test 2 RPE:   F=        5.2189           P= 0.0075
test 1 RPE with test 3 RPE:   F=       29.5859           P= 0.0001
test 1 RPE with test 4 RPE:   F=       17.0888           P= 0.0001
test 2 RPE with test 3 RPE:   F=        9.9527           P= 0.0033
test 2 RPE with test 4 RPE:   F=        3.4201           P= 0.0360
test 3 RPE with test 4 RPE:   F=        1.7041           P= 0.1967
```

# APPENDIX E

## STATISTICAL ANALYSIS FOR TREATMENT EFFECTS

```
----------------------------------------------------------------------

                       File Name:   stats

                       REPEATED MEASURES ANOVA

----------------------------------------------------------------------
Source              Sum of Sqr.    DF   Var. Est.   F-Ratio   Prob. F
----------------------------------------------------------------------

Between Subj          8287.094      7    1183.870    16.839    0.0001

Within Subj.          1687.375     24      70.307

  Treatments           356.406      3     118.802     1.874    0.1649

  Error               1330.969     21      63.379

Total                 9974.469     31     321.757

----------------------------------------------------------------------

       Treatment           N           Mean         Std. Dev.

         ST hr             8          144.063        15.747

         LT hr             8          152.000        20.466

         NT hr             8          143.625        18.767

        Shr hr             8          146.188        18.841

----------------------------------------------------------------------
```

```
--------------------------------------------------------------------

                  File Name:    stats

                  REPEATED MEASURES ANOVA

---------------------------------------------------------------------
Source             Sum of Sqr.    DF   Var. Est.    F-Ratio   Prob. F
---------------------------------------------------------------------

Between Subj          3.2168       7     0.4595      8.1359    0.0001

Within Subj.          1.3556      24     0.0565

  Treatments          0.2790       3     0.0930      1.8139    0.1755

  Error               1.0766      21     0.0513

Total                 4.5724      31     0.1475

---------------------------------------------------------------------

          Treatment          N        Mean       Std. Dev.

           ST ear            8       37.3312      0.4259

           LT ear            8       37.4000      0.4375

           NT ear            8       37.3125      0.3137

           Shr ear           8       37.5500      0.3779

---------------------------------------------------------------------
```

```
------------------------------------------------------------------------

                      File Name:   stats

                      REPEATED MEASURES ANOVA

-------------------------------------------------------------------------
Source              Sum of Sqr.    DF   Var. Est.    F-Ratio     Prob. F
-------------------------------------------------------------------------

Between Subj          7.626422      7   1.089489    7.680726    0.0001

Within Subj.          3.404331     24   0.141847

  Treatments          0.388917      3   0.129639    0.902835    0.4564

  Error               3.015414     21   0.143591

Total                11.030753     31   0.355831

-------------------------------------------------------------------------

      Treatment              N           Mean         Std. Dev.

      ST mskin               8        35.074825       0.692836

      LT mskin               8        34.886364       0.425082

      NT mskin               8        34.840225       0.755065

     Shr mskin               8        35.087513       0.537979


-------------------------------------------------------------------------
```

```
----------------------------------------------------------------------

                  File Name:    stats

                  REPEATED MEASURES ANOVA

----------------------------------------------------------------------
Source            Sum of Sqr.    DF   Var. Est.    F-Ratio    Prob. F
----------------------------------------------------------------------

Between Subj       3.0364754      7   0.4337822   9.4846506    0.0001

Within Subj.       1.0976443     24   0.0457352

  Treatments       0.2498873      3   0.0832958   2.0633399    0.1353

  Error            0.8477570     21   0.0403694

Total              4.1341200     31   0.1333587

----------------------------------------------------------------------

     Treatment             N          Mean          Std. Dev.

    ST mbody               8      36.8799670      0.4291834

    LT mbody               8      36.8972740      0.3810853

    NT mbody               8      36.8180470      0.3659745

   Shr mbody               8      37.0575030      0.3025370


----------------------------------------------------------------------
```

```
---------------------------------------------------------------------

                    File Name:   stats

                    REPEATED MEASURES ANOVA

---------------------------------------------------------------------
Source              Sum of Sqr.   DF   Var. Est.   F-Ratio   Prob. F
---------------------------------------------------------------------

Between Subj          94.4043      7    13.4863    17.9974    0.0001

Within Subj.          17.9844     24     0.7493

  Treatments           0.4121      3     0.1374     0.1642    0.9193

  Error               17.5723     21     0.8368

Total                112.3887     31     3.6254

---------------------------------------------------------------------

       Treatment          N          Mean       Std. Dev.

        ST RPE            8         4.2813       1.4420

        LT RPE            8         4.5938       2.1874

        NT RPE            8         4.4688       2.3995

        Shr RPE           8         4.5000       1.8371


---------------------------------------------------------------------
```

```
------------------------------------------------------------------------

                      File Name:   wt loss

                      REPEATED MEASURES ANOVA

------------------------------------------------------------------------
Source              Sum of Sqr.    DF   Var. Est.    F-Ratio   Prob. F
------------------------------------------------------------------------

Between Subj      4.084065900      70.583437980%13.687537200    0.0001

Within Subj.      1.023011800     240.042625491

  Treatments      0.241131276      30.0803770942.158793900    0.1231

  Error           0.781880560     210.037232406

Total             5.107077600     310.164744437

------------------------------------------------------------------------

         Treatment            N          Mean       Std. Dev.

           ST n               8    1.767792700   0.438596700

           LT n               8    2.006179300   0.454469740

           NT n               8    1.840705870   0.442651300

          Shr n               8    1.991540530   0.316678400

------------------------------------------------------------------------
```

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---------------------------------------------------------------------

                    File Name:   wt diff

                    REPEATED MEASURES ANOVA

---------------------------------------------------------------------
Source              Sum of Sqr.    DF   Var. Est.   F-Ratio   Prob. F
---------------------------------------------------------------------

Between Subj     0.947406530      70.1353437903.648107100     0.0081

Within Subj.     0.890393560     240.037099730

  Treatments     0.067496844      30.0224989490.574164330     0.6383

  Error          0.822896720     210.039185558

Total            1.837800030     310.059283875

---------------------------------------------------------------------

        Treatment           N            Mean        Std. Dev.

        ST diff             8     0.321935830    0.425041170

        LT diff             8     0.374149770    0.221844822

        NT diff             8     0.245772019    0.105012469

       Shr diff             8     0.302343160    0.109534167


---------------------------------------------------------------------
```

## APPENDIX F

## INDIVIDUAL TEST DATA

Male Subject M.C.

| minute | hr | ear | mskin | mbody | rpe | corrected wt loss | evap prop |
|---|---|---|---|---|---|---|---|
| | | | Long T | | | | |
| 30 | 138.50 | 36.90 | 35.43 | 36.61 | 3.00 | | |
| 60 | 147.00 | 36.75 | 35.36 | 36.47 | 4.00 | | |
| 90 | 160.50 | 37.30 | 35.48 | 36.94 | 4.00 | | |
| 120 | 171.50 | 37.45 | 35.58 | 37.08 | 5.00 | 2.75 | 0.54 |
| | | | Short T | | | | |
| 30 | 140.50 | 37.05 | 35.41 | 36.72 | 2.00 | | |
| 60 | 146.00 | 37.30 | 35.45 | 36.93 | 3.00 | | |
| 90 | 161.50 | 37.50 | 35.63 | 37.13 | 3.50 | | |
| 120 | 169.00 | 37.75 | 35.18 | 37.24 | 4.00 | 1.91 | 1.05 |
| | | | No T | | | | |
| 30 | 135.50 | 36.95 | 35.60 | 36.68 | 1.50 | | |
| 60 | 135.50 | 37.15 | 35.12 | 36.74 | 2.00 | | |
| 90 | 151.00 | 37.25 | 35.85 | 36.97 | 4.00 | | |
| 120 | 155.00 | 37.45 | 35.47 | 37.05 | 3.50 | 2.11 | 0.27 |
| | | | Shroud | | | | |
| 30 | 136.50 | 37.25 | 36.06 | 37.01 | 2.00 | | |
| 60 | 143.50 | 37.20 | 35.70 | 36.90 | 3.50 | | |
| 90 | 156.50 | 37.55 | 35.82 | 37.20 | 5.00 | | |
| 120 | 159.50 | 37.60 | 36.06 | 37.29 | 4.00 | 2.38 | 0.41 |

### Male Subject T.R.

| minute | hr | ear | mskin | mbody | rpe | corrected wt loss | evap prop |
|---|---|---|---|---|---|---|---|
| | | | No T | | | | |
| 30 | 132.50 | 36.80 | 35.30 | 36.50 | 2.00 | | |
| 60 | 147.00 | 36.75 | 34.87 | 36.37 | 4.50 | | |
| 90 | 163.00 | 37.45 | 35.45 | 37.05 | 5.50 | | |
| 120 | 169.00 | 37.50 | 34.92 | 36.98 | 7.50 | 2.71 | 0.46 |
| | | | Long T | | | | |
| 30 | 140.50 | 36.95 | 34.97 | 36.55 | 2.00 | | |
| 60 | 155.50 | 37.05 | 34.54 | 36.55 | 3.50 | | |
| 90 | 169.00 | 37.45 | 34.43 | 36.85 | 5.50 | | |
| 120 | 176.00 | 37.60 | 34.40 | 36.96 | 7.25 | 2.60 | 0.77 |
| | | | Shroud | | | | |
| 30 | 132.50 | 36.95 | 34.62 | 36.48 | 2.00 | | |
| 60 | 135.00 | 36.95 | 33.67 | 36.29 | 3.50 | | |
| 90 | 142.00 | 37.30 | 35.45 | 36.93 | 3.50 | | |
| 120 | 152.50 | 37.35 | 35.54 | 36.99 | 4.25 | 2.27 | 0.35 |
| | | | Short T | | | | |
| 30 | 121.50 | 36.80 | 35.90 | 36.62 | 1.00 | | |
| 60 | 129.00 | 36.85 | 35.56 | 36.59 | 2.50 | | |
| 90 | 137.50 | 37.05 | 35.74 | 36.79 | 3.50 | | |
| 120 | 143.00 | 37.15 | 35.32 | 36.78 | 5.00 | 2.67 | 0.45 |

## Male Subject D.B.

| minute | hr | ear | mskin | mbody | rpe | corrected wt loss | evap prop |
|---|---|---|---|---|---|---|---|
| | | | Shroud | | | | |
| 30 | 119.50 | 37.05 | 35.19 | 36.68 | 3.00 | | |
| 60 | 119.00 | 37.10 | 34.96 | 36.67 | 3.50 | | |
| 90 | 128.00 | 37.50 | 35.36 | 37.07 | 4.00 | | |
| 120 | 136.50 | 37.65 | 35.39 | 37.20 | 5.00 | 1.93 | 0.35 |
| | | | No T | | | | |
| 30 | 121.50 | 37.20 | 35.14 | 36.79 | 3.00 | | |
| 60 | 130.50 | 37.20 | 34.91 | 36.74 | 3.00 | | |
| 90 | 134.50 | 37.45 | 35.49 | 37.06 | 3.00 | | |
| 120 | 134.00 | 37.45 | 35.52 | 37.06 | 3.50 | 1.90 | 0.23 |
| | | | Short T | | | | |
| 30 | 126.50 | 36.90 | 35.79 | 36.68 | 3.00 | | |
| 60 | 129.50 | 37.30 | 35.78 | 37.00 | 3.00 | | |
| 90 | 134.50 | 37.60 | 36.04 | 37.29 | 3.50 | | |
| 120 | 135.50 | 37.60 | 36.03 | 37.29 | 3.00 | 2.02 | 0.54 |
| | | | Long T | | | | |
| 30 | 117.00 | 36.80 | 34.98 | 36.44 | 2.50 | | |
| 60 | 122.50 | 37.05 | 35.03 | 36.65 | 3.00 | | |
| 90 | 133.50 | 37.20 | 35.31 | 36.82 | 3.00 | | |
| 120 | 142.00 | 37.60 | 35.15 | 37.11 | 3.50 | 2.09 | 0.45 |

Male Subject K.C.

| minute | hr | ear | mskin | mbody | rpe | corrected wt loss | evap prop |
|---|---|---|---|---|---|---|---|
| | | | Short T | | | | |
| 30 | 114.50 | 36.90 | 35.69 | 36.66 | 1.00 | | |
| 60 | 113.00 | 36.60 | 34.38 | 36.16 | 1.25 | | |
| 90 | 119.00 | 37.05 | 34.73 | 36.59 | 2.50 | | |
| 120 | 118.00 | 37.00 | 34.56 | 36.52 | 2.25 | 1.80 | 0.36 |
| | | | Shroud | | | | |
| 30 | 115.00 | 37.20 | 35.09 | 36.78 | 1.25 | | |
| 60 | 114.00 | 37.25 | 34.94 | 36.79 | 1.25 | | |
| 90 | 119.50 | 37.25 | 35.36 | 36.87 | 2.00 | | |
| 120 | 118.50 | 37.15 | 34.53 | 36.63 | 1.75 | 1.96 | 0.41 |
| | | | Long T | | | | |
| 30 | 113.50 | 37.05 | 35.17 | 36.67 | 1.00 | | |
| 60 | 114.50 | 36.90 | 34.37 | 36.39 | 0.75 | | |
| 90 | 122.50 | 37.05 | 30.81 | 35.80 | 1.00 | | |
| 120 | 123.00 | 37.10 | 34.52 | 36.58 | 2.00 | 1.92 | 0.32 |
| | | | No T | | | | |
| 30 | 110.50 | 35.85 | 34.79 | 36.44 | 1.00 | | |
| 60 | 110.00 | 36.85 | 34.48 | 36.38 | 1.25 | | |
| 90 | 113.00 | 36.95 | 33.83 | 36.33 | 1.75 | | |
| 120 | 115.50 | 36.90 | 34.08 | 36.34 | 2.00 | 1.95 | 0.27 |

Female Subject R.L.

| minute | hr | ear | mskin | mbody | rpe | corrected wt loss | evap prop |
|---|---|---|---|---|---|---|---|
| | | | No T | | | | |
| 30 | 144.50 | 37.70 | 35.62 | 37.28 | 3.50 | | |
| 60 | 146.00 | 37.65 | 35.23 | 37.17 | 4.00 | | |
| 90 | 147.00 | 37.90 | 35.37 | 37.39 | 5.50 | | |
| 120 | 150.00 | 37.80 | 34.80 | 37.20 | 9.00 | 1.33 | 0.23 |
| | | | Long T | | | | |
| 30 | 148.00 | 37.70 | 35.37 | 37.23 | 2.50 | | |
| 60 | 158.00 | 37.85 | 35.10 | 37.30 | 4.50 | | |
| 90 | 162.50 | 38.05 | 35.28 | 37.50 | 6.00 | | |
| 120 | 164.50 | 38.25 | 35.02 | 37.60 | 7.50 | 1.51 | 0.14 |
| | | | Shroud | | | | |
| 30 | 149.00 | 37.55 | 35.05 | 37.05 | 3.50 | | |
| 60 | 154.00 | 37.95 | 34.93 | 37.33 | 5.00 | | |
| 90 | 159.00 | 38.15 | 34.72 | 37.46 | 6.50 | | |
| 120 | 162.00 | 38.25 | 34.60 | 37.52 | 7.50 | 1.67 | 0.23 |
| | | | Short T | | | | |
| 30 | 142.00 | 37.80 | 35.26 | 37.29 | 3.00 | | |
| 60 | 145.00 | 37.90 | 35.01 | 37.32 | 4.50 | | |
| 90 | 150.00 | 38.00 | 34.99 | 37.40 | 5.50 | | |
| 120 | 152.00 | 39.00 | 35.01 | 37.40 | 7.00 | 1.58 | 0.05 |

Female Subject A.K.

| minute | hr | ear | mskin | mbody | rpe | corrected wt loss | evap prop |
|---|---|---|---|---|---|---|---|
| | | | Shroud | | | | |
| 30 | 154.50 | 37.65 | 35.56 | 37.23 | 3.25 | | |
| 60 | 157.50 | 37.50 | 35.22 | 37.04 | 4.00 | | |
| 90 | 166.50 | 37.60 | 34.93 | 37.07 | 5.00 | | |
| 120 | 174.50 | 37.75 | 34.66 | 37.13 | 6.00 | 1.81 | 0.32 |
| | | | No T | | | | |
| 30 | 145.50 | 37.10 | 35.21 | 36.72 | 3.00 | | |
| 60 | 147.00 | 37.25 | 34.90 | 36.78 | 3.50 | | |
| 90 | 156.00 | 35.90 | 34.91 | 36.50 | 5.00 | | |
| 120 | 164.00 | 37.05 | 34.88 | 36.62 | 5.75 | 1.69 | 0.23 |
| | | | Short T | | | | |
| 30 | 149.50 | 37.20 | 35.12 | 36.73 | 2.50 | | |
| 60 | 149.00 | 37.05 | 35.10 | 36.66 | 3.00 | | |
| 90 | 152.00 | 36.90 | 35.29 | 36.58 | 3.25 | | |
| 120 | 158.50 | 36.95 | 35.24 | 36.61 | 4.25 | 2.08 | 0.54 |
| | | | Long T | | | | |
| 30 | 147.00 | 37.25 | 35.54 | 36.91 | 2.00 | | |
| 60 | 148.50 | 37.15 | 35.20 | 36.76 | 3.00 | | |
| 90 | 150.50 | 36.95 | 35.20 | 36.60 | 4.25 | | |
| 120 | 158.00 | 36.80 | 34.78 | 36.40 | 5.00 | 1.74 | 0.27 |

Female Subject D.H.

| minute | hr | ear | mskin | mbody | rpe | corrected wt loss | evap prop |
|---|---|---|---|---|---|---|---|
| | | | Long T | | | | |
| 30 | 132.50 | 37.40 | 35.37 | 36.99 | 3.00 | | |
| 60 | 138.50 | 37.25 | 35.19 | 36.84 | 3.00 | | |
| 90 | 151.50 | 37.35 | 35.43 | 36.97 | 4.50 | | |
| 120 | 157.50 | 37.25 | 35.21 | 36.84 | 5.00 | 1.59 | 0.09 |
| | | | Short T | | | | |
| 30 | 127.50 | 37.45 | 35.71 | 37.10 | 2.00 | | |
| 60 | 137.50 | 37.45 | 35.56 | 37.07 | 3.00 | | |
| 90 | 137.50 | 37.55 | 35.76 | 37.19 | 4.50 | | |
| 120 | 141.50 | 37.40 | 35.54 | 37.03 | 5.00 | 1.55 | 0.09 |
| | | | No T | | | | |
| 30 | 127.00 | 37.50 | 35.72 | 37.14 | 2.00 | | |
| 60 | 126.50 | 37.50 | 35.25 | 37.05 | 3.00 | | |
| 90 | 134.50 | 37.50 | 35.40 | 37.08 | 3.50 | | |
| 120 | 134.00 | 37.40 | 35.61 | 37.04 | 4.00 | 1.43 | 0.09 |
| | | | Shroud | | | | |
| 30 | 129.50 | 37.25 | 35.76 | 36.95 | 2.00 | | |
| 60 | 126.50 | 37.30 | 35.25 | 36.89 | 3.00 | | |
| 90 | 131.00 | 37.20 | 35.41 | 36.84 | 4.00 | | |
| 120 | 135.00 | 37.05 | 35.12 | 36.66 | 5.00 | 1.44 | 0.09 |

Female Subject D.B.

| minute | hr | ear | mskin | mbody | rpe | corrected wt loss | evap prop |
|---|---|---|---|---|---|---|---|
| | | | Short T | | | | |
| 30 | 128.50 | 37.00 | 34.01 | 36.40 | 3.00 | | |
| 60 | 130.00 | 36.80 | 33.44 | 36.13 | 3.50 | | |
| 90 | 135.50 | 36.65 | 33.72 | 36.06 | 3.50 | | |
| 120 | 135.00 | 36.80 | 33.70 | 36.13 | 3.75 | 1.60 | 0.4 |
| | | | Shroud | | | | |
| 30 | 125.50 | 37.40 | 35.16 | 36.95 | 1.25 | | |
| 60 | 129.00 | 37.50 | 35.03 | 37.01 | 1.50 | | |
| 90 | 130.50 | 37.55 | 35.15 | 37.07 | 2.00 | | |
| 120 | 131.00 | 37.60 | 34.81 | 37.04 | 2.50 | 1.67 | 0.2 |
| | | | Long T | | | | |
| 30 | 131.00 | 37.10 | 35.14 | 36.71 | 1.00 | | |
| 60 | 126.50 | 37.15 | 34.49 | 36.62 | 1.00 | | |
| 90 | 126.00 | 36.95 | 34.56 | 36.47 | 1.50 | | |
| 120 | 123.50 | 37.15 | 34.43 | 36.61 | 1.50 | 1.65 | 0.41 |
| | | | No T | | | | |
| 30 | 129.00 | 37.50 | 34.49 | 35.90 | 1.00 | | |
| 60 | 125.50 | 37.40 | 33.92 | 36.69 | 1.00 | | |
| 90 | 124.00 | 37.15 | 33.12 | 36.34 | 1.00 | | |
| 120 | 127.50 | 36.95 | 33.44 | 36.25 | 1.50 | 1.55 | 0.19 |

Note: complete raw data is available on computer disk from the Health and Human Performance Lab, University of Montana