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Heat acclimatization during seasonal wildfire suppression

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The University of Montana

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HEAT ACCLIMATIZATION DURING SEASONAL WILDFIRE SUPPRESSION

By

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Heat Acclimatization During Seasonal Wildfire Suppression

Purpose: The purpose of this study was to determine heat acclimatization across a 4-month fire season in the western United States. Methods: Wildland firefighters (WLFF) (n =12) and non-WLFFs (n =14) completed a 60-min heat stress trial (treadmill walking at 50% peak VO$_2$) in a climate controlled chamber (43.3°C, 33% RH) prior to and following the fire season (May through September). Peak VO$_2$, body composition, core (T$_c$) and skin (T$_sk$) temperatures, heart rate (HR), physiological strain index (PSI), plasma volume change, sweat rate and perceived exertion (RPE) were measured during the heat stress trials. Results: Average peak VO$_2$ was similar between groups (54.1 ± 1.3 and 57.3 ± 2.0 ml·kg$^{-1}$·min$^{-1}$, WLFFs and non-WLFFs respectively, p>0.05) and did not change over the season. During the heat trial, WLFFs demonstrated a season-by-time reduction in T$_c$ at 45 and 60-min (38.3 ± 0.3°C vs. 38.1 ± 0.3°C and 38.5 ± 0.3°C vs. 38.2 ± 0.4°C at 45 and 60-min, pre- vs. post- season, respectively, p<0.05), and PSI for the last 30-min (5.6 ± 0.9 vs. 4.9 ± 1.0; 6.5 ± 0.9 vs. 5.8 ± 1.2; 7.1 ± 1.1 vs. 6.3 ± 1.3 at 30, 45, and 60-min, pre- vs. post-season, respectively, p<0.05), as well as a decrease in RPE (11.2 ± 2.1 vs. 10.2 ± 1.6, pre- vs. post-season, main effect for season, p<0.05). In contrast, there was no difference in T$_c$, PSI or RPE for non-WLFFs. Conclusion: WLFFs demonstrated less physiological strain with significant decreases in T$_c$ and PSI despite no change in aerobic fitness (peak VO$_2$), suggesting that heat acclimatization adaptations are accrued due to long-term environmental/occupational heat exposure.
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Chapter One: Introduction

Introduction

Wildland fire suppression is a seasonal occupation that involves strenuous working conditions, such as hiking, digging fire lines, clearing brush, and chainsawing on steep terrain\textsuperscript{1-3}. These firefighters are required to wear protective clothing while working for long hours in unpredictable, hazardous conditions and often under high ambient heat\textsuperscript{2,3}. These arduous conditions and strenuous tasks can challenge whole body homeostasis causing physiological and psychological stress that can potentially lead to heat stress\textsuperscript{2}. Physical exertion, clothing and hot/humid environments are all factors that contribute to and/or exasperate the level of heat stress a person may experience\textsuperscript{4,5}. Collectively, these conditions experienced by wildland firefighters increase the risk for exertional heat stress\textsuperscript{4,6,7}. In fact, our lab has recently completed a case study that suggests evidence of overexertion in wildland firefighting that caused and individual to succumb to heat related illness\textsuperscript{8}.

The leading cause of U.S firefighter fatalities are due to stress and overexertion, resulting in sudden cardiac events such as heart attack or stroke. In 2005 and 2008, about 2,000 firefighters were tested for body fat; 44.7% were found to be obese (≥25% body fat). This finding suggests that sudden cardiac death is due to low fitness levels and pre-existing heart disease, which could be exasperated by heat strain\textsuperscript{9,10}, as it causes physiological stress on the cardiovascular system and a decrease in thermoregulatory function\textsuperscript{4}. Based on Washington State’s occupational HRI incidence rates, the number of HRI claims
increases dramatically throughout the summer months\textsuperscript{11}. Risk factors for HRI are dehydration, seasonal increases in temperature (summer months), working during the hottest part of the day (10am to 6pm), and the type of clothing worn\textsuperscript{11,12}. Wildland firefighters expend between 2800 – 6200 kCal per day and work approximately sixteen-hour shifts for fourteen days before they have a two-day rest\textsuperscript{8}. Protective clothing worn by firefighters could lack permeability and can affect the body’s cooling capacity by decreasing the ability to evaporate sweat from the skin. These factors, along with hot environmental conditions, high skin temperatures (37°C) and a rise in core temperature (≥39.5°C) all increase the individual’s risk for HRI\textsuperscript{6,7,12,13}.

Heat related illness (HRI) is a physiological consequence of heat stress, which occurs when the body’s metabolic heat gain exceeds the evaporative cooling capacity\textsuperscript{4,7,14}. The inability to maintain thermoregulatory responses\textsuperscript{4,6} due to heat stress in the summer environment and/or with physical exertion can present HRI, such as heat cramps, heat exhaustion and heat stroke\textsuperscript{12}.

Prevention strategies to maintain thermoregulatory homeostasis include pre-cooling the body’s core temperature by means of cooling vests, ice baths, or ingestion of ice-slurry drinks, as well as with acclimatization\textsuperscript{6,12,15-17}. Heat acclimatization begins to occur within a few days, and full adaptation occurs within 7-14 days\textsuperscript{12}. It is a cardiovascular and thermoregulatory adaptation that occurs as a response to repeated bouts of heat stress from the outdoor, natural environment\textsuperscript{18}. It has been shown to decrease heart rate, core temperature and skin temperature, while increasing sweat rate\textsuperscript{13,14,19}. This response
enables the body to tolerate heat with less physiological strain\textsuperscript{20}, thereby, decreasing the risk of HRI\textsuperscript{6,10,11,17}. Poor acclimatization is a well-known risk factor for HRI\textsuperscript{11}. Outdoor occupations, such as wildland firefighting, would benefit from understanding their rate of seasonal heat acclimatization, as it may be considered a way to mitigate the chance of heat related casualties and decrease the possibility of HRI.

**The Problem**

Western Montana wildland firefighters begin their season in May when average temperatures are in the 10°C (50°F) range\textsuperscript{21}. At that time, they may be sent to fight fires in Florida, Texas or Arizona, where temperatures can sometimes exceed 32.2°C (90°F)\textsuperscript{21}. These firefighters are not acclimatized to the hot conditions, which places them at risk for exertional heat stress due to strenuous working conditions, protective clothing and high ambient heat; Poor acclimatization could be a factor in many occupational and recreational heat related illnesses. The degree to which wildland firefighters seasonally acclimatize is not known.

**Purpose**

The purpose of this study is to determine the variable characteristic changes in acclimatization that occurs throughout the western Montana wildland firefighter season.

**Research Hypotheses**

1. There will be no difference in acclimatization rate between wildland firefighters and non-wildland firefighters.
2. There will be no change in average wildland firefighter VO$_{2}\text{peak}$, percent body fat or weight throughout the season.

3. There will be no difference in the rise in core temperature throughout the season in wildland firefighters and non-wildland firefighters.

4. There will be no difference in the amount of time spent at, or above a PSI of 7.0 in wildland firefighters compared to non-wildland firefighters.

5. Sweat rate will increase throughout the season in both wildland firefighters and non-wildland firefighters alike.

6. Throughout the season, there will be no difference in the change in plasma volume in wildland firefighters compared to non-wildland firefighters.

**Significance and Rationale**

This study will determine the effect of seasonal acclimatization in wildland firefighters. The findings of this study could be used in real-life to help prevent heat related illness or heat injury occurrences and prepare both firefighters and recreationally active individuals to safely undergo physical exertion in hot and humid, summer environments.
Limitations

1. Due to availability of the wildland firefighters, the trials have to be spaced out throughout the season. However, the placement of the trials will correspond to the seasonal environmental changes in Montana, resulting in trials that are pre-, mid- and post- firefighting season.

2. We are not able to control the environmental conditions outside of the lab, such as: the amount of time each firefighter spends on the line, the amount of fires the firefighters are called out to fight, the amount of time indoors or outdoors.

3. Participants’ fitness levels could vary throughout the summer months. In an attempt to minimize error due to fitness, we will perform a post-maximal aerobic test at the end of the post-season trial.

4. The use of any instrumentation could cause error. To limit the occurrence of instrumentation error, all researchers will be trained and equipment will be carefully calibrated.

5. Participants are not randomly selected; they are acquired via word of mouth and on a volunteer basis.

Delimitations

1. All participants in this study will be males who are recreationally active and exercise regularly. Therefore, the results of this study will be applicable to all males who are wildland firefighters, have occupations that require working in high ambient heat, and who are relatively active.
Definition of Terms

*Acclimation*: Simulated laboratory environment (hot or cold) resulting in an acute physiological adaptation.

*Acclimatization*: Chronic physiological adaptation occurring in every human being as a response to repeated bouts of heat stress from the outdoor, natural environment.

*Heat stress*: Factors such as physical exertion, clothing and hot/humid environments that result in physiological consequences, such as heat stroke, heat exhaustion, muscle cramping and hyperthermia.

*Physiological strain index (PSI)*: A valid, non-invasive measurement model of core temperature or skin temperature and/or heart rate that utilizes heat strain and identifies individuals who are “at risk” or “not at risk” of heat injury\(^\text{10}\).

*Recreationally active individuals*: Individuals may work indoor during the workweek and/or exercise outdoors on a varying basis (≤30 hours) throughout the week.

*\(\text{VO}_{2\text{max}}\)*: The maximal amount of oxygen an individual can consume during a graded exercise test; therefore, it is the individual’s maximal aerobic capacity to do work.

*Wildland firefighting season*: The summer months in which the wildland firefighting crews are active fighting fires; May through September.
Chapter Two: Review of Literature

Wildland Firefighters

Past research on wildland firefighters (WLFFs) has recognized that wildland fire suppression throughout the summer months in the western United States requires long work shifts and a variety of strenuous tasks performed in high ambient heat\(^1-3,8\). Tasks include hiking, clearing debris and brush, digging lines, standing look-out, sawing, and moving hoses. All tasks vary from crew to crew, person to person, day to day, and hour by hour. Thus, physical demands are not entirely uniform; however, most of these efforts do exert physiological stress on the individual\(^1-3\) due to physical exertion and/or heat.

Our lab has recently presented a case study on a WLFF who suffered from HRI on the line during the hottest part of the day in the middle of summer. The WLFF was exposed to ambient temperatures between 44.6°C and 59.7°C (112.3°F and 139.5°F). During this time his core temperature and skin temperature increased to 40.1°C (104.2°F) and 33.1°C (91.6°F), respectively. Even though he was drinking an abundance of fluids, the extreme temperatures and strenuous working environment inevitably caused him to succumb to heat exhaustion; he had to be medically evacuated by helicopter due to his heat injuries. This study demonstrates the hazards of working outdoors in the summer environment while on the line as a wildland firefighter\(^8\).
Heat Related Illness and Heat Stress

Heat Stress

Wenger (1988) wrote an extended review on heat stress and thermoregulation\textsuperscript{19}. He states that thermoregulation is either behavioral or physiological. An example of behavioral regulation would be choice of clothing, shelter or air conditioning; most choices an individual decides on are based on thermal sensation or discomfort. Physiological regulation is controlled by internal thermoregulatory responses of the hypothalamus, which is sensitive to changes in skin or core temperatures. When the body and skin are cold, blood flow decreases to the skin and periphery in order to keep the body warm. When core temperature or skin temperature are elevated, the opposite occurs; Blood flow increases to the skin and periphery to enable sweating and cooling of the skin and body temperatures. These effects are heightened with exercise and external, environmental conditions, which can ultimately compromise the ability to thermoregulate and cause heat stress\textsuperscript{19}.

Montain et al. (1994) studied the effects of exercise intensity, protective clothing and climate on seven soldiers. The soldiers were acclimated for 10 days in a laboratory setting where they completed a total of 8 trials. Four trials were done in hot and dry conditions, and four trials were done in “tropical” hot and humid conditions. The subjects walked for 180 minutes on a treadmill with either partial or full protection clothing on, and the trial was terminated when the subject reached a core temperature of 40°C (104°F), 95% maximal heart rate, or when physiological heat stress symptoms (headache, disorientation, syncope) occurred. They found that full protective clothing reduced the
physiological strain that could be tolerated during heat stress, and when exhaustion occurred, it was at a lower core temperature than with partial clothing donned. The study found that heart rate was influenced by exercise intensity, the amount of clothing worn, and climate; heart rate was elevated at exhaustion when there was an increase in exercise intensity, in the amount of clothing worn, or climate, thereby, increasing cardiovascular strain. Lastly, they provided evidence that suggests that core temperature was able to predict the incidence of exhaustion due to heat stress whether the individual was wearing partial clothing or full protective clothing, such as the clothing worn by military personnel or firefighters.

Sawka et al. (2001) studied 12 soldiers in dry, desert heat and their physiological tolerance to uncompensable heat stress. They wanted to determine if exercise-rest cycles would increase physiological tolerance to heat strain. Uncompensable heat stress occurs when evaporative cooling requirements of the body exceed the cooling capacity of the environment due to clothing and hot ambient conditions. Eventually, thermal steady-state cannot be reached and core temperature rises until exhaustion occurs. Individuals who work in high ambient heat while wearing protective clothing are particularly at risk for this type of heat stress. The study confirmed that core temperatures of 38.7°C and 39.5°C (101.7°F and 103.1°F) could produce an estimation of exhaustion due to heat stress. They also found that exercise-rest cycles did not alter physiological tolerance to heat, which lead them to indicate that further research would be needed to determine if natural heat acclimatization would produce greater physiological heat tolerance.
Heat Illness

Heat edema, heat cramps, heat syncope, heat exhaustion, heat stroke and death are examples of heat illnesses that occur due to heat stress\(^6,11,12\). Bonauto et al. (2007) reviewed records that identified occupational heat related illness claims in Washington State over an 11-year time period, from 1995 to 2005. The state accepted 480 claims, and 377 out of the 480 claims were due to high outdoor ambient temperatures (mean temperature of 84.9°F). The incidence rate for the HRI claims peaked in the summer months, with the highest being in July. There was also an increase in the number of claims that occurred during the hottest hours of the day, which was from around ten in the morning until six in the evening. The authors suggested that the seasonal increases in temperatures and the increasing temperatures throughout the day were risk factors for HRI. They also suggested ways to reduce or prevent these risk factors, which included intervention methods of work/rest cycles, fluid intake, general education, and acclimatization\(^11\).

Acclimatization

Heat acclimation is done under simulated hot environments\(^18\). At absolute workloads, acclimation has shown to increase sweat rate, decrease heart rate, decrease core temperature and decrease skin temperature\(^7,13,14,23\). Acclimatization has the same effects as acclimation\(^18\); however, it is a chronic physiological adaptation occurring in every human being as a response to repeated bouts of heat stress from the outdoor, natural environment\(^18\). Acclimation and acclimatization both begin to occur within a few days,
and full adaptation occurs within 7-14 days\textsuperscript{12}. This response enables the body to tolerate the heat with less physiological strain\textsuperscript{20}.

One of the first studies to examine the effects of thermal, circulatory and body fluid responses during heat acclimatization was done by Mitchell et al (1976). They focused on the changes in body temperature, sweat production and energy exchange in four trained, male subjects. The subjects participated in a cross over study where they cycled at 40-50% of their maximal aerobic capacity, for four hours, at two different temperature conditions. The first environment condition was at 25°C (77°F) and was used as control, whereas the second condition was 45°C (113°F) and was used as the test exposure. The subjects were exposed to the control environment for a total of 3, non-consecutive days, after which, they were exposed for 10-consecutive days in the test environment. The study showed that by the fourth day and fourth hour, heart rate and core temperature decrease by one degree and thirty beats, respectively. Energy budgets showed that the subjects accumulated heat in the control environment, but were able to achieve thermal steady state, which was the rate of sweat evaporation sufficient enough to allow heat to dissipate from the body; 200 W of energy were lost due to heat dissipation and achievement of steady state. When the subjects were exposed to the hot, test environment, they lost 500 W due to the requirements needed to reach thermal steady state. Total sweat evaporated increased by 10% over the 10-day period, whereas the total amount of sweat produced, but not evaporated increased by 200%. Since the rate of evaporation could not be maintained at in the hotter environment, heat accumulated and core body temperature rose. They also found that on days one through four, skin
temperature rose immediately upon entering into the hot environment and was maintained for one hour, after which, skin temperature continued to rise throughout the test. By the seventh day, throughout all four hours of the test, skin temperature remained low. In conclusion, this study was the first to determine the rise in sweat rate and energy needed to keep the body cool in hot conditions. They also determined the decrease in heart rate and core temperature, and found that it takes about 7-10 days to show signs of acclimatization, and a decrease in discomfort to due heat strain.

Nielsen et al. (1993) conducted an acclimation study with a total of 13 subjects. Eight subjects cycled for 90-minutes, or until exhaustion at 60% of their maximal aerobic capacity for 9-12 consecutive days at a temperature of 40°C (104°F) and 10% humidity. Five subjects were used as the control group and cycled at 18-20°C (64.4°F-68°F), while three out of the five control subjects cycled at the same temperature as the control group, but on the first and last day they cycled at 42°C. The authors found that acclimation increased sweat rate, skin temperature at 30-minutes into the exercise was lower in the last experiment compared to the first, plasma volume increased, heart rate showed a lower rate of rise, and the subjects were able to continue exercising for longer duration. Finally, the study showed that the subjects core temperature decreased with acclimation, which explained why they were able to exercise for a longer period of time; however they always stopped exercising when their core temperature reached about 39.5°F (103.1°F). This core temperature may be the “critical factor” for fatigue in heat stress.
At higher environmental temperatures, the onset of fatigue occurs earlier, but that can be delayed with heat acclimation. Lorenzo et al. (2010) were the first to study the impact of heat acclimation on aerobic performance in a cooler environment, as well as lactate threshold, and time-trial performance. All of their subjects (n = 12) cycled in the cool, control conditions (13°C (55.4°F) and 30% humidity). Four of the twelve then completed a heat acclimation cycling protocol that lasted 10 days. The remaining eight subjects performed the same cycling protocol in the control conditions. The study found that the final heart rate on days one and ten for the subjects in the control group remained the same, while the final heart rate for the heat acclimation group dropped about 15 beats per minute from the first day to the last day. Plasma volume increased 6.5% (200mL) in the heat acclimated group compared to a reduction in the control group. This expansion in plasma volume increased cardiac output, which then increased the subjects’ maximal aerobic capacity by 5%. This study demonstrated how the effects of heat acclimation improved aerobic capacity, and decreased the time to the onset of fatigue.

In summary, all of the studies show that the biological acclimation effects carried out in a laboratory environment mimic natural acclimatization, and occur within 7-14 days of exposure. Heat acclimatization shows a decrease in final heart rate, skin temperature, core temperature, physiological strain and discomfort due to heat stress, while sweat rate increases at a quicker rate. These adaptations increase plasma volume, thereby increasing aerobic fitness. However, although there is an increase in exercise performance, individuals will usually stop exercising when their core
temperatures reach about 39.5°C (103.1°F). All of these factors can reduce the risk of heat illness when strenuously working or exercising in high ambient conditions.

**Markers of Acclimatization**

Heart rate, skin temperature, core temperature, and sweat rate are all important markers in determining the rate of acclimatization in an individual. Researchers have evaluated these factors in depth and have determined non-invasive ways to estimate or measure and classify physiological strain from heat stress\(^26,27\).

**PSI**

Heat stress increases physiological heat strain in the body, and can compromise the safety of workers, especially those that are required to wear protective clothing in hot environments\(^27\), such as wildland firefighters. Moran et al. (2000) developed a way to measure and standardize the interpretation of heat strain by developing a scale called the physiological strain index (PSI)\(^26\). Gotshall et al. (2001) evaluated and validated PSI in a study performing continuous and intermittent exercise in the heat. They were able to confirm that PSI could appropriately measure and interpret heat strain during continuous and intermittent exercise. This non-invasive index could become an important monitor in the field, especially for individuals who wear protective clothing while working in the heat\(^27\).

Buller et al. (2008) took it one step farther and used heart rate, skin temperature and PSI data to construct a new model in order to identify who may be “at risk” from heat strain.
They used different sets of data from other studies to analyze. Half of the subjects were wearing personal protective equipment and clothing and the other half were not wearing protective equipment while exercising. They separated these sets into two groups, a data group for training, and a data group of validation. Before they analyzed the group data, they chose a PSI of 7.5 for the threshold value, due to the fact that Moran et al. labeled a PSI of 7 to be “high” strain, and their review guidelines set core temperature and heart rate at a PSI value of 8. Therefore, they chose any values equal to, or above 7.5 as “at risk” for thermal injury, and any values below 7.5 as “not at risk” for thermal injury. After analyzing the combined data and developing a logistic regression model, they were able to successfully “identify subjects with a PSI $\geq$ 7.5 with minimal false negative errors,” even if they were wearing protective clothing. Thus, individuals who are working at a high ambient heat and are unacclimatized, or unfit, could be “at risk” for heat illness due to a high heart rate and/or high skin temperature. Whereas, acclimatized individuals with a lower skin temperature and heart rate would “not be at risk” for heat illness. This new PSI model could be an important tool in monitoring individuals in the field and help to prevent heat injuries.

Sweat Rate

An early study conducted by Fox et al. (1964) investigated acclimatization effects on sweating response in the heat. They had a total of four groups of subjects, and only groups one through three were acclimatized for fifteen days at 37.9°C (100.2°F); The fourth group sat in a cool room for fifteen days. Then, group one dipped their arms in an arm bath at 13°C (55.4°F), group two at 37°C (98.6°F), group three and four at 43°C
(109.4°F). They did this in order to determine localized sweat loss and whether the increase in whole body sweating was due to localized sweat glands or to the central nervous system. They found that local skin temperature was what influenced the local sweat rate after acclimatization even though there was an increase in total body sweat rate. They also found that the local response was due to training of the sweat glands from repeated heat exposure in acclimatization, rather than an increase in stimulation of the central nervous system, this effect allows for evaporation and cooler of core and skin temperatures

Due to contradicting studies, Buono et al. (2008) felt that the mechanism that increased whole body sweat rate with heat acclimation was unclear, so they conducted a study that essentially supported the experiment done by in 1964 by Fox et al. Fifteen subjects were acclimated to the heat for eight days and were analyzed for sweat rate, heart rate and core temperature. They were the first to discover that within three days of exposure to the heat, there was a decrease in thermoregulatory markers, such as heart rate and core temperature. During those three days, they also found that sweat rate increased significantly by 63%. The increase of sweat rate in the heat was due to peripheral sweat gland hypertrophy rather than central nervous system mechanism. This increase in sweat rate within the first three days of exposure allowed the body to cool and maintain a lower core temperature in higher ambient heat. These effects could help to decrease the discomfort and possibility of heat illness compared to the unacclimated individual.
Thermoregulation Marker Summary

Wendt et al. (2007) wrote an extensive review article on thermoregulation during exercise in the heat. They state that most heat illnesses, such as heat cramps, heat exhaustion and heat stroke, are due to individuals who are physically working in hot and humid environments. This activates sweat glands and causes an increase in sweating, which promotes heat loss by evaporation and cooling of the core temperature. They also describe strategies to decrease a person’s chance for heat illness, such as whole-body pre-cooling with water-cooled garments, and heat acclimatization.\textsuperscript{12}

The authors also state that acclimatization begins within a few days, and full adaptation occurs between seven and fourteen days of heat exposure; However, these responses can be lost in less than a month. The effects of acclimatization, such as a decrease in core temperature, decrease in heart rate, increase in sweat rate, decrease in electrolyte losses, and increase in plasma volume allows for cardiovascular stability and a decrease in discomfort and physiological strain, thus, mitigating the risk for heat illness.\textsuperscript{12}
Chapter Three: Methodology

Participants and Setting

Participants were recruited to voluntarily participate, which included male wildland firefighters \((n = 12)\) from the local Missoula area Hand Crews and the Lolo hotshot crews, as well as recreationally active males \((n = 14)\) from the Missoula, MT area. This was a total of 30 subjects between the ages of 18 and 40 years of age. Prior to testing, all participants were required to fill out a medical history form on heat injury and were provided a written consent form, which was approved by the Institutional Review Board of the University of Montana in Missoula. Testing for the study took place in the Montana Center for Work Physiology and Exercise Metabolism lab (WPEM) at the University of Montana in Missoula, MT.

Experimental Design

Preliminary and Post-Experimental Testing

The experimental testing revolved around the wildland firefighters pre- and post- fire fighting seasons. Prior to the experimental trials, participants performed a maximal aerobic capacity (peak VO\(_2\)) test and body composition assessment. Peak VO\(_2\) testing was determined by using a continuous incremental protocol on a treadmill and body composition was determined by hydrodensitometry with estimated residual volume. This was repeated in September, post-season.
Experimental Protocol

This experimental research design was conducted in May and September in Missoula, MT with a total of four visits to the lab pre- and post- firefighting season. Prior to their heat stress trials, the participants came into the lab fasted for at least 10 hours. Throughout the fasting hours, they were allowed water, but no other foods or drinks, including alcohol, were permitted. Upon arrival, the participants initially voided their bladder, however, after this, all urine was collected for measurement at the end of each trial. They privately inserted a rectal thermometer (Mallinckrodt Medical, St. Louis, MO) to a depth of 15-cm in order for core body temperature to be monitored throughout the trial. Heart rate monitor straps (Polar Electro, Kempele, FL) were also be fitted to each participant upon arrival for each trial. Nude body weight was taken before and after the exercise session on a private, calibrated scale (Ohaus, Pine Brook, NJ). Wired skin temperature sensors (Mallinckrodt Medical, St. Louis, MO) were adhered to the pectoralis muscle. Blood samples were taken via venipuncture pre- and post- exercise sessions. The participants exercised for 60 minutes in a hot environmental chamber (Tescor, Warminster, PA) at a constant environmental temperature of approximately 43.3°C and 33% humidity. Water was consumed every fifteen minutes throughout the 60-minute exercise session.

Experimental Procedures

Maximal Aerobic Capacity (peak VO₂):

Participants fasted for at least 3-hours prior to their first visit of preliminary testing. Testing on a motorized treadmill (Fullvision, Inc., Newton, KS) began with a 3-min
warm up. After the warm up, the participants performed an incremental protocol, which started at 1.8 m·s⁻¹ and 0% incline. After 1-minute, the incline increased to 4% and continued to increase 2% each minute until a maximum of 10% incline was reached. Speed remained at 1.8 m·s⁻¹ until minute 6, at which time it was increased to 2.0 m·s⁻¹ and continued to increase 0.18 m·s⁻¹ each minute. This protocol continued until the participant reached volitional exhaustion. Heart rate (Polar Electro, Kempele, FL) was continuously monitored, and RPE was recorded every minute using the 6- to 20-point Borg Scale (4). Expired gases were continuously collected and analyzed every 15-sec throughout the test using a calibrated metabolic cart (Parvomedics, Inc., Sandy, UT). Maximal aerobic capacity was achieved when at least three of the following required criteria were met: 1) a plateau in oxygen uptake (VO₂) despite an increase in work rate, 2) respiratory exchange ratio (RER) higher than 1.1, 3) heart rate that was at least 10 beats per minute below the estimated maximal heart rate of 220 – age of the subject and 4) perceived exertion rated at, or above, seventeen.

Hydrodensitometry:
Participants fasted for 3-hours prior to arrival for preliminary testing of body fat composition. Body weight was recorded on a dry weight scale (Befour Inc., Cedarburg, WI) and height was measured. Body fat was assessed using a calibrated underwater weighing tank with computerized scales (Exertech, Dresbach, MN). They were submerged in the weighing tank to obtain body density. Underwater weighing continued until at least three measurements within 100 grams of each other were documented.
These underwater body density measurements were converted to percent body fat using estimated residual volume and the Siri equation\textsuperscript{31}.

**Heat Trials**

**Exercise Protocol**

Participants walked for 60-minutes in an environmental chamber (Tescor, Warminster, PA) at 43.3°C and 33% humidity. They walked on the same treadmill ergometers (Fullvision Inc., Newton, Kansas) used in the preliminary testing at 50% of their relative maximal aerobic capacity, which was based on their peak VO\textsubscript{2} preliminary test. The participants were allowed to drink water every 15 minutes throughout the exercise session.

**Drinking Schedule**

Throughout the 60-minute heat trial, each participant was given a measured amount of water (0.7g/kg) every 15-minutes.

**Heart rate, core temperature and skin temperature**

Heart rate (HR), core temperature (T\textsubscript{c}) and skin temperature (T\textsubscript{s}) were continuously monitored throughout the entire exercise session. Heart rate data was collected with a chest-strap and receiver (Polar Electro, Kempele, FL). Core temperature was collected with the rectal thermometers (Mallinckrodt Medical, St. Louis, MO) that were privately inserted 15-cm past the anal sphincter, and skin temperature was collected with wired
skin temperature sensors (Mallinckrodt Medical, St. Louis, MO). The sensors were adhered to the pectoralis major muscle about 1 to 2 inches away from the sternum; the skin was alcohol swabbed and properly prepped to ensure adhesion of the sensors. $T_s$ and $T_c$ was continuously recorded with DASYLab Software (Measurement Computing Co., Norton, MA). Data for each variable was collected at 15-minute increments throughout the experimental heat trials.

**Physiological Strain Index**

PSI was collected as an actual PSI value, which was determined by heart rate and core temperature by the following equation \(^{10, 32}\):

$$\text{PSI} = 5(T_{\text{core(t)}} - T_{\text{core(0)}})(39.5 - T_{\text{core(0)}})^{-1} + 5(HR_t - HR_0)(180 - HR_0)^{-1}$$

**Body mass and sweat loss**

Nude body weight was collected before and after the exercise session on a private, calibrated scale (Ohaus, Pine Brook, NJ). Urine was also collected at the end of the exercise session in order for sweat loss to be accurately calculated. Whole body sweat loss was determined by the difference in nude body mass before and after exercise, urine output and fluid intake.

**Blood Samples**

5-mL of blood was collected before and after the 60-minute exercise sessions from an anticubital vein into a heparinized vacutainer vial (Becton, Dickinson and Co., Franklin Lakes, NJ), for a total of approximately 10-mL of blood drawn at each trial. Hematocrit
was assessed and the remaining blood will be frozen at -80°C for further analysis of hemoglobin.

**Blood Analysis**

**Hematocrit**

Heparinized microhematocrit capillary tubes (Iris sample processing, Westwood, MA) were used to analyze hematocrit after being properly centrifuged for 3-minutes (Jouan A13, Winchester, VA) and accurately measured.

**Hemoglobin**

Hemoglobin analysis was done by adding 20 µL of blood to 5mL of Drabkin’s reagent in a 13x100 mm test tube. A total of 2 test tubes were analyzed and compared against a standard curve. All assay absorbances were read on a spectrophotometer (Thermoscientific, Madison, WI) at 540 nm. This protocol was followed using the Sigma Assay Kit (SIGMA, St. Louis, MO).

**Statistical Analysis**

*Descriptive data*

Weight, percent body fat and peak VO₂, was analyzed using a group-by-trial (pre-, and post- heat trials), 2x2 mixed ANOVA with repeated measures between the WLFF and recreationally active controls.
90-minute heat trial

Body weight, hemoglobin and hematocrit were separately analyzed pre- and post- trial, and across the seasons for both WLFF and non-WLFF using a trial-by-season (May and September), 2x2 repeated measures ANOVA.

Sweat rate, percent plasma volume and rate of rise in core temperature for WLFF and non-WLFF were compared and analyzed using a group-by-season, 2x2 mixed ANOVA with repeated measures.

Time 0, 30, 45, and 60 minutes

Core temperature, heart rate, skin temperature, PSI and RPE at times 0, 15, 30, 45 and 60-minutes, for both WLFF and non-WLFF were separately analyzed using a season-by-minute, 2x5 repeated measures ANOVA.

The level of statistical significance will be set at p<0.05 and all values will be reported as +/- SD.
References


Chapter 4: Manuscript

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Heat acclimatization during seasonal wildfire suppression.

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Running Title: Seasonal acclimatization and fire
ABSTRACT

Purpose: The purpose of this study was to determine heat acclimatization across a 4-month fire season in the western United States. Methods: Wildland firefighters (WLFF) (n =12) and non-WLFFs (n =14) completed a 60-min heat stress trial (treadmill walking at 50% peak VO$_2$) in a climate controlled chamber (43.3°C, 33% RH) prior to and following the fire season (May through September). Peak VO$_2$, body composition, core (T$_c$) and skin (T$_sk$) temperatures, heart rate (HR), physiological strain index (PSI), plasma volume change, sweat rate and perceived exertion (RPE) were measured during the heat stress trials. Results: Average peak VO$_2$ was similar between groups (54.1 ± 1.3 and 57.3 ± 2.0 ml kg$^{-1}$ min$^{-1}$, WLFFs and non-WLFFs respectively, p>0.05) and did not change over the season. During the heat trial, WLFFs demonstrated a season-by-time reduction in T$_c$ at 45 and 60-min (38.3 ± 0.3°C vs. 38.1 ± 0.3°C and 38.5 ± 0.3°C vs. 38.2 ± 0.4°C at 45 and 60-min, pre- vs. post- season, respectively, p<0.05), and PSI for the last 30-min (5.6 ± 0.9 vs. 4.9 ± 1.0; 6.5 ± 0.9 vs. 5.8 ± 1.2; 7.1 ± 1.1 vs. 6.3 ± 1.3 at 30, 45, and 60-min, pre- vs. post- season, respectively, p<0.05), as well as a decrease in RPE (11.2 ± 2.1 vs. 10.2 ± 1.6, pre- vs. post- season, main effect for season, p<0.05). In contrast, there was no difference in T$_c$, PSI or RPE for non-WLFFs. Conclusion: WLFFs demonstrated less physiological strain with significant decreases in T$_c$ and PSI despite no change in aerobic fitness (peak VO$_2$), suggesting that heat acclimatization adaptations are accrued due to long-term environmental/occupational heat exposure.

Keywords: HEAT STRESS, PHYSIOLOGICAL STRAIN INDEX, HEAT RELATED ILLNESS, HEAT INJURY
INTRODUCTION

**Paragraph Number 1** Wildfire suppression is a seasonal occupation that involves working long hours in unpredictable, hazardous conditions and often under high ambient heat (11, 13, 28, 29). The duties of a typical wildland firefighter (WLFF) are dependent on the crew they are assigned (jumper, hotshot, district), but typically include hiking, digging fire lines, clearing brush, standing lookout and chain sawing on steep terrain (13, 28, 29), which can differ with each days work assignment (13). We have previously demonstrated that the total energy demands of wildfire suppression in the United States ranges between 12 – 26 MJ day\(^{-1}\) (2800 – 6200 kCal day\(^{-1}\)) (13, 28), with work shifts lasting approximately 12-16-hrs for 14-days before a 2-day rest (11, 13, 28). The long hours, coupled with periods of vigorous muscular work, result in a loss of muscle glycogen, which is accelerated by heat stress (10) and can ultimately impair physical performance if proper feeding strategies are not utilized (10, 13). This, along with the addition of protective clothing and high ambient heat, challenges whole body homeostasis causing physiological and psychological stress (23, 28) that can potentially lead to heat stress and heat related illness (HRI) (12).

**Paragraph Number 2** Heat related illness is a physiological consequence of heat stress that occurs when the body’s metabolic heat gain exceeds the evaporative cooling capacity rendering its inability to adequately thermoregulate (5, 9, 10, 31, 35). Physiological heat strain can compromise the safety of workers, especially those who are required to wear protective clothing in hot environments (23), such as WLFFs. The prevalence of HRI cases in wildfire suppression is low (3, 12). However, in a previous case study, we describe an HRI in an experienced 24- year old WLFF who was working in the middle of
the summer, during the hottest part of the day. Even though he had been drinking an abundance of fluids, he ultimately succumbed to HRI ($T_c > 40^\circ C$). In this particular case, the WLFF collapsed and was evacuated from the fire line, for medical attention (12) and recovered from the injury. However, fatalities involving HRI can occur, which was the case early in the month of July 2011. An experienced 23-year old WLFF was on an initial attack assignment at a fire in Palo Pinto County, TX. He worked much of the day in extremely hot ambient temperatures ($>41^\circ C$) and as 4 pm approached, the WLFF reported that he was hot and had a headache. Within minutes, he collapsed at the scene and arrived at the hospital approximately 1-hr after the incident. Later, it was reported that the WLFF died due to hyperthermia (high body $T_c$) despite no apparent irregularities in hydration or electrolyte status (8, 16).

**Paragraph Number 3** The ability to reduce the risk for HRI is a critical concern as it can be life threatening (5, 8, 12, 16). High aerobic fitness aids in protecting the body from heat stress due to a superior cardiovascular system and improved tolerance to the heat (32, 36). However, poor heat acclimatization is a well-known risk factor in many occupational and recreational HRI cases (3). In individuals with lower heat tolerance, $T_c$ will rise at a much quicker rate compared to heat resilient individuals (15). Natural heat acclimatization is not well documented but is assumed to contribute to the adaptations necessary for safely working in outdoor occupations. Understanding the seasonal adaptations that WLFFs accrue may provide insight into increased preparedness and reduce the risk for HRI (5, 23, 27, 31, 35).

**Paragraph Number 4** WLFFs in the northern Rocky Mountains begin their season in May when temperatures average 10$^\circ C$ (50$^\circ F$). However, early season assignments may
require work in the Southeastern or Southwestern U.S. where temperatures can often exceed 32°C (90°F). Thus, it is anticipated that in the early portion of the fire season, WLFFs from the north may not be adequately acclimatized to the hot working conditions of these initial assignments. Early season acclimatization and the changes that occur due to natural heat acclimatization during outdoor, seasonal wild fire suppression have not been evaluated.

**Paragraph Number 5** The purpose of this study was to determine changes in the markers of heat acclimatization, which occur as a result of seasonal, occupational wildfire suppression. We hypothesized that physiological markers of heat stress would respond to seasonal occupational heat exposure similarly to previous short term laboratory heat acclimation studies.

**METHODS**

**Paragraph Number 6 Participants.** Twenty-six healthy males volunteered for this study. This included WLFF ($n = 12; 27 \pm 7$ yrs; $179 \pm 7$ cm; $79 \pm 10$ kg) and a group of non-WLFF ($n = 14, 25 \pm 4$ yrs; $180 \pm 7$ cm; $77.7 \pm 8.8$ kg) from the local community. The non-WLFFs were recreationally active (exercising $\geq 30$-min per day, but $<15$-hrs per week). Prior to data collection, all participants completed a University Institutional Review Board approved written consent form. They also completed a medical history form to screen for any previous heat injuries.

**Paragraph Number 7 Preliminary Testing.** Preliminary testing was done pre- and post-fire season before the experimental trials (May and September, respectively). Participants fasted for at least 3-hrs prior to performing a maximal aerobic capacity (peak VO$_2$) test and body composition assessment. Peak VO$_2$ testing was done on a motorized treadmill.
(Fullvision, Inc., Newton, KS) and started with a 3-min warm up. After the warm up, the participants performed an incremental protocol, which started at 1.8 m s\(^{-1}\) and 0\% incline. After 1- min, the incline increased to 4\% and continued to increase 2\% each minute until a maximum of 10\% incline was reached. Speed remained at 1.8 m s\(^{-1}\) until minute 6, at which time it was increased to 2.0 m s\(^{-1}\) and continued to increase 0.18 m s\(^{-1}\) each minute. This protocol continued until the participant reached volitional exhaustion. Heart rate (Polar Electro, Kempele, FL) was continuously monitored, and RPE was recorded every minute using the 6- to 20- point Borg Scale (4). Expired gases were continuously collected and analyzed every 15-sec throughout the test using a calibrated metabolic cart (Parvomedics, Inc., Sandy, UT).

**Paragraph Number 8** Body composition was determined by hydrodensitometry with estimated residual volume. Body weight was recorded on a dry weight scale (Befour Inc., Cedarburg, WI) and height was measured. Body density was assessed using a calibrated underwater weighing tank with computerized scales (Exertech, Dresbach, MN). Body density was converted to percent body fat using estimated residual volume (20) and the Siri equation (34).

**Paragraph Number 9** Experimental Design. The experimental heat trials were conducted pre- and post- fire season (May and September, respectively). In the 10-hr period before the heat trials, participants fasted, but were permitted to consume water *ad-lib.* Throughout the heat trial, each participant was given a measured amount of water (0.7 g kg\(^{-1}\)) every 15-min.

**Paragraph Number 10** Experimental Procedures. Upon arrival, participants voided their bladder and a nude body weight was obtained on a calibrated scale (Ohaus, Pine Brook,
All urine used in the estimation of sweat rate was collected for measurement after this initial void. The participants then inserted a rectal thermometer (Mallinckrodt Medical, St. Louis, MO) to a depth of 15-cm (Mallinckrodt Medical, St. Louis, MO), which continuously recorded $T_c$ throughout the trial. A HR monitor (Polar Electro, Kempele, FL) was affixed around the chest and a wired skin temperature sensor (Mallinckrodt Medical, St. Louis, MO) was adhered to the left pectoralis muscle. Blood samples (5 mL) were collected before and after the 60-min exercise sessions from an antecubital vein into a heparinized vacutainer vial (Becton, Dickinson and Co., Franklin Lakes, NJ). The participants walked at 50% of their relative peak VO$_2$ in a climate controlled chamber (Tescor, Warminster, PA) at a constant temperature of 43.3°C and 33% relative humidity for 60- min. After exercise, participants voided and urine was collected for measurement. A post exercise nude body weight and blood sample was collected as previously described. In September (post- season), the participants repeated the heat trial at the same absolute work rate (50% of their pre–season peak VO$_2$). At that time exercise history (minutes of exercise the non-WLFF participated in each week) via questionnaire and interview was collected. For WLFF, shift logs and word schedules were reviewed and recorded (dates and locations of fire work).

**Paragraph Number 11 Physiological Measurements.** Skin temperature and $T_c$ were continuously monitored throughout the exercise session at 0.5-sec intervals using DASYLab Software (Measurement Computing Co., Norton, MA). Heart rate, $T_{sk}$, $T_c$ and RPE were averaged at 15-min intervals starting at time zero for statistical analyses.

**Paragraph Number 12** Whole body sweat loss was determined by the difference in nude body mass before and after exercise, urine output and fluid intake (corrected for
respiratory water loss (22) and water vapor pressure (17)). Sweat loss was converted to sweat rate relative to body surface area (25).

**Paragraph Number 13** PSI was determined with HR and T_c using an established equation (6, 24) where “t” is core temperature/HR at the time of reading, and “0” is core temperature/HR at time zero, prior to the start of exercise.

**Paragraph Number 14** PSI = \[5(T_{\text{core}(t)} - T_{\text{core}(0)}) \cdot (39.5 - T_{\text{core}(0)})^{-1} + 5(HR_t - HR_0) \cdot (180 - HR_0)^{-1}\]

**Paragraph Number 15** Changes in plasma volume were evaluated and determined as previously described by Dill and Costill (14). Acute plasma volume (%ΔPV) was evaluated using pre- and post- exercise values of Hb and Hct at the beginning and end of the season.

**Paragraph Number 16 Statistical Analyses.** Weight, percent body fat, peak VO_2, sweat rate, change in plasma volume (%ΔPV) and rate of rise in T_c were compared and analyzed using a group-by-season (pre-, and post- season), 2x2 mixed ANOVA with repeated measures between the WLFF and non-WLFF. Body weight, hemoglobin and hematocrit were separately analyzed pre- and post- 60-min heat trial, and across the seasons for both WLFF and non-WLFF using a trial-by-season (May and September), 2x2 repeated measures ANOVA. Physiological variables (T_c, T_sk, HR, PSI) and RPE were analyzed at times 0, 15, 30, 45 and 60-min, for both WLFF and non-WLFF separately using a season-by-time, 2x5 repeated measures ANOVA. Statistical significance was set at p < 0.05 for all analyses. Descriptive data is reported as mean ± SD and graphic values are reported as mean ± SEM; Data was analyzed using SPSS (Version 13.0 for Windows: SPSS Inc., Chicago, IL).
RESULTS

**Paragraph Number 17 Preliminary Testing.** There was no difference in body weight, percent body fat or peak VO$_2$ across the season for either group. There were also no differences between the WLFF and non-WLFF (Table 1).

*Insert Table 1*

**Paragraph Number 18 Core Temperature (T$_{c}$).** Wildland firefighter’s T$_{c}$ showed a significant season-by-time interaction during the heat stress trial, with post-season values being significantly lower at time points 45 and 60-min (p < 0.05). In contrast, there were no differences in T$_{c}$ for the non-WLFF group across the season (Figure 1).

**Paragraph Number 19** There was no difference in the rate of rise in T$_{c}$ pre- to post-season for WLFF (1.6 ± 0.4°C min$^{-1}$ vs. 1.4 ± 0.4°C min$^{-1}$), or non-WLFF (1.9 ± 0.6°C min$^{-1}$ vs. 1.8 ± 0.6°C min$^{-1}$).

*Insert Figure 1*

**Paragraph Number 20 Heart Rate (HR).** There was a main effect for time for both WLFF and non-WLFF during the 60 min heat trials (Figure 2). However, there were no differences in the HR response across the season.

*Insert Figure 2*

**Paragraph Number 21 Physiological Strain Index (PSI).** There was a season-by-time interaction for WLFF with significantly lower PSI at time points 30, 45 and 60- min, post-season compared to pre-season (p < 0.05). In contrast, non-WLFF showed no difference in PSI post-season compared to pre-season (Figure 3).

*Insert Figure 3*
**Paragraph Number 22 Rating of Perceived Exertion (RPE).** The average RPE for WLFF was lower throughout the post-season heat trial compared to pre-season; main effect for season (p < 0.05). However, the RPE remained unchanged in the non-WLFF across the season (p > 0.05) (Figure 4).

*Insert Figure 4*

**Paragraph Number 23 Skin Temperature (T_{sk}).** There was no difference across the season in T_{sk} for both WLFF and non-WLFF (Figure 5). However, the T_{sk} response during the post-season heat trial demonstrated a trend towards a lower average in the WLFF (p = 0.08).

*Insert Figure 5*

**Paragraph Number 24 Sweat Rate and Blood Analysis.** Values for hematocrit (Hct), hemoglobin (Hb), body mass, sweat loss and %ΔPV for both the WLFF and non-WLFF, pre- and post-heat trials in May and September are shown in Table 2. Minor differences were apparent across the season with no differences between groups.

*Insert Table 2*

**DISCUSSION**

**Paragraph Number 25** The purpose of this study was to determine changes in select physiological markers of heat acclimatization, which occur as a result of seasonal occupational wildfire suppression. The key findings of this study are observed in the WLFFs, post-wildfire suppression season, which is represented by the significant decreases in T_{c} and PSI during controlled heat stress (Figure 1 and 3, respectively). Since there was no change in peak VO_{2} across the season or the HR response during the heat stress trials, acclimatization to the heat due to extended occupational exposure most
likely explains the observed adaptation in $T_c$. This thermoregulatory advantage is most apparent in the overall reduction in PSI post-season (Figure 3).

**Paragraph Number 26** Individuals who have “high heat strain” may be susceptible to HRI and can be identified with elevated values of PSI ($>7.0$), as previously explained by Moran et al. (24). As a result of seasonal work, the WLFFs in our current study demonstrated lower $T_c$ and thus, “low heat strain” PSI values ($<7.0$). These physiological changes were observed during the heat stress trials, as it brought 6 out of the 12 WLFFs from “high heat strain” pre-season, down to 3 out of the 12 post-season. The remaining 9 WLFFs who had “low” PSI post-season, also demonstrated a reduction in HR and $T_{sk}$ compared to the 3 WLFFs who did not demonstrate a reduction in PSI over the season. In contrast, 10 out of the 14 non-WLFFs experienced “high heat strain” both pre- and post-season. Although the subjects were exercising at the same absolute work rate from pre- to post-season, based on the observed changes in $T_c$ and PSI, the majority of the WLFFs demonstrated greater physiological tolerance to heat stress post-season. Interestingly, these adaptations occurred despite changes in aerobic fitness (peak VO$_2$).

**Paragraph Number 27** It has been suggested that high aerobically fit individuals (>55 ml·kg$^{-1}$·min$^{-1}$) acclimate to the heat quicker than unfit individuals (9). This has been attributed to an increase in heat dissipation, evaporative heat loss capacity and a lower resting HR and $T_c$ at the start of exercise (32, 36). Starting off the season highly fit should be a consideration for WLFFs as it can provide early-season, early-shift protection and prevent over-exertion from heat strain prior to acclimatization. Although these benefits may improve exercise tolerance in the heat, previous literature suggests that higher aerobic fitness is only beneficial for work periods up to approximately 4-hrs (9, 36).
However, the collective benefits of increased early season fitness and heat acclimatization could decrease the rate of rise in $T_c$ and HR, which could better maintain PSI values below 7.0 during work rates commonly associated with the arduous tasks of wildfire suppression. Regardless, fire crews from varied geographic regions should consciously reduce their absolute work rate during wildfire suppression in hot climates to reduce the risk for exertional HRI.

*Paragraph Number 28* The effects of acclimation in previous laboratory studies demonstrates physiological changes beginning to occur within a few days, with full adaptation possibly occurring within 7-14 days (35). These changes include decreases in HR, $T_{sk}$ and $T_c$ and an increase in sweat rate at the same absolute work rate (9, 27, 36). Thus, thermoregulation and exercise performance in the heat is improved while reducing PSI and decreasing the risk of HRI (3, 5-7, 21, 30). It has also been suggested that acclimation in laboratory conditions and natural acclimatization have the same effect (19, 36), yet, the time course and workload requirements to achieve the same physiological adaptations outside the controlled laboratory environment have not been described. Moreover, outside of the laboratory, the worker self-regulates work rate, and therefore heat stress, whereas acclimation studies are controlled by specific laboratory protocol. These uncontrolled conditions throughout the wildfire suppression season could explain why WLFFs demonstrated a decrease in $T_c$ and PSI, without demonstrating differences in seasonal $\%\Delta PV$ or sweat rate (Table 2). However, it has been suggested that plasma volume increases early on in acclimatization, improving cardiovascular responses and lowering $T_c$ due to an improvement in heat transfer and dissipation. The increases in plasma volume, however, drop back to pre- acclimatization levels after 14- days of heat
exposure (2). Sweat rate and %ΔPV in the WLFFs may not have increased due, in part, to an inadequate sample size, a large individual variability between subjects, and/or differences in hydration status. Nonetheless, if sweat rate did increase, it may not benefit the WLFF in the field, as evaporative-heat loss is limited while wearing protective clothing. Therefore, for the WLFF, an increase in sweat rate could actually be a less effective adaptation (9).

Paragraph Number 29 Since the occupational heat stress throughout the work/study season was uncontrolled, one may question the amount of heat exposure the non-WLFFs and WLFFs actually endured. Fortunately, we were able to assess the amount of time both the WLFFs and non-WLFFs were working/exercising in the heat. Considering work shift reports, we estimated the WLFF to have worked on fires 61% of the summer, for a total of about 73 out of 120 days between May and September. When we consider the typical 14-hr shift and assume 7-hrs of warm environmental exposure, it results in approximately 500-hrs of heat exposure. After asking the non-WLFFs their daily exercise routines and assuming each person exercised during the warmest part of the day, we found that they exercised, at most, 200-hrs in the heat (running, cycling, hiking, etc.). The WLFFs worked in the heat roughly 2.5-times more than the non-WLFF. Even though the WLFFs did not show significant changes in HR, %ΔPV, or sweat rate, their long-term heat exposure is likely the cause for the observed decreases in $T_c$ and PSI. Although these results are somewhat in contrast to classic laboratory acclimation response patterns, we speculate that the natural acclimatization accrued required a longer time course due to a likely reduction in self-selected work rate corresponding to the environmental conditions.
However, our data suggests that adaptations from constant exposure to the heat still result in an overall reduction in $T_c$ and PSI.

**Paragraph Number 30** Along with the observed changes in $T_c$ and PSI, the WLFFs demonstrated a significant decrease in RPE post-season compared to pre-season ($p < 0.05$) (Figure 4), decreasing from a mean of $11.2 \pm 2.1$ pre-season, to a mean of $10.2 \pm 1.6$ post-season. In contrast, RPE remained similar both pre- and post- season ($12.2 \pm 2.3$) for the non-WLFF. The WLFFs are likely to perceive less exertion due to the lower $T_c$ and PSI, but as exercise in the heat continues, both RPE and $T_c$ will inevitably increase as previously demonstrated in other studies (33). Therefore, in the field, WLFFs should continuously be mindful of their work rate and perceived exertion and take breaks as needed to reduce the possibility of dangerously high $T_c$, and ultimately, HRI in environments they are not fully acclimatized to.

**Paragraph Number 31** During exercise in hot environments, $T_{sk}$ is an important variable to consider. After a season of work, there was an observed trend in reduced $T_{sk}$ for the WLFFs ($p = 0.08$), which alludes to the concept that a fit and heat acclimatized individual is able to dissipate heat better than those that are only fit (26). Combined, these physiological responses lead to an overall decrease in discomfort (RPE) while exercising in the heat. When compared to an unacclimatized individual, these physiological adaptations could decrease the risk for HRI (3, 18). A potential limitation to the current study is that subjects wore partial clothing (shorts and no shirt) during the heat trials. Therefore, our results could change considerably once protective clothing is worn and uncompensable heat stress is increased (23). During uncompensable heat stress, higher $T_{sk}$, along with higher $T_c$ can act to increase both PSI and RPE due to physiological and
cardiovascular strain (10), thus requiring a further reduction in work rate in hot
environments the WLFF is not acclimatized to.

**Paragraph Number 32** Despite the significant decreases in $T_c$ and PSI observed, WLFF
may not be acquiring as much protection as they perceive in regards to a reduction in
HRI. Since laboratory acclimation studies show decreases in $T_c$ ranging from $0.2{}^\circ C - 0.8{}^\circ C$ (1, 2, 9, 26, 32), the observed decrease in $T_c$ of $0.2{}^\circ C$ over the course of 4 months is a
rather minimal change. Since RPE is significantly reduced from pre- to post- season,
WLFFs may inadvertently develop a false sense of thermoregulatory adaptation. This sets
the stage for potential HRI if WLFFs do not adhere to appropriate work:rest cycles and
take breaks when they are experiencing periods of perceived hyperthermia resulting from
hard work. Since the benefits of natural acclimatization may not be enough to protect
WLFFs from HRI, other ways to mitigate the risk of HRI should be considered. For
example, increasing aerobic fitness pre-season could lower resting HR and $T_c$, which
could provide early- season protection against HRI. Also, as previously stated, “a WLFF
should periodically withdraw from the heat and find cooler refuge if feeling excessively
hot from exposure to high ambient/fire temperatures” (12).

**Paragraph Number 33** In summary, at the end of the wildland fire suppression season,
WLFFs demonstrated significant decreases in $T_c$ and PSI and RPE during controlled heat
stress independent of changes in aerobic fitness (peak VO$_2$). This suggests that
adaptations accrued by natural heat acclimatization are due to long-term occupational
heat exposure. These subtle changes in heat acclimatization across the fire season suggest
that the WLFF should remain consistently aware of the interaction between the
environment and work rate while seeking additional strategies to mitigate the risk for HRI.

Acknowledgements

Paragraph Number 34 We wish to express sincere appreciation to the wildland firefighter volunteers as well as their supervisors who allowed them to participate in this study.

Paragraph Number 35 The results of this study do not constitute endorsement by American College of Sports Medicine (ACSM).
References


FIGURE 1. Changes in $T_c$ during exercise in the heat for WLFF (A) and non-WLFF (B). * $p < 0.05$ vs. pre-season, season-by-time interaction; † $p < 0.05$, shows the difference at specific time points (pre- vs. post-season) and differences from time 0.

FIGURE 2. Changes in HR during exercise in the heat for WLFF (A) and non-WLFF (B). † $p < 0.05$, main effect for time vs. time 0.

FIGURE 3. Changes in PSI during exercise in the heat for WLFF (A) and non-WLFF (B). * $p < 0.05$ vs. pre-season, season-by-time interaction; † $p < 0.05$, shows the difference at specific time points (pre- vs. post-season) and differences from time 0.

FIGURE 4. Changes in RPE during exercise in the heat for WLFF (A) and non-WLFF (B). Δ $p < 0.05$, main effect for season; † $p < 0.05$, main effect for time vs. time 0.

FIGURE 5. Changes in $T_{sk}$ during exercise in the heat for WLFF (A) and non-WLFF (B). † $p < 0.05$, main effect for time vs. time 0.
Table 1 – Mean ± SD. The wildland firefighter (WLFF) and non-wildland firefighter (non-WLFF) physical characteristics pre- and post- firefighting season (May and September, respectively).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>WLFF</th>
<th>Non-WLFF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-Season</td>
<td>Post-Season</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>27 ± 4.6</td>
<td>25 ± 3.8</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>179.2 ± 7.6</td>
<td>180.2 ± 6.8</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>79.9 ± 9.7</td>
<td>77.7 ± 8.6</td>
</tr>
<tr>
<td>Body Fat (%)</td>
<td>15.2 ± 6.1</td>
<td>14.7 ± 6.4</td>
</tr>
<tr>
<td>Peak VO₂ (ml·kg⁻¹·min⁻¹)</td>
<td>53.2 ± 5.2</td>
<td>55.0 ± 7.6</td>
</tr>
</tbody>
</table>
Table 2 – Mean ± SD. The wildland firefighter (WLFF) and non-wildland firefighter (non-WLFF) analysis of blood pre- and post-heat trial as well as sweat rate pre- and post- season (May and September, respectively). * P < 0.05 vs. pre- trial, main effect for trial; (Dagger) P < 0.05 vs. pre- season, main effect for season.

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<thead>
<tr>
<th>Characteristic</th>
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<th>Non-WLFF</th>
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<tbody>
<tr>
<td></td>
<td>Pre- Trial</td>
<td>Post- Trial</td>
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<tr>
<td>Body Weight (kg)</td>
<td>79.3 ± 10.8</td>
<td>78.7 ± 10.8</td>
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<tr>
<td>Hct (%)</td>
<td>47.1 ± 2.1</td>
<td>47.7 ± 1.8*</td>
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<tr>
<td>Hb (g/dl)</td>
<td>16.8 ± 1.5</td>
<td>16.9 ± 1.9</td>
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<tr>
<td>Change in Plasma Volume (%)</td>
<td>-1.1 ± 12.8</td>
<td>-3.3 ± 10.2</td>
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<tr>
<td>Sweat Loss (kg)</td>
<td>1.5 ± 0.3</td>
<td>1.6 ± 0.2</td>
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<tr>
<td>Sweat Rate (g m⁻² min⁻¹)</td>
<td>12.7 ± 1.8</td>
<td>13.0 ± 1.1</td>
</tr>
</tbody>
</table>

* P < 0.05 vs. pre- trial, main effect for trial; (Dagger) P < 0.05 vs. pre- season, main effect for season.
APPENDIX I

Institutional Review Board, Informed Consent, Questionnaires and Data Sheets
At The University of Montana (UM), the Institutional Review Board (IRB) is the institutional review body responsible for oversight of all research activities involving human subjects outlined in the U.S. Department of Health and Human Services Office of Human Research Protection (www.hhs.gov/ohrp) and the National Institutes of Health, Inclusion of Children Policy Implementation (http://grants.nih.gov/grants/funding/children/children.htm).

Instructions: A separate registration form must be submitted for each project. IRB proposals are approved for three years and must be continued annually. Faculty members may email the completed form as a Word document to IRB@umontana.edu. Students must submit a hardcopy of the completed form to the Office of the Vice President for Research & Development, University Hall 116.

1. Administrative Information

<table>
<thead>
<tr>
<th>Project Title: The rate of heat acclimatization in wildland firefighters</th>
<th>Title: Professor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principal Investigator: Brent C. Ruby</td>
<td></td>
</tr>
<tr>
<td>Email address: <a href="mailto:brent.ruby@mso.umt.edu">brent.ruby@mso.umt.edu</a></td>
<td></td>
</tr>
<tr>
<td>Work Phone: 2117</td>
<td>Cell Phone: 406-396-4382</td>
</tr>
<tr>
<td>Department: HHF</td>
<td>Office location: McGill 244</td>
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</tbody>
</table>

2. Human Subjects Protection Training (All researchers, including faculty supervisors for student projects, must have completed a self-study course on protection of human research subjects within the last three years (http://www.umt.edu/research/complianceinfo/IRB/) and be able to supply the “Certificate(s) of Completion” upon request. Add rows to table if needed.

<table>
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<tr>
<th>NAME and DEPT.</th>
<th>PI</th>
<th>CO-PI</th>
<th>Faculty Supervisor</th>
<th>Research Assistant</th>
<th>DATE COMPLETED Human Subjects Protection Course</th>
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<tr>
<td>Brent C. Ruby</td>
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<tr>
<td>John Cuddy</td>
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<td>3/2009</td>
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<tr>
<td>Walter Halees</td>
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<td>X</td>
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<tr>
<td>Tyler Tucker</td>
<td></td>
<td></td>
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3. Project Funding

<table>
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<th>Agency</th>
<th>Grant No.</th>
<th>Start Date</th>
<th>End Date</th>
<th>PI</th>
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</table>

Is grant application currently under review at grant funding agency? ☐ Yes (if yes, cite sponsor on ICF if applicable) ☑ No

Has grant proposal received approval and funding? ☐ Yes (If yes, cite sponsor on ICF if applicable) ☑ No

Is this part of your thesis or dissertation? ☐ Yes ☑ No

If yes, date you successfully presented your proposal to your committee: n/a

IRB Determination:

- Approved Exempt from Review, Exemption # ______ (see memo)
- Approved by Expedited/Administrative Review (see *Note to PI)
- X Full IRB Determination
  - Approved (see *Note to PI)
  - Conditional Approval (see memo) - IRB Chair Signature/Date: ______ Conditions Met (see *Note to PI)
  - Resubmit Proposal (see memo)
- Disapproved (see memo)

For UM-IRB Use Only

* Note to PI: Study is approved for one year. Use any attached IRB-approved forms (signed/dated) as "masters" when preparing copies. If continuing beyond the expiration date, a continuation report must be submitted. Notify the IRB if any significant changes or unanticipated events occur. Notify the IRB in writing when the study is terminated.

Final Approval by IRB Chair: ___________ Date: 4/25/2011 Expires: 4/19/2012

[Signature]

[Handwritten Notes]
SUBJECT INFORMATION AND CONSENT FORM

PROJECT IN BRIEF: The rate of heat acclimatization in wildland firefighters

RESEARCHERS: Dr. Brent Ruby (406) 243-2117
              John Cuddy
              Walter Hailes
              Tyler Tucker

The University of Montana
Montana Center for Work Physiology and Exercise Metabolism
32 Campus Drive
McGill Hall – HHP
Missoula, MT 59812
(406) 243 – 2117 (Dr. Brent Ruby)

Please read the following information carefully and feel free to ask questions. Only sign the final page when you are satisfied procedures and risks have been sufficiently explained to you.

REQUIREMENTS

This study requires that you meet the following criteria:

➢ Participants must be wildland firefighter or recreationally active (exercise on most days of the week for >30 min/day) males or females between the ages of 18 and 40.

PURPOSE OF THE STUDY

The purpose of this study is to determine the effect of seasonal acclimatization in wildland firefighters and how it compares to the acclimatization of recreationally active individuals.

TEST PROCEDURES

4 VISITS (5.5 hours) TO THE LABORATORY WILL BE REQUIRED, AS SUMMARIZED BELOW
PRE TESTING (Visit 1)

1. A pre-screening assessment which involves a health/exercise questionnaire (Par-Q) and family history questionnaire.
   a. Prior to any testing, you will complete a physical activity readiness questionnaire (PAR-Q) to screen for known risk factors of coronary heart disease and a family history questionnaire to screen for history of heat related illness or death.
2. A measure of percent body fat obtained using underwater weighing
   a. This test session will require that you do not eat for a minimum of 3 hours prior to the testing. Prior to the test, body weight will be recorded in your bathing suit. You will then be asked to complete between 3 – 6 underwater weighing procedures. The underwater weight requires that you are submerged in our weighing tank (similar to a hot tub) and that you maximally exhale as much air as possible while underwater. The underwater weight will be recorded within 2-4 seconds and then you will be signaled to surface. This procedure will be repeated until three measurements have been obtained that are within 100 grams of each other. A nose clip will be provided upon request. This test will take approximately 20 minutes.
3. A maximal treadmill ergometer test to measure aerobic fitness
   a. This test will consist of walking and running on a laboratory treadmill to volitional fatigue. The speed and/or grade of the treadmill will increase every three minutes and will progress to fatigue. You will be encouraged to continue to walk/run until volitional fatigue. During this test you will wear a nose clip and headgear that will support a mouthpiece. This will allow us to measure the amount of oxygen that the body uses during this exercise. Heart rate will be measured using an elastic chest strap that is worn on the skin under your shirt around your chest. This test will take approximately 30 minutes. You will be asked to fast for approximately 3 hours prior to this test.

ACCLIMIZATION TESTING (Visits, 2, 3, and 4)

1. You will exercise (walk on a treadmill) for 90 minutes in a hot room (approximately 110°F) at 40-50% of the maximal exercise intensity that you achieved during the maximal exercise test. Relative humidity will be kept constant at 40%. During the 90 minute walk exercise session you will consume 1.5 to 3.5 liters of fluid (depending on body weight).
2. Venous blood samples collected from an arm vein pre and post treadmill walking
   a. A total of 6 blood samples over the course of the study will be collected using a 61enipuncture technique. The site will be cleaned with alcohol prior to the blood draw, and wiped clean afterwards. All of the blood samples will be obtained under the direction of Dr. Brent Ruby, PhD. ~10 ml of blood will be drawn each time.
3. Prior to each trial, you will insert a rectal thermometer so that your core body temperature can be monitored throughout the exercise period.
4. Nude body weight will be taken before and after each exercise session. Nude body weight will be measured in private on a calibrated scale.

5. Urine volume will be measured during each exercise session. You will be asked to void your bladder before each session. After the initial void, urine will be collected in a disposable plastic container and urine volume will be measured for the duration of each trial.

6. The day prior to all acclimation sessions, you are required to do the following:
   a. You will be asked to begin the sessions having completed at least a 10 hour fast. During the 10 hours preceding the sessions you are permitted water, but no other food or beverage.
   b. NO ALCOHOL CONSUMPTION the night before testing. Alcohol is a diuretic and compromises hydration status so its use must not occur during the testing.

RISKS AND DISCOMFORTS

1. Mild discomfort may result during and after the exercise. These discomforts include shortness of breath, tired or sore legs, nausea and possibility of vomiting.

2. Exercising in the heat chamber at 110°F will result in profuse sweating and the perception of feeling very hot. Adverse reactions to heat stress can include heat exhaustion, heat stroke, heat syncope, and death. However, core body temperature will be monitored during every testing session; if body temperature goes above 41°C, the exercise test will be terminated. Fluids will be provided to you as well to mitigate these risks. If you feel too hot to continue exercise, the test will be terminated and you will be removed from the heat chamber.

3. Muscle soreness after the tests may occur as a result of the exercise, but should not persist.

4. Certain changes in body function take place when any person exercises. Some of these changes are normal and others are abnormal. Abnormal changes may occur in blood pressures, heart rate, heart rhythm or extreme shortness of breath. Very rare instances of heart attack have occurred. Every effort will be made to minimize possible problems by the preliminary evaluation and constant surveillance during testing. The laboratory has standard emergency procedures should any potential problems arise.

5. Mild symptoms of dehydration such as headache and general fatigue may result during and after the exercise. To minimize the risk of excessive dehydration, your body temperature will be monitored continuously during exercise. If body temperature goes above 41°C, the exercise test will be terminated.

6. You will be informed of any new findings that may affect your decision to remain in the study.

7. The blood sampling techniques may cause some local and temporary discomfort. Occasionally participants experience a small bruise around the site of the blood draw.

8. There is a minor risk of infection associated with blood sampling. Should you notice unusual redness or swelling at the blood sampling sites you should seek medical attention and then notify Dr. Brent Ruby, PhD, study director.

9. During any of the exercise tests should symptoms, such as chest discomfort, unusual shortness of breath or other abnormal findings develop, the exercise physiologist conducting the research will terminate the test. Guidelines by the American College of Sports Medicine will be followed to determine when a test should be stopped. These
symptoms include moderate to severe angina (chest pain), increased dizziness, shortness of breath, fatigue and your desire to stop.

10. Certain medications could increase your risk for adverse effects during this heat related study. If you are taking any medications, you are advised to check with your physician before participating in the study.

PAYMENT FOR PARTICIPATION

Payment will be according to the following scale:
- Preliminary tests: $25
- Acclimatization sessions: $25 (for a total of $75)

Therefore, upon completion of the entire study, you will be paid a total of $100. If you decide to withdraw at any time, you will be compensated for the test sessions you have completed or initiated.

BENEFITS OF PARTICIPATION

1. The information from these tests will provide you with an accurate assessment of your aerobic fitness and body composition that can be compared with norms for your age and sport but may be of little benefit to your understanding of your personal fitness. There are no other direct benefits to the participants in the study.
2. The scientific benefit includes elucidating the rate of seasonal acclimatization in wildland firefighters compared to recreationally active individuals.

CONFIDENTIALITY

1. Your records will be kept private and not be released without consent except as required by law.
2. Only the researcher and his research assistants will have access to the files.
3. Your identity will be kept confidential.
4. If the results of this study are written in a scientific journal or presented at a scientific meeting, names will not be used.
5. All data, identified only by an anonymous ID #, will be stored in our laboratory.
6. The signed consent form and information sheet will be stored in a locked cabinet separate from the data.

COMPENSATION FOR INJURY

Although we believe that the risk of taking part in this study is minimal, the following liability statement is required in all University of Montana consent forms. In the event that you are injured as a result of this research you should individually seek appropriate medical treatment. If the injury is caused by negligence of the University or any of its employees, you may be entitled to reimbursement 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 injury, further information may be obtained from the University’s Claim representative or University Legal Counsel.

VOLUNTARY PARTICIPATION AND WITHDRAWAL
It is important that you realize that you are free to withdraw from the study at any time. As mentioned above, even if you decide to drop out of the study, you will receive full compensation for all the test sessions you complete or initiate. A copy of this consent form will be provided for you at your request. In addition, the data collected during this study will be done at no cost to you.

QUESTIONS

You may wish to discuss this with others before you agree to take part in this study. If you have any questions about the research now or during the study contact Dr. Brent C. Ruby, PhD at (406) 243-2117 (office) or (406) 396-4382. If you have any questions regarding your rights as a subject, you may contact the chair of the IRB through the University of Montana Research Office at (406) 243-6670.

STATEMENT OF CONSENT

I have read the above statements and understand the risks involved with this study. I authorize Dr. Brent C. Ruby, PhD, and such assistants that he may designate, to administer and conduct the testing as safely as possible with a minimal amount of discomfort. If I have additional questions, I may contact Dr. Brent C. Ruby, PhD, at home (406) 542-2513, cell (406) 546-4691 or at the Human Performance Laboratory (406) 243-2117.

Participant (print)    ________________________________

Signature                  ________________________________

Date                        ________________________________

STATEMENT OF CONSENT TO BE PHOTOGRAPHED DURING DATA COLLECTION

During the study, I understand that pictures may be taken. I provide my consent to having my picture taken during the course of the research study. I provide my consent that my picture may be used in some presentations related to this study. If pictures are used at any time for presentation, names will not be associated with them.

Signature                   ________________________________    Date    __________
Family History Questionnaire

Please answer the following questions. (Malignant hyperthermia is defined as an extreme temperature elevation related to anesthesia or other drug)

Do you have a personal history of any of the following:

- Heat exhaustion
  
  YES  NO
- Heat stroke
  
  YES  NO
- Malignant hyperthermia
  
  YES  NO
  If yes to any, please explain:

Are you currently taking any medications?

  YES  NO

If yes, please list the names:

Do you have a family history of any of the following:

- Heat stroke
  
  YES  NO
- Malignant hyperthermia
  
  YES  NO
  If yes to any, please explain:

Do you have any family history of serious illness or death related to exercise in extreme heat?

  YES  NO

If yes, please explain:
Participant Exclusion Questionnaire (via phone or email)

1. What is your age?

2. Male/Female

3. Are you around this month and in August/September to complete the study?

4. How many hours per week, if any, do you think you do structured training/exercise (ie. Mt. biking > 1 hour)?

5. How many hours per week do you think you do other activities (bike around town, walk, hike, yardwork, etc.)?

6. Does your job require you to work outdoors with high physical exertion (ex. Landscaping, roofing, construction, etc.)? If yes, what do you do for work?
Please complete the chart starting with yesterday, which is day 1 prior to today’s trial, to 10 days prior to today’s trial.

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<thead>
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<th>Date</th>
<th>Where/location (city, state etc.)</th>
<th>Hours of Exercise</th>
<th>Type of Exercise</th>
<th>Hours of Work</th>
<th>Type of Work (yardwork, fire, etc.)</th>
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**May 2011**

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Name: ___________________________ Date of Trial: __________

Please complete the chart starting with yesterday, which is day 1 prior to today’s trial, to 10 days prior to today’s trial.

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<th>Days Prior</th>
<th>Date</th>
<th>Where/location (city,state etc.)</th>
<th>Hours of Exercise</th>
<th>Type of Exercise</th>
<th>Hours of Work</th>
<th>Type of Work (yardwork, fire, etc.)</th>
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**August 2011**

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**September 2011**

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</table>
Subject: 
Date: 

Age: ________________  UWW (kg): __________

Height: ___________ in  cm ______________

Mass: ___________ lbs/ kg ______________

H2O Temp: ________________

Finish Time: __________

Heart rate strap __

VO2 L/min: __________

VO ml/kg/min: __________

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<th>Speed</th>
<th>Incline</th>
<th>HR</th>
<th>RPE</th>
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Subject:  

Date: ____________

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<th>Pre-Weight (lbs)</th>
<th>Speed (mph)</th>
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| Skin Temp Port | Time for Temp start: |
| Core Temp Port |                      |

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<th>Time</th>
<th>HR</th>
<th>Skin Temp (Laser)</th>
<th>Skin Temp (Sensor)</th>
<th>Core Temp</th>
<th>RPE</th>
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<table>
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