THE INFLUENCE OF AEROBIC FITNESS AND BODY FATNESS ON TOLERANCE TO UNCOMPENSABLE HEAT STRESS

by

Glen A. Selkirk

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Graduate Department of Community Health
University of Toronto

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Abstract

The purpose of this study was to determine the separate and combined importance of aerobic fitness and body fatness to uncompensable heat stress. Twenty-four subjects (16 men; 8 women) matched for aerobic fitness and body fatness, performed light exercise to exhaustion at 40°C, 30% relative humidity while wearing nuclear, biological and chemical protective clothing. Thermoregulatory responses were compared between four matched groups; endurance trained (T) or untrained (UT) with high and low levels of body fatness. The change in core temperature from the beginning to end of the heat stress exposure was significantly greater in T compared to UT due to the higher core temperature tolerated at exhaustion. Tolerance time was significantly longer for T_{Low} (116.2 ± 6.5 min) compared to UT_{Low} (69.5 ± 3.6 min) and T_{High} (82.2 ± 3.9 min), indicating an effect of both fitness and fatness, respectively. However, similar effects were not evident between T_{High} and UT_{High} (73.7 ± 4.1 min) or between the UT groups because of the lower average rate of heat storage for UT_{High} compared with the other matched groups. In conclusion, the present data suggest that fitness is a key factor for enhanced tolerance to uncompensable heat stress because it enables continued and sustained performance even at higher T_{re}, through mechanisms which remain to be elucidated.

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List of Abbreviations

A_D	Surface area
A_D:mass	Surface area-to-mass ratio
BM	Body mass
BUN	Blood urea nitrogen
BMI	Body mass index
C	Convection
$C_{p.b}$	Heat capacity of the body
$\dot{C}$	Rate of convective heat transfer
$\dot{C}_{resp}$	Rate of convective respiratory heat transfer
clo	Unit of thermal insulation
$\dot{E}$	Rate of evaporative heat loss
E_{req}	Required evaporative cooling
E_{max}	Maximum evaporative cooling capacity
$\dot{E}_{resp}$	Rate of respiratory evaporative heat loss
EP	Theoretical evaporative potential
Glu	Glucose
HR	Heart Rate
HR_{peak}	Highest observed heart rate during exercise
h_e	Evaporative heat transfer coefficient
HF	High fit group
HFT	Heat flow transducer
HSI	Heat strain index
HST	Heat-stress test
i_m	Woodcock water vapour permeability coefficient
I_T	Thermal resistance of clothing
K	Conduction
$\dot{K}$	Rate of conductive heat transfer
kPa	Kilopascals

LBM	Lean body mass
$\dot{M}$	Rate of metabolic heat production
$\dot{m}_e$	Rate of respiratory water-loss
Na^+	Sodium
NBC	Nuclear, Biological and Chemical
P_A	Ambient water vapour pressure
P_{sk}	Skin vapour pressure
P_{resp}	Respired mouth water vapour pressure
R	Radiation
$\dot{R}$	Rate of radiative heat transfer
RER	Respiratory exchange ratio
R.H.	Relative humidity
RPE	Rating of overall perceived exertion
RTC	Rating of thermal comfort
S	Heat storage
$\dot{S}$	Rate of heat storage
SR	Sweat rate
T	Endurance trained
T_A	Ambient air temperature
T_{sk}	Skin temperature
$\overline{T}_{sk}$	Mean skin temperature
TT	Tolerance time
T_{Low}	Endurance trained; low fat
T_{High}	Endurance trained; high fat
T_{re}	Rectal temperature
$T_{re, Final}$	Final rectal temperature tolerated
$T_{re, Initial}$	Initial rectal temperature
ΔT_{re}	Delta rectal temperature (change)
T_{resp}	Mouth temperature
UT	Untrained

UT_{Low}	Untrained; low fat
UT_{High}	Untrained; high fat
UHS	Uncompensable heat-stress
$\dot{V}_E$	Expired minute ventilation
$\dot{V}O_2$	Rate of oxygen consumption
$\dot{V}O_{2peak}$	Peak rate of oxygen consumption
$\dot{V}O_{2\max}$	Maximum rate of oxygen consumption
$\dot{V}CO_2$	Rate of carbon dioxide production
$\dot{W}$	Rate of external work

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Chapter 1

Introduction

Many occupational settings, ranging from fire fighting to mining, dictate the use of protective clothing and equipment to combat hazardous environments (Montain et al., 1994). However, because the characteristics of the clothing materials restrict avenues for body heat loss, the protective clothing can create a condition where the required evaporative cooling necessary for the body to achieve a thermal steady state exceeds the maximum evaporative potential of the environment. This condition defines uncompensable heat stress (Kraning and Gonzalez, 1991), a condition where the body continues to store heat and core temperature continues to rise to dangerously high levels. The increased physiological and psychological strain associated with the wearing of protective clothing makes it extremely important that factors contributing to heat illness are monitored, and well documented. Heat illness has a high incidence rate, and over the course of a year, as many as 1 out of 100 men may suffer from a heat related illness (Crockford, 1999). During 1979-1991, a total of 5,224 deaths in the United States were attributed to excessive heat (Johnson et al., 1994).

One unique situation where protective clothing is utilized can be found in the military. Canadian soldiers, at times are expected to operate in areas with high environmental temperature and/or relative humidity. Furthermore, these areas have the potential to be contaminated with hostile nuclear, biological or chemical (NBC) agents. As a precaution, soldiers wear a semi-permeable NBC overgarment along with impermeable rubber gloves, boots and a respirator. The clothing ensemble is designed to prevent NBC agents from interacting with the face, skin and/or respiratory tract. Present NBC clothing designs typically feature a low water vapour permeability and high insulation, due to the thickness of the clothing and its multi-layered construction (Cheung and McLellan, 1998c). The multi-layered construction results in a trapping of insulative air pockets impairing heat transfer (Holmer, 1995). Dry heat exchange, and wet heat flux by evaporation are limited due to the trapped air pockets and clothing fibers (Givoni and Goldman, 1972).

During uncompensable heat stress, tolerance time can be influenced by the initial and final core or rectal temperature (T_{re}), the heat capacity of the body ($C_{p,b}$), and the rate of heat storage ($\dot{S}$) as shown in the following equation (Cheung et al., 2000) ;

$$\text{Tolerance Time} = (T_{re,Final} - T_{re,Initial}) \cdot C_{p,b} \cdot \text{mass} \cdot (\dot{S} \cdot 60 \cdot A_D)^{-1} \qquad \text{(Eqn: 1)}$$

where tolerance time is expressed in minutes, $C_{p,b}$ is in $J \cdot kg^{-1} \cdot {}^{\circ}C^{-1}$, $\dot{S}$ is in $W \cdot m^{-2}$ and A_D represents the body surface area in m^2. In order to better understand the ways to affect tolerance time, modifiers of the principal components within this equation need to be examined. For example, factors such as high aerobic fitness (Aoyagi et al., 1994; Cheung et al., 1999), heat acclimation (Aoyagi et al., 1994; Aoyagi et al., 1995) and the follicular phase of the menstrual cycle (Tenaglia et al., 1999) have all been shown to lower the initial core temperature and prolong tolerance time. Conversely, factors which raise the starting T_{re}, such as hypohydration (Cheung and McLellan, 1998b; Cheung and McLellan, 1998a) or the luteal phase of the menstrual cycle (Tenaglia et al., 1999), are associated with shorter tolerance times. It has also been shown that the T_{re} tolerated at exhaustion and tolerance time are influenced by aerobic fitness (Cheung and McLellan, 1998a) and body fatness (McLellan, 1998). Cross-sectional comparisons have revealed that individuals with a high aerobic fitness have longer tolerance times than their less fit counterparts due to a lower starting T_{re} and a higher T_{re} tolerated at exhaustion (Cheung and McLellan, 1998a).

In addition to those factors that influence the initial and final T_{re}, tolerance time is also influenced by factors such as, $\dot{S}$ and $c_{p,b}$, both of which affect the rate of increase in T_{re}. Clearly then, if $\dot{S}$ decreases, the rate of change in T_{re} will be slowed and tolerance time will be extended. In the NBC clothing, the metabolic rate is the primary determinant of $\dot{S}$ and the relationship between tolerance time and metabolic rate has been clearly defined for many different environmental conditions (McLellan et al., 1993b; McLellan et al., 1996; McLellan 1993). The rate of increase in core temperature can also vary despite similar $\dot{S}$, because of differences in the heat capacity of the body tissues. Adipose tissue has a lower heat capacity compared with lean tissue such as blood, muscle, water, and bone (Gephart and DuBois, 1915). Therefore, individuals with a higher percentage of body fat will have a lower whole body heat capacity, and therefore, a faster rate of increase in core temperature for a given rate of heat storage. Females typically have a significantly higher body fat content when compared to males, and it is not surprising that they are at a thermoregulatory disadvantage during uncompensable heat stress (McLellan, 1998). Confounding the conclusion regarding the benefits of aerobic fitness reported by Cheung and McLellan (1998a), described above, was the fact that their high fit subjects also had a significantly lower body fatness of 11.5% compared with the 21% levels for their less fit subjects. It is not entirely clear therefore, whether aerobic fitness or body fatness or both contributed to the differences in tolerance time between the fitness groups compared by Cheung and McLellan (1998a).

Therefore, the purpose of this study was to determine the separate and combined importance of aerobic fitness and body fatness on tolerance time while exercising in NBC protective clothing. This was achieved by matching subjects within four groups defined by high and low levels of both fitness and fatness.

Chapter 2

Review of Literature

2.1 – Temperature Regulation

2.1.1 - Thermal Homeostasis:

Homeothermic organisms maintain core temperature independent of the external environment (Brooks et al., 1996), and rely on thermal equilibrium for internal physiologic processes to function properly (Fortney and Vroman, 1985). Thermal equilibrium within the body is accomplished by balancing heat production and heat loss. Heat production is determined by the metabolic activity within the body. At rest, there is a minimal amount of heat produced through metabolic processes to maintain basic body functions (Havenith, 1999). A resting 70-kg human generates approximately 80W of power (Sternheim and Kane, 1991). However during exercise, metabolic heat production can increase substantially 10-15 fold, in a very short time. If homeostatic mechanisms are not activated, body temperature may rise to life-threatening levels within 10 to 15 minutes (Fortney and Vroman, 1985).

Heat loss from the body occurs through several pathways, and always across either a temperature or water vapour pressure gradient from regions of high temperature or water vapour pressure to regions of low temperature or water vapour pressure. The body loses heat through conduction, convection, radiation and evaporation. Conduction (K), is the transfer of heat between the body to an object while in contact or within the organism down a thermal gradient. Convection (C), is the transfer of heat to or from air or water (Sternheim and Kane, 1991). Air near the body is heated and expands, rising above the surrounding air and is then replaced by cooler surroundings. This process, when repeated creates a circulative flow for heat transfer to the environment from the body. Convection also occurs within the circulation, by a process called circulatory convection. Heat is transferred from the inner core to the blood and then the blood is circulated to the periphery allowing heat exchange to occur at the skin surface (Fortney and Vroman, 1985). Radiation (R) is heat transfer through the emission and absorption of electromagnetic radiation. Evaporation occurs due to the body's ability to sweat. Moisture appearing on the skin surface evaporates, allowing for large amounts of heat to be dissipated (Havenith, 1999). The quantity of heat absorbed by sweat through evaporation is called the latent heat of vaporization. Approximately, 2.4 kJ or 0.58 kcal of heat are lost for each gram of sweat which is evaporated (Nielsen, 1996).

2.1.2 - Heat storage:

Heat storage (S) is determined by the balance of metabolic heat production from internal processes, external work and heat loss through various pathways. The rate of heat storage ($\dot{S}$) can be calculated using a heat balance equation, in $W \cdot m^2$, based on principles of the first law of thermodynamics (Cooper, 1991):

$$\dot{S} = \dot{M} \pm \dot{W} \pm \dot{C} \pm \dot{K} \pm \dot{R} - \dot{E} \qquad \text{(Eqn: 2)},$$

where, $\dot{M}$ is the rate of metabolic heat production, $\dot{W}$ is the rate of external work, $\dot{C}$, $\dot{K}$ and $\dot{R}$ are the rates of convective, conductive and radiative heat transfer, respectively, and $\dot{E}$ is the rate of evaporative heat loss. At rest in a thermoneutral environment, evaporative heat loss accounts for 20-25% of the total body heat loss with conduction and convection contributing 3% and 12%, respectively (Brooks et al., 1996; Fortney and Vroman, 1985). During exercise or in warm environments (>35°C) most or all heat liberated by metabolic processes must be dissipated primarily through evaporation of sweat (Nielsen, 1996).

2.1.3 - Human Heat Loss:

In the heat, humans rely primarily on physiological thermoregulation to maintain a thermal balance. The body is cooled by convection and radiation from the skin surface and the evaporation of sweat from the skin and water from the lungs (respiratory heat loss) (Fortney and Vroman, 1985). If core temperature begins to increase, such as during activity, there will be an initial increase in blood flow to the periphery to increase convective and radiative heat loss at the skin surface (Wenger et al., 1975). If these responses are not enough to maintain thermal equilibrium, evaporative heat loss is activated. Sweat glands, located over much of the body, secrete sweat, creating a large surface area for evaporation to occur. The body's temperature is controlled in the hypothalamus, which is set to maintain thermal balance at 37°C ± 1°C (Holmer, 1995). When core temperature exceeds 41.5°C the hypothalamus shuts down, leaving only external means of cooling (Crockford, 1999). The preoptic area of the anterior hypothalamus is primarily responsible for handling increases in body temperature. Heat sensitive neurons receive afferent nerve impulse signals from both skin and deep body core temperature receptors (Boulant, 1999).

At the onset of exercise, an increased sympathetic vasoconstrictor tone shunts blood away from the non-exercising muscles, the splanenic, and renal vascular beds towards the exercising muscles. The initial cutaneous vasoconstriction is accompanied by a fall in skin temperature at the start of exercise (Torii et al., 1992). A reduced skin temperature increases the thermal gradient between the skin and core, thus increasing both conductive and circulatory convective heat loss, prior to the activation of the sudomotor response. The cutaneous vasodilatory threshold for skin blood flow is proportional to a combination of both core and skin temperature, with core temperature being more influential (Wyss et al., 1974). Once the cutaneous vasodilatory threshold is reached, there is a linear increase in skin blood flow and sweat production (Roberts et al., 1977). Perfusion of skin capillaries and active skeletal muscle compromise central blood volume and subsequently reduce venous return. To compensate for the decrease in stroke volume, there is an increase in heart rate for a given exercise intensity (Fortney and Vroman, 1985). This phenomenon is commonly called cardiovascular strain. A further reduction in cardiac filling may result in a fall in central venous pressure due to continued exercise, and blood volume loss due to excessive sweating can stimulate the baroreceptor vasoconstrictor reflex (Fortney and Vroman, 1985). Competition from the baroreceptor output modifies thermal drive for skin blood flow, and sweat gland activity. In this situation cardiovascular control takes precedence over temperature regulation. During heavy exercise in the heat, an attenuation of skin blood flow is seen after reaching values around 20mL·min^{-1} (Nadel et al., 1979). Active vasodilation is amended by nonthermoregulatory influences, such as the baroreflexes (Kenney et al., 1992), and heat transfer from the core to the periphery is reduced, increasing heat storage (Nadel et al., 1979) because skin blood flow has been compromised (Fortney and Vroman, 1985).

2.1.4 - Compensable versus Uncompensable Heat Stress:

The required evaporative cooling (E_{req}) necessary to achieve a thermal steady state is defined as (Givoni and Goldman, 1972),

$$\dot{E}_{req} = \dot{M} \pm \dot{W} \pm (\dot{R} + \dot{C} + \dot{K}) \pm \dot{C}_{resp} - \dot{E}_{resp} \qquad \text{(Eqn: 3)},$$

where $\dot{C}_{resp}$ is the convective respiratory heat transfer and $\dot{E}_{resp}$ is the respiratory evaporative heat loss. The maximum evaporative cooling capacity of the environment (E_{max}) is defined as (Berglund, 1988),

$$E_{max} = h_e (P_{sk} - P_A) \qquad \text{(Eqn: 4)},$$

where, h_e is the evaporative heat transfer coefficient, P_{sk} is skin vapour pressure with the assumption of 100% saturation at mean skin temperature and P_A is the ambient water vapour pressure of the surrounding environment. The heat strain index (HSI) is defined as the ratio between E_{req} and E_{max} (HSI = $E_{req} \cdot E_{max}^{-1}$). If E_{req} is less than or equal to E_{max} (HSI ≤ 1), a thermal steady state can be achieved. These conditions define compensable heat stress. In contrast, when E_{req} exceeds E_{max} (HSI >1), the body continues to store heat, defining the state of uncompensable heat stress (UHS) (Givoni and Goldman, 1972). Compensable heat stress can become UHS when the restriction of evaporative heat loss over the skin surface is reduced by biophysical characteristics such as: 1) an increase in the ambient water vapour pressure, 2) a reduction in air movement (effective air velocity) and 3) by the wearing of clothing that restricts the evaporation of sweat from the skin surface (Kraning and Gonzalez, 1991).

2.1.5 - Heat Tolerance:

Heat tolerance is defined in a number of ways in the literature. Some authors choose to use the final core temperature ($T_{re,\ final}$) tolerated at exhaustion as the physiological determinant to define heat tolerance (Gonzalez-Alonso et al., 1999). Others define heat tolerance as an increase in body heat storage (Webb, 1995). Tolerance time can be influenced by the initial and final core temperature (T_{re}), the heat capacity of the body ($C_{p,b}$), and $\dot{S}$ (see Eqn: 1). End-point criteria are determined through ethical considerations and experimental design. $T_{re,\ final}$ at exhaustion can range between 39°C and 40°C depending on experimental conditions and/or ethical constraints (Bomalaski et al., 1995; Constable et al., 1994; Latzka et al., 1998; Shapiro et al., 1982). Due to the differences in end-point criteria, it is important that the dependent measure of tolerance time be viewed with caution among studies.

2.1.6 - Impact of Clothing on Heat Transfer:

Clothing fabric and air trapped between clothing layers act as an impediment to convective and evaporative heat transfer between the skin and the environment (Havenith, 1999). Heat and water vapour transfer can be quantified using the following equations:

$$\text{Dry Heat Loss} = \frac{(\overline{T}_{sk} - T_A)}{I_T} \qquad \text{(Eqn: 5)},$$

where, $\overline{T}_{sk}$ is the mean skin temperature; T_A is the ambient air temperature and I_T is the total insulation or thermal resistance of the clothing, including air layers (Havenith 1999), and,

$$\text{Evaporative Heat Loss} = \frac{16.5 \cdot i_m \cdot (P_{sk} - P_A)}{I_T} \qquad \text{(Eqn: 6)},$$

where, 16.5 is the Lewis relation which converts a temperature gradient to a pressure difference, and i_m is the Woodcock water vapour permeability coefficient (Gonzalez et al., 1993). Heat is transferred through the various air and clothing layers mainly by conduction and convection before being lost to the environment. Air is an excellent insulator, which is why clothing fit is an important factor. Havenith et al. (1990b) found that tight clothing had 6-31% lower insulation than tight and loose fitting ensembles. Looser clothing would have greater air pockets leading to greater insulation. However, Havenith et al. (1990a) found no effect of the fit of clothing when 2 permeable and 1 impermeable ensembles were compared. Walking speed and/or movement also have a linear effect on the intrinsic clothing insulation (Havenith et al., 1990b). Movement of clothing layers during walking affects the air layers within the clothing to produce a bellowing effect. The additional air movement in loose fitting clothing will have a greater increase in effective air velocity than in tight clothing (Havenith et al., 1990b; Givoni and Goldman, 1972), producing a greater decrease in insulative values with motion.

The unit of thermal insulation is the clo, and can be defined as the measure of insulation provided to the person as a whole (Burton and Edholm, 1955). One clo is equivalent to 0.155 $m^2 \cdot °C \cdot W^{-1}$ of thermal resistance and can be considered equivalent to the insulation provided by wearing a business suit (Havenith, 1999). The water vapour permeability index of a clothing system, i_m, is measured with a 'wetted' thermal mannikin (Givoni and Goldman, 1972). The ratio of the water vapour permeability and thermal resistance ($i_m \cdot I_T^{-1}$) can be used to approximate the resistance to evaporative heat loss of the clothing ensemble (Martin and Goldman, 1972).

2.1.7 - NBC Protective Clothing Ensemble:

NBC Protective Clothing is designed to prevent NBC agents from interacting with the face, skin and/or respiratory tract. The clothing ensemble consists of a semi-permeable overgarment, impermeable rubber gloves, boots, respirator and canister. T-shirt, combat clothing (shirt/trousers), underwear, socks and combat boots are worn beneath the protective clothing ensemble. The Canadian Forces NBC protective ensemble has a thermal resistance of 0.291 $m^2 \cdot {}^\circ C \cdot W^{-1}$ (1.88 clo) determined using a heated copper manikin, and a water vapour permeability coefficient of 0.33 determined with a completely wetted manikin (Gonzalez et al., 1993). These values signify high thermal insulation and low water vapour permeability.

Beneath the semi-permeable outer layer a microclimate is created which affects the heat exchange at the skin surface (Holmer, 1995). Air temperature and vapour pressure within a clothing ensemble are related to the thermal properties of the clothing. When the clothing has limited permeability, accumulation of heat and water vapour occurs (Sullivan and Mekjavic, 1992). Water vapour pressure continues to increase until the environment becomes saturated (100% R.H.). Once saturated, evaporation can no longer occur unless temperature is increased and/or water vapour is transferred to the clothing fabric. With enough time, the clothing may become saturated, allowing for evaporation from the outer surface of the clothing (McLellan et al., 1996; Chang and Gonzalez, 1999). For this to occur, sweat must first saturate the underlying layers of clothing. Evaporation at a site removed from the skin surface leads to an inefficient mechanism of evaporative heat loss from the body since the energy for the water vapourization comes from the environment and surrounding clothing layers rather than from the body itself. Under some conditions evaporated sweat from the skin may condense in the clothing layers before escaping to the environment, giving off heat to surrounding layers (Holmer, 1995).

2.1.8 - Impact of NBC Protective Clothing on Heat Tolerance:

Wearing an NBC protective ensemble creates an increase in physiological and psychological strain on the soldier (McLellan, 1993; McLellan et al., 1993ab; Aoyagi et al., 1998). The added weight of the ensemble increases the energy cost for a given level of physical performance (Duggan, 1988). Even at low intensity, exercise in the heat wearing a chemical ensemble requires shorter work times and more frequent rest periods due to increases in heart rate, skin and core temperature (White, 1991). It has been reported that the increased weight (~8kg) of the NBC protective clothing corresponded to a 13% increase in metabolism when compared to similar exercise levels during combat clothing trials (Aoyagi et al., 1994). It is also well documented that there is a significant reduction in evaporative efficiency while wearing the full NBC protective clothing ensemble compared with wearing combat clothing (McLellan et al., 1993; McLellan et al., 1993b), thus increasing $\dot{S}$ for any given $\dot{M}$. Furthermore, there is an increased respiratory dead space associated with wearing the respirator and canister, increasing discomfort and ventilatory strain (Aoyagi et al., 1994).

Due to these limitations, decreased work time and rapid onset of heat exhaustion has been observed (McLellan, 1993). Montain et al. (1994) found that the wearing of full protective clothing lowered the core temperature (~0.4°C) at exhaustion and exercise time compared to partial encapsulation. These findings suggest that the protective clothing decreased the amount of stress an individual can tolerate. A lower $T_{re,\ final}$ limits the potential heat storage within the body, affecting tolerance time (see eqn. 1). Exercising at a low intensity in a hot and humid environment (40°C, 4.8 kPa) with protective clothing also lowered the final T_{re} and total heat storage at exhaustion (McLellan et al., 1996). Gonzalez-Alonso et al. (1999) found that fatigue during prolonged exercise in an uncompensable hot environment without encapsulation occurred at the same critical level of hyperthermia despite alterations in starting T_{re} and the rate of increase in core temperature.

The relationship between tolerance time and metabolic rate while wearing the full NBC ensemble has been accurately described by a unique hyperbolic function for a variety of environmental conditions (McLellan, 1993; McLellan et al., 1996). These curvilinear relationships converge at metabolic rates above 400 W, implying that variations in ambient temperature and vapour pressure have little influence on tolerance time with high rates of heat production. This is because the effect of a given change in P_A on E_{max} will represent a greater percentage of E_{req} when the value of E_{max} is lower due to a lower $\dot{M}$ (see eqn 4). For example, a change in P_A from 4.8 kPa (40°C, 65% R.H.) to 1.1 kPa (40°C, 15% R.H.) will increase E_{max} from approximately 30 to 100 $W \cdot m^2$, assuming a saturated P_{sk} of 6.3 kPa at 37°C (see eqn 6). This change in E_{max} of 70 $W \cdot m^2$ represents approximately 25% of $\dot{M}$ during heavy exercise of 350 $W \cdot m^2$, but it represents a much higher percentage of 50% when $\dot{M}$ is lower with lighter exercise around 150 $W \cdot m^2$. Thus, McLellan et al. (1996) showed that the change in P_A from 1.1 to 4.8 kPa had a greater impact on the relative change in tolerance time during light compared to heavy exercise.

Intermittent work and rest schedules have been implemented to lower the overall metabolic rate in order to delay the onset of exhaustion due to rising T_{re}. Kraning and Gonzalez (1991) compared an intermittent work schedule with a continuous time-weighted metabolic average for the intermittent work. The study concluded that the intermittent work schedule produced a greater physiological strain, with a 14-minute reduction in endurance time, a 0.4°C increase in T_{re} and a 33 % greater rate of change in core temperature after 30 minutes. These findings suggest that the interruptions in exercise, caused by postural and work load transitions, potentially affected the cutaneous circulation and heat transport (Kraning and Gonzalez, 1991). It is important to realize, however, that strategically placed rest periods can reduce the strain produced during heavy intensity exercise by reducing the average metabolic rate of the exercise. For example, McLellan et al. (1993b) found reductions in the rate of change in T_{re} during an intermittent protocol. The overall metabolic rate of exercise was reduced during the intermittent schedule due to rest pauses, thus enabling the heavy intensity intermittent work to produce a $1°C \cdot h^{-1}$ lower rate of change in T_{re} compared to continuous heavy intensity exercise.

2.2 - Physiological Manipulations

2.2.1 – Hydration:

During prolonged exercise in the heat, even minor changes in hydration level (-1 to –2% body mass) can lead to an increase in cardiovascular and thermoregulatory strain (Montain and Coyle, 1992b). Dehydration is defined as the acute loss of body water that occurs, for example, during activity due to excessive sweating. Hypohydration on the other hand, refers to a lower than normal state of body water that resulted from prior dehydration. The level of cardiovascular strain produced is directly related to the magnitude of dehydration that occurs with exercise (Montain and Coyle, 1992b). Not only does dehydration reduce cardiac output, but it increases systemic and cutaneous vascular resistance during exercise (Fortney and Vroman, 1985). The increase in vascular resistance reduces skin blood flow and lowers heat exchange at the skin surface. Gonzalez-Alonso et al. (1995) found increases in HR and reductions in stroke volume and mean arterial pressure in endurance trained athletes during the second hour of exercise with approximately 4.9 % dehydration. Rehydration during exercise can help to reduce the effects of fluid loss and the resultant cardiovascular drift by maintaining blood volume and skin blood flow, thus helping to maintain heat transfer. Montain and Coyle (1992a) found that fluid ingestion during exercise lowered core temperatures by 0.5-0.8°C, increased forearm blood flow, and lowered serum osmolality.

Hydration status prior to exercise is also an important determinant of tolerance to exercise and heat stress. Hypohydration of 5% body mass (BM) produced shorter tolerance times, lower core temperatures and higher heart rates at exhaustion compared to the euhydrated condition (Sawka et al., 1992). When comparing hydration status and fluid replacement during exercise, Armstrong et al. (1997) found that the combination of hypohydration (3.6%BM) with no fluid replacement produced the greatest increase in physiological strain compared to hypohydration with fluid replacement and euhydration with or without fluid replacement. Significant increases in heart rate, plasma osmolality, sweat sensitivity and core temperature were observed during the hypohydration with no fluid replacement condition (Armstrong et al., 1997).

Hydration status is also an important determinant of tolerance while wearing NBC protective clothing. During heavy exercise approaching 500 W, hypohydration of 2.2% BM produced a greater cardiovascular strain, as illustrated by increased heart rates, as well as decreased tolerance time compared to the euhydrated condition (Cheung and McLellan, 1998b). At this high metabolic rate, however, fluid replacement during exercise offered no benefit. In contrast, during lower metabolic rates at 300 W, both fluid restriction during exercise and beginning the exercise in a hypohydrated state of 2.2% BM significantly reduced exercise tolerance while wearing the NBC clothing (Cheung and McLellan, 1998). Hypohydration of ~2.5% body weight has also been found to produce an increase in resting core temperature, a decreased tolerance time and an increase in heart rates during light exercise of about 300 W irrespective of fitness level or heat acclimation status (Cheung and McLellan, 1998). Since the core temperature tolerated at exhaustion was not affected by hydration status, the reduced tolerance times were largely attributed to the increase in resting T_{re} (Cheung and Mclellan, 1998ac). These findings are illustrative of the role that initial temperature plays in tolerance time, and it's effect on the range in T_{re} that can be tolerated from the beginning to the end of the heat-stress exposure.

Both water and glycerol hyperhydration have also been examined in an uncompensable heat stress environment (Latzka et al., 1998). Glycerol hyperhydration was found to provide no meaningful advantage over water hyperhydration equivalent to 29 $mL \cdot kgLBM^{-1}$. However, the authors evaluated the effects of hyperhydration at a very heavy metabolic rate which approximated 800 W. It is possible that this high rate of heat production precluded the opportunity to observe any beneficial effects of hyperhydration since tolerance time averaged 30-35 minutes across treatments. It remains to be seen if hyperhydration would offer any benefit during lighter exercise and/or if accompanied by a rehydration schedule.

2.2.2 - Thermoregulatory Adaptation With Endurance Training:

With the proper stimuli, the thermoregulatory effector responses to heat stress can be significantly modified. High levels of aerobic fitness lead to beneficial changes in thermoregulation. Increasing aerobic fitness with regular endurance training results in an increase in sweat production at a given T_{re} mediated through adaptations in the sweat glands (Sato and Sato, 1983). In addition, there is a lowering of the T_{re} threshold for the onset of sweating, and an increase in the sensitivity of the sweating response (Nielsen et al., 1997; Fox et al., 1963; Nielsen et al., 1998; Buono et al., 1998; Aoyagi et al., 1994; Armstrong and Pandolf, 1998; Regan et al., 1996; Shvartz et al., 1977; Roberts et al., 1977; Nadel et al., 1974; Wyndham, 1967). Similarly, there is an increase in skin perfusion, seen as a decrease in the T_{re} threshold for vasodilation (Buono et al., 1998; Roberts et al., 1977; Armstrong and Maresh, 1991). Increases in plasma volume are also observed which decreases cardiovascular strain by maintaining central blood volume and cardiac output while maintaining adequate skin blood flow and increased sweat production (Nielsen et al., 1998; Senay et al., 1979; Allan and Wilson, 1971; Nielsen et al., 1997; Fellman, 1992; Aoyagi et al., 1994). The increase in skin perfusion and sweat rate lead to an increase in heat loss by evaporation, radiation and convection, thus allowing for reductions in both skin and core temperatures at any given rate of heat production (Allan and Wilson, 1971).

2.2.3 - Aerobic fitness:

It is well documented that an increase in aerobic fitness results in a decrease in cardiovascular and thermoregulatory strain during compensable heat stress (Cadarette et al., 1984). This reduction in strain is due to the increase in evaporative heat loss that accompanies the increased sweat rate (Nadel et al., 1974; Henane et al., 1977) and skin blood flow (Nadel et al., 1979; Roberts et al., 1977) at a given T_{re} and the decrease in resting T_{re} associated with aerobic fitness (Armstrong and Pandolf, 1988). However, the benefits of these adaptations during UHS have been questioned (Aoyagi et al., 1994; Cheung and McLellan, 1998c). For example, Aoyagi et al. (1994) reported that an 8-week endurance training program which increased aerobic fitness ($\dot{V}O_{2max}$) by 16%, failed to increase work tolerance to heavy exercise (4.8 $km \cdot h^{-1}$ at 2% grade, 40°C and 30% R.H.) lasting less than 1 hour. Windle and Davies (1996) observed similar mean aural and skin temperature responses for high ($\dot{V}O_{2max} = 74.7 mL \cdot kgLBM^{-1} \cdot min^{-1}$) and moderately fit ($\dot{V}O_{2max} = 59.7 mL \cdot kgLBM^{-1} \cdot min^{-1}$) subjects during a stepping protocol wearing NBC clothing at 40°C and 50% R.H. There were also no significant differences between fitness groups in tolerance times that approximated 50 minutes. However, the metabolic rates used in these studies (~500 W) may have been too high, and tolerance times too short, therefore, to allow the benefits of an increased sweat rate with training to be observed (Cheung and McLellan, 1998b). Daily aerobic training for two weeks, which increased $\dot{V}O_{2max}$ by 6.5%, also failed to improve tolerance during light exercise lasting approximately 80-90 minutes (Cheung and McLellan, 1998c). In contrast, cross-sectional comparisons have revealed that high fit ($60 mL \cdot kg^{-1} \cdot min^{-1}$) subjects have extended tolerance times, lower starting T_{re} and higher T_{re} at exhaustion when compared to subjects with lower fitness levels ($46 mL \cdot kg^{-1} \cdot min^{-1}$) during UHS (Cheung and McLellan, 1998b). Others have also reported that high fit individuals tolerate higher T_{re} at exhaustion (Gonzalez-Alonso et al., 1999; Latzka et al., 1998). These latter data imply that a high level of aerobic fitness, acquired through a long-term commitment to regular aerobic activity, is an important determinant of tolerance during UHS.

2.2.4 – Heat Acclimation:

Heat acclimation is a commonly adopted tactic to reduce thermoregulatory and cardiovascular strain when subjects must work in the heat. Increased sweating, expanded plasma volume, lower metabolic rates and resting body temperature combine to produce a greater potential for heat loss and lower rates of heat storage (Aoyagi et al., 1994). In a compensable heat stress environment, the classical adaptations that occur with heat acclimation vastly improve temperature regulation (Aoyagi et al., 1997; Armstrong and Maresh, 1991; Armstrong and Maresh, 1998; Buono et al., 1998; Cotter et al., 1997; Nadel et al., 1974; Nielsen, 1998; Nielsen et al., 1997; Pandolf, 1998; Regan et al., 1996; Roberts et al., 1977; Sawka et al., 1996; Shvartz et al., 1977; Wyndham, 1967). However, because of the limited vapour permeability and increased insulation of the NBC protective clothing, physiological strain could increase with elevated sweat rates that follow heat acclimation by promoting a faster rate of dehydration rather than increasing evaporative heat loss (Cheung and McLellan, 1998a).

The effects of heat acclimation on tolerance time during UHS are influenced by the rate of heat production chosen to evaluate the heat acclimation program. For example, a six day dry-heat acclimation procedure (45-55% $\dot{V}O_{2max}$ for 60 min·day^{-1} at 40°C, 30% R.H.) produced an increase in sweat rate (0.14-0.23 kg·h^{-1}), an 8% increase in plasma volume, a 4-5% decrease in the metabolic cost of work, and a 0.2-0.4°C reduction in T_{re} in untrained subjects (44 mL·kg^{-1}·min^{-1}) (Aoyagi et al., 1994). However, despite these alterations, no significant increase in tolerance time or sweat evaporation were observed at a metabolic rate of 500 W while wearing NBC protective clothing. With no change in body cooling, the increased sweat rates potentially increased subject discomfort by increasing skin wettedness masking any benefits from heat acclimation. Using a similar acclimation protocol, Aoyagi et al. (1995) examined the influence of 6 versus 12 days of acclimation at a lower metabolic rate of 300 W. With similar physiological responses to heat acclimation following either the 6- or 12-day program, subjects had a significant increase in tolerance time of approximately 15 min or 15%. The increase in tolerance time was accompanied by reductions of 0.1°C in resting T_{re}, 0.2°C in skin temperature (T_{sk}) and a lower T_{re} response throughout the heat stress exposure (Aoyagi et al., 1995). As well, heart rate was approximately 8 b·min^{-1} lower in the NBC condition, signifying a reduction in cardiovascular strain. Thus, a reduction in metabolic rate from 500 W to 300 W allowed more time for the mass flow of water vapour through the outer protective garment. Psychological strain, as indicated by ratings of thermal comfort and perceived exertion, was also reduced when there was greater time for sweat evaporation (Aoyagi et al., 1998).

McLellan and Aoyagi (1996) compared the effects of hot-wet and hot-dry heat acclimation protocols using an intermittent protocol to extend tolerance time from 50 to 100 minutes while exercising in the heat and wearing the NBC protective clothing. Following a hot-wet heat acclimation protocol, which involved wearing the protective ensemble each day, a greater relative increase in tolerance time, and a slower rate of T_{re} increase were observed when compared with the responses observed following a heat acclimation protocol which involved daily exercise in the heat wearing only shorts, T-shirt and running shoes. As well, the elevated whole body sweat rates that accompanied the hot-wet heat acclimation program were associated with a significant increase in evaporative heat loss from the clothing ensemble. Thus, there appears to be some greater benefit with heat acclimation that involves exposure to the microenvironment of the clothing ensemble (McLellan and Aoyagi, 1996). However, Cheung and McLellan (1998a), using a 10 day hot-wet heat acclimation protocol, found no increase in the rate of sweat evaporation despite a significant increase in the rate of sweat production. Interestingly, when fluid replacement was provided during the exercise and heat stress while wearing the protective clothing, there was no added benefit of heat acclimation (Cheung and McLellan, 1998a). It was suggested, therefore, that fluid replacement could be a suitable alternative to heat acclimation while wearing NBC protective clothing

(Cheung and McLellan, 1998a). Alternatively, there was a suggested possibility that the increase in sweat rate due to heat acclimation could increase dehydration without significant increases in evaporative heat loss (Cheung and McLellan, 1998a).

Theoretically, heat acclimation can provide numerous benefits for men exercising in NBC protective clothing. Heat acclimation provides a greater potential for heat storage by reducing resting core temperatures (Aoyagi et al., 1994; Aoyagi et al., 1995). Furthermore, heat production is reduced through a reduction in the metabolic cost of exercise (Aoyagi et al., 1994; Aoyagi et al., 1995). Thermoregulatory stress is reduced through an enhanced sweating response, provided that the exercise is light enough to allow for adequate saturation of the clothing layers. And finally, heat acclimation can also provide a reduction in cardiovascular stress through increases in plasma volume. However, it appears that only minimal increases in tolerance time (~15 min) are observed, attributed mainly to the changes in starting core temperature as opposed to any changes in evaporative heat loss due to the limitations on evaporative heat transfer (Aoyagi et al., 1995).

The theoretical evaporative potential ($EP = i_m \cdot I_T^{-1}$), developed by Martin and Goldman (1972), has been suggested as a useful quantitative index to determine, *a priori*, whether heat acclimation would be helpful when wearing protective clothing (Chang and Gonzalez, 1999). These authors suggested that when EP is 0.15, heat acclimation affords no benefit. These conclusions are consistent for the Canadian NBC protective clothing based on the findings of Aoyagi et al. (1994). However, fluid replacement, the metabolic rate chosen to evaluate the heat acclimation protocol and the climatic conditions selected for the heat acclimation are also important factors that must be considered (Aoyagi et al., 1995; McLellan and Aoyagi, 1996; Cheung and McLellan, 1998a).

2.2.5 – Interactions:

The thermoregulatory adjustments that occur following physical training or heat acclimation are quite similar. Aerobic training is associated with partial increases in sweat sensitivity and a decrease in the T_{re} threshold for sweating (Roberts et al., 1977; Nadel et al., 1974}, and skin perfusion (Roberts et al., 1977). As well, training has been shown to elicit increases in plasma volume (Convertino, 1991; Fellmann, 1992; Green et al., 1987) and reduce both resting and exercising core temperatures and heart rates (Avellini et al., 1982; Shvartz et al., 1974). In fact, some authors have suggested physical training provides benefits equivalent to a partial heat acclimation during work in the heat (Gisolfi and Robinson, 1969). There are specific criteria cited that need to be met in the training regimen to induce changes in thermoregulation. Training needs to be at an intensity greater than 50% $\dot{V}0_{2max}$ for 8-12 weeks (Armstrong et al., 1998) to produce an increase in $\dot{V}0_{2max}$ of approximately 15-20% (Henane et al., 1977). Most importantly, a rise in core temperature during exercise, which stimulates the heat-dissipating responses, is necessary for physical training to significantly improve tolerance to a hot-dry environment (Avellini et al., 1982; Henane et al., 1977). Findings suggest that both skin and body core heating are necessary to elicit an increase in local sweat rates and plasma volume changes (Regan et al., 1996).

Endurance trained subjects require less time to demonstrate full heat acclimation, possibly due to the increases in core temperature that are experienced during the training process (Pandolf, 1998). Pandolf et al. (1977) suggested that the number of days of heat acclimation needed for T_{re} to reach a plateau during a given bout of heat exposure was a function of the individual's initial $\dot{V}0_{2max}$. The implication of this relationship is that physically fit individuals acclimate to heat more rapidly than persons with a low $\dot{V}0_{2max}$. In fact, it has been documented that subjects with a very low $\dot{V}0_{2max}$, as is seen in congestive heart failure, cannot be heat acclimated (Wenger, 1988). A greater retention following acclimation is also seen in physically fit individuals (Armstrong and Maresh, 1991). The greater retention could be due to daily maintenance of fitness through training, causing repeated increases in core temperature. Finally, a high fit subject who loses their heat acclimation status will regain heat acclimation faster than a low fit subject (Pandolf, 1998).

A number of studies have looked at the relationship between aerobic training and heat acclimation and their effects during UHS. Following 8-weeks of endurance training, 6 days of heat acclimation had no additional effects on the increased sweat response obtained from the training program while wearing NBC protective clothing (Aoyagi et al., 1994). These findings are illustrative of the partial heat acclimation effects which could be attributed to the 8-week training regimen. However, since even following the 8 weeks of training, these subjects had only a moderate aerobic fitness, complete heat acclimation may have required greater than 6 days (Pandolf et al., 1977). When comparing the effects of 10 days of heat acclimation for both high and moderately fit subjects, sweat rates were increased for both groups at the end of the heat acclimation procedure (Cheung and Mclellan, 1998a). However, not only did the high fit subjects have higher sweat rates at the onset of the acclimation procedure, they attained greater increases in their sweat response during the 10-day protocol. Yet, while wearing the NBC protective clothing, no differences in evaporative heat loss were noted between fitness groups. Thus, the greater sweat rates for the more fit subjects led to faster rates of dehydration and no significant advantage towards heat storage or tolerance time. Circulatory gains from the endurance training or heat acclimation induced expansion of plasma volume were partially offset by the increase in sweat rate (Aoyagi et al., 1997; Aoyagi et al., 1994). Similarly, heart rates were unaffected at the onset of exercise, suggestive that plasma volume alterations are distributed towards an increase in skin blood flow as opposed to increasing central blood volumes (Aoyagi et al., 1994).

Hydration is a known modifying factor of heat acclimation (Aoyagi et al., 1997). When hydration status was examined together with aerobic fitness and heat acclimation, the role of hydration had a greater impact on heat tolerance above either heat acclimation or aerobic fitness (Cheung and McLellan, 1998a). Hypohydration of approximately 2.5%

BM increased the physiological strain while exercising in NBC protective clothing independent of either aerobic fitness or heat acclimation status, thus making hydration a primary concern when evaluating the interaction of aerobic fitness and heat acclimation on tolerance time in NBC protective clothing.

2.3 - Individual Characteristics

2.3.1 - Body Composition:

Individual characteristics are important determinants of heat storage and heat tolerance. Obesity is often associated with poor heat tolerance. Obese soldiers, with a body mass index (BMI) greater than 27, have been found to have a 3.5 times greater risk of suffering from a heat disorder compared to normal weight soldiers (BMI<27) (Chung and Pin, 1996). Similarly, obese subjects have been found to exhibit higher T_{re}, T_{sk}, heart rate (HR) and lower sweat rates for a given effective temperature, which is suggestive of a higher strain during exercise (Bar-Or et al., 1969). Obesity can be confounded by the fact that overweight individuals are usually more sedentary and presumably unfit and have a lower exercise tolerance (Chung and Pin, 1996). However, when taking into account aerobic power, the effect of adiposity remained significant with fatter subjects having a higher increase in body heat storage (Havenith et al., 1995). In studies examining the influence of anthropometric characteristics, the combination of A_D:mass and percentage of body fat, have been found to explain approximately 27% of the residual variance during reaction to heat stress (Havenith and van Middendorp, 1990).

Given the poor conduction characteristics of adipose tissue, subcutaneous fat deposits are a potential insulating layer. Whether an insulating effect will be present is strongly dependent on blood perfusion of the fat layer (Havenith et al., 1998). Havenith et al. (1998) found that body fatness significantly elevated T_{re} during exercise. However, the insulative effect of increased body fatness was only present when skin blood flow was minimal in a cool environment (21°C, 50% R.H.). During trials in the heat, forearm blood flow increased significantly, creating a shortcut for heat transfer, bypassing the insulative layer and allowing for adequate heat exchange. It appears that the insulative property of an increase in subcutaneous fat is diminished when there is an adequate increase in skin blood flow during exercise in the heat (Havenith et al., 1998). However, the forearm blood flow to core temperature relationship has been found to be significantly less in obese subjects during exercise (Vroman et al., 1983; Havenith, 1995), suggestive that the lean individual would posses a greater heat loss capacity. The reduction in skin blood flow was reportedly due to an increased sympathetic vasoconstriction, with no differences in the T_{re} threshold for skin perfusion.

A second effect of body fatness is the role that it plays as a passive mass. The higher the passive mass, the higher the metabolic rate needed to carry the added weight (Havenith et al., 1998). Obese individuals have been found to have a greater absolute oxygen consumption (Alexander, 1965) and increased left ventricular work during exercise in the heat (Vroman et al., 1983). A similar effect is seen from the increased bulk of the protective clothing that adds to the metabolic cost of work for a given exercise intensity (Aoyagi et al., 1994). A lower mechanical efficiency, caused by the extra body weight that high fat individuals have to carry, was a suggested contributor to the observed increased metabolic rate (Epstein et al., 1983).

Deposits of subcutaneous fat cause changes in body contour such that the ratio of body surface area to body mass (A_D:mass) is decreased (Bar-Or et al., 1969; Epstein et al., 1983). Hence, heat exchange with the environment per unit of tissue mass will be reduced in the obese. The more A_D available for evaporative heat loss per unit of weight the more efficient the thermoregulation (Epstein et al., 1983). Shvartz et al. (1973) found lean women possess a double advantage while exercising at low ambient temperatures. These women had a decrease in metabolic heat production per unit of surface area and a greater relative heat loss through radiation and convection. However, at higher ambient temperatures, these advantages were offset by the added heat gain from radiation and convection. During a situation where environmental temperature approximates skin temperature, the heat gain from radiation and convection is minimal. Therefore, evaporative heat loss becomes a more critical factor, and the high A_D:mass becomes more of an advantage due to the added surface area available for heat exchange. Shapiro et al. (1980) reported that during light exercise women (who in general have a higher surface area to mass ratio) were at a thermoregulatory advantage in hot and humid temperatures compared with men. However, in a comparison of men and women exercising in the heat and wearing NBC protective clothing, McLellan (1998) found $\dot{S}$ to be similar between the sexes despite significantly higher T_{re}, $\overline{T}_{sk}$, and HR for females throughout the trial. These findings are in direct contradiction to the responses reported for men and women in humid environments (Shapiro et al., 1980; Avellini et al., 1980), and suggest that as the HSI increases from 1.25 to above 2 with wearing of protective clothing (McLellan, 1998), the potential advantage of a larger A_D:mass for increasing evaporative heat loss becomes less evident.

The traditional approach for determining S assumes the heat capacity of all body tissue is similar and equals $3.47\,kJ \cdot kg^{-1} \cdot {}^{o}C^{-1}$ (Kakitsuba and Mekjavic, 1987). However, since S is often used as an index of thermal stress, particularly in predicting tolerance time to a variety of thermal exposures, it is important to take into consideration differences in body composition. Different body tissues have different heat capacities. The heat capacity of adipose tissue is approximately one half that of lean tissue which is comprised of blood, muscle, water and bone (Bar-Or et al., 1969; Gephart and Dubois, 1915). Hence, a given heat load per kilogram of body weight will cause a higher temperature elevation in the obese than in the lean, despite similar rates of heat storage per unit of mass. McLellan (1998) observed similar $\dot{S}$ but different T_{re} in a comparison of men and women. These sex-related differences could be attributed to the higher body fatness of the females.

When comparing individual characteristics it is important to consider metabolic heat production. In a very humid environment where heat loss is very limited, equivalent metabolic rates would result in higher T_{re} for the small subjects due to their small storage capacity. This situation removes the effects of A_D:mass, since evaporative efficiency was low, as well as differences in metabolic rate due to differences in body size. Therefore, given the same rate of evaporation (heat loss) and similar rates of heat production, T_{re} will increase because of the decreased capacity to store heat through a decreased body mass of the smaller subject or an increased body fatness (Havenith et al., 1998). Similarly, it is important to consider whether the activity is weight bearing or non-weight bearing. In the latter situation, an increased mass would not substantially increase the metabolic cost of exercise (absolute workload), but the added mass would increase the heat storage capacity of the individual.

2.3.2 - Gender:

It has been concluded that females are at a thermoregulatory disadvantage compared with males when wearing protective clothing and exercising in a hot environment. This disadvantage can be attributed to the lower heat capacity of adipose versus non-adipose tissue and the higher body fatness of women (Mclellan, 1998). Further, when subjects were matched for aerobic fitness and body composition the gender differences were removed. When matching for anthropometric factors, the major difference which remains between the genders is an elevated sweat production in males (Avellini et al., 1980). Still there are other differences which exist between men and women, aside from the individual anthropometric differences, which pertain to thermoregulation in the heat.

2.3.2.1 - Menstrual phase:

There is considerable evidence that during conditions of compensable heat stress, the menstrual cycle affects temperature regulation (Bemben et al., 1995; Stephenson and Kolka, 1993). Basal body core temperature exhibits a biphasic rhythm in which the luteal phase is approximately 0.4°C higher compared with the follicular phase (Kolka and Stephenson, 1989). Therefore, $T_{re,\ initial}$ will be affected depending on menstrual phase during the heat stress trial. During UHS, Kolka and Stephenson (1989) found that T_{re} remained significantly higher during the mid-luteal phase compared with the early follicular phase, although tolerance time, HR, $\overline{T}_{sk}$, sweat rates, and evaporative heat loss did not differ between the phases. Tenaglia et al. (1999) found similar elevations in T_{re} during the mid-luteal phase compared to the early follicular phase. However, $T_{re,\ final}$ and rate of change in T_{re} were similar between the phases, allowing for longer tolerance times in the early follicular phase. Extended tolerance time in the early follicular phase was attributed to the lower $T_{re,\ initial}$, allowing for a greater change in T_{re}. These findings agree with the findings of Aoyagi et al. (1995) and McLellan and Aoyagi (1996) that showed following heat acclimation that if the rate of heat storage and $T_{re,\ final}$ do not differ, then changes in tolerance time can be accounted for by alterations in $T_{re,\ initial}$.

2.3.2.2 - Oral Contraceptive Use:

Investigations have demonstrated that T_{re} is higher during exercise in the heat with oral contraceptive pill use during the quasi mid-luteal phase (day 24-27) than during the quasi early follicular phase (day 3-6) when no exogenous steroids are ingested (Martin and Buono, 1997). Tenaglia et al. (1999) found that, similar to non-users of oral contraceptives, T_{re} was approximately 0.2°C higher during the quasi mid-luteal phase of the menstrual cycle. Despite an increase in T_{re}, however, there were no differences in the other dependent variables such as HR, $\dot{M}$, $\overline{T}_{sk}$, and $\dot{S}$ when the NBC protective clothing was worn in the heat. Furthermore, tolerance time did not differ between the quasi phases nor from the tolerance time of non-users (Tenaglia et al., 1999). These findings suggest that the use of oral contraceptives has only a minimal impact on temperature regulation in the heat (Tenaglia et al., 1999) and their use may create a more uniform response to uncompensable heat stress.

2.3.3 - Circadian Rhythm:

Resting core temperature follows a circadian rhythm with the lowest values occurring in the early morning and then rising throughout the day. Core temperature values can vary up to 0.5°C from early morning to mid afternoon (Krauchi and Wirz-Justice, 1994). It has been hypothesized that due to elevations in $T_{re,\ initial}$ during the afternoon, ΔT_{re} and tolerance time would be reduced when exercising in the heat and wearing NBC protective clothing (McLellan et al., 1999). However, $T_{re,\ final}$ also increased in the afternoon to offset the circadian effect on resting T_{re}, and maintain similar tolerance times between morning and afternoon trials (McLellan et al., 1999). These findings are suggest that it is not necessarily a set core temperature that can be tolerated as much as a defined change in T_{re} which determines tolerance during UHS.

2.3.4 - Age:

Epidemiological evidence indicates that during periods of hot weather, mortality and morbidity rates in the elderly (>50years) are increased (Ellis et al., 1976). There is a debate as to whether the increased morbidity is because of a decrease in direct thermoregulatory function such as decreased sweat rates and skin perfusion (Wagner et al., 1972; Lind et al., 1970), or whether the observed effects of aging on temperature regulation are due to other anthropometric variables (Kenney, 1997; Pandolf et al., 1988). Aging is associated with a decrease in cardiovascular function, such as a decrease in HR_{max}, and a lowering of $\dot{V}O_{2max}$ (Kenney, 1997). A 1% decrease in $\dot{V}O_{2max}$ per year has been documented after the age of 25 (Kenney, 1997). In comparing physically fit older and sedentary young subjects, the older subjects did not exhibit higher levels of thermal strain when exercising in the heat and had comparable sweat rates (Kenney, 1997; Pandolf et al., 1988). To further examine this relationship, Smolander et al. (1990) examined eight sedentary young men and six older moderately active men on a treadmill at 30% $\dot{V}O_{2max}$. No significant differences between the groups were observed in SR, evaporation rate, or HR. The older subjects did not become more hyperthermic, and their performance times were similar to the younger subjects. From these findings, it was concluded that calendar age is not necessarily associated with a reduced ability to exercise in a hot environment.

There does appear to be an attenuation of heat regulation responses with age when subjects are matched for aerobic fitness. When matched for physical characteristics and $\dot{V}O_{2max}$, Armstrong and Kenney (1993) found that older subjects had an attenuated forearm blood flow in the heat compared to younger subjects. Sweat gland density did not change with age, although there was a documented decrease in sweat gland function (Kenney, 1997).

2.4 - *Conclusions:*

The wearing of protective clothing limits the evaporation of sweat during exercise in hot environments and creates a condition of UHS. The metabolic rate is the primary determinant of $\dot{S}$ under these conditions when protective clothing is worn. Factors that lower the initial core temperature, such as heat acclimation, aerobic fitness and the follicular phase of the menstrual cycle, will increase tolerance time, whereas factors such as hypohydration and the luteal phase of the menstrual cycle which increase $T_{re,\ initial,}$ decrease tolerance time. Fitness levels and total body fatness levels can either raise or decrease the final core temperature which is tolerated, increasing or decreasing the potential heat storage capacity of the body, respectively. Further, factors that affect the heat capacity of the body will affect the increase in T_{re} for any given rate of heat production.

Chapter 3

Study Objectives and Hypotheses

3.1 – Objectives:

The objectives of this study were to:

i. Document the heat strain experienced by men and women wearing Canadian Forces NBC protective clothing during light exercise in the heat.

ii. Determine the separate and combined importance of aerobic fitness and body fatness on tolerance time while exercising in NBC protective clothing

3.2 – Hypotheses:

The hypotheses tested in this study were that:

i. Individuals with a high aerobic fitness through regular training will exhibit enhanced tolerance times because of their ability to tolerate higher core temperatures at exhaustion.

ii. Individuals with a low body fatness will, also exhibit enhanced tolerance times because of their increased capacity to store heat.

Chapter 4

Methods

4.1 - Subjects:

Twenty-four subjects (16 men; 8 women) were selected from a subject pool of 49 healthy volunteers (36 men; 13 women) from the surrounding university and military communities, who had all completed the heat stress trials described below. Prior to participation, the subjects were medically screened and a full explanation of procedures, discomforts and risks were given prior to obtaining written informed consent. Medical screening consisted of a baseline electrocardiogram (ECG), a medical history questionnaire, a pulmonary function assessment and a doctor's examination. Testing was performed in the climatic chamber at the Defence and Civil Institute of Environmental Medicine (DCIEM) and was approved by both DCIEM and University of Toronto ethics committees. Testing was conducted from January to June in order to limit heat acclimation through casual exposure to hot environments. The climatic chamber was controlled at 40°C and 30% R.H. for the duration of the trials.

4.1.1 - Definition of Groups:

Subjects were matched for aerobic fitness and body fatness in a 2x2 factorial design. The four groups were defined as endurance trained (T) or untrained (UT) with low or high levels of body fatness. The T subjects were those individuals engaged in regular aerobic exercise (4-5 times·week^{-1}) and had a measured peak aerobic power ($\dot{V}O_{2peak}$) greater than approximately 65 and 60 mL·kgLBM (lean body mass)$^{-1}$·min^{-1} for men and women, respectively. The UT subjects were not involved in a regular aerobic exercise program and had a $\dot{V}O_{2peak}$ less than 55 and 50 mL·kgLBM^{-1}·min^{-1} for men and women, respectively. The value of 65 mL·kgLBM^{-1}·min^{-1} represents a corresponding value of 58.5 and 52 mL·kg total mass^{-1}·min^{-1} for an individual with 10% and 20% body fatness, respectively. Similarly, the value of 55 mL·kgLBM^{-1}·min^{-1} corresponds to respective values of 49.5 and 44 mL·kg total mass^{-1}·min^{-1} for 10% and 20% body fatness.

A high body fatness was defined as 20% of total body mass or greater, whereas low body fatness was defined as 13% of total mass or less. The groups T_{Low} and UT_{Low}, and groups T_{High} and UT_{High} were matched for fatness but differed in fitness. Similarly, groups T_{Low} and T_{High}, and groups UT_{High} and UT_{Low} were matched for fitness but differed in fatness. Each group consisted of six matched subjects, 4 males and 2 females.

Subjects refrained from hard exercise (i.e., running, swimming, cycling and weight lifting), alcohol, non-sterodial anti-inflammatories, and sleep medication 24 hours before, and also refrained from ingesting caffeine or nicotine 12 hours before each session. Although non-smokers would have been preferred, it was difficult to find and match subjects in terms of fitness and fatness. Three subjects in UT_{low}, one in UT_{high} and one in T_{high} smoked cigarettes.

Women matched for either fitness or fatness were tested during the same menstrual phase to control for the influence of menstrual phase on temperature regulation during uncompensable heat stress (Tenaglia et al., 1999). Women were tested during the early follicular phase (day 2-5) of the menstrual cycle for non-users of oral contraceptives and during days 3-6 of the week when no exogenous steroidal supplement was provided for the one woman using oral contraceptives. Tengalia et al. (1999) have shown that heat tolerance while wearing the NBC clothing is similar for non-users and users of oral contraceptives during the follicular phase of the menstrual cycle. The familiarisation trial was performed one week prior to the experimental trial during the late luteal phase for non-users (7 out of 8 women) and during days 24-27 of the 28-day cycle for the user of oral contraceptives.

4.2 - Experimental Protocol

4.2.1 - Determination of Peak Aerobic Power:

$\dot{V}O_{2peak}$ was measured at a comfortable room temperature (22°C) using open-circuit spirometry. The test consisted of 3 minutes of steady-state running (0% elevation;

wind speed <0.1m·s^{-1}) on a motorized treadmill (Quinton Instruments., Q65, Seattle Washington) at a self-selected pace, which was dependent on the aerobic fitness level of each subject. Thereafter, treadmill grade was increased 1%·min^{-1}, up to a 10% elevation. At this point, an alternating increase in speed (0.22 m·s^{-1}) and elevation (1%) each minute was implemented until the subject could no longer continue. During the final stages of the protocol, verbal encouragement was given. $\dot{V}O_{2peak}$ was defined as the highest observed 30-s value for oxygen consumption ($\dot{V}O_2$) together with a respiratory exchange ratio (RER) > 1.15. Absolute values for $\dot{V}O_{2peak}$ were expressed relative to LBM (see below) for the groupings and matching of subjects. HR was monitored during the treadmill protocol using a transmitter/telemetry unit (Polar Vantage XL, Finland). The highest value recorded at the end of the exercise test was defined as HR_{peak}. Subjects' physical activity profile was obtained from a verbal questionnaire to determine the presence or absence of regular involvement in aerobic activities.

4.2.2 - Anthropometric Measurements:

Height (in cm) and body mass (in kg) were measured for each subject. Body surface area (A_D) was calculated using the DuBois equation (1915) and A_D:mass was calculated. Body density was determined from underwater weighing (UWW) using helium dilution to determine residual lung volume. Body fatness was calculated using the Siri equation (Siri, 1956). For two subjects who were unable to feel comfortable while trying to submerge themselves underwater, body fatness was estimated from skin caliper measurements and a gender-specific regression equation developed from hydrostatic measurements of body density (Forsyth et al. 1984). LBM was calculated by subtracting the calculated mass of body fat from the total body mass.

4.2.3 - Familiarisation Trial:

A familiarisation exposure to the hot-dry environmental chamber (40°C, 30% R.H., wind speed <0.1m·s^{-1}) was performed while wearing the Canadian Forces NBC protective ensemble and walking on a level treadmill at 0.97 $m \cdot s^{-1}$ (3.5 $km \cdot h^{-1}$). Rectal temperature (T_{re}), mean skin temperature (T_{sk}), skin and clothing vapour pressure, heart rate and gas exchange were monitored. End-point criteria included the following:

1) 4 hours of continuous exercise;
2) Rectal Core temperature reaching 39.5°C;
3) Heart Rate reaching or exceeding 95% of maximum for three minutes;
4) Dizziness, or nausea precluding further exercise;
5) Subject volition (exhaustion/ discomfort); or
6) The investigator terminating the trial.

4.2.4 - Experimental Trial (Heat Stress Test):

The experimental trial was performed approximately 1 week following the familiarisation exposure. End-point criteria were identical to those described above.

4.2.5 - Tolerance Time:

Tolerance time (TT) was defined as the elapsed time from the beginning of the exercise to the attainment of one or more of the end-point criteria that resulted in removal from the chamber.

4.2.6 - Clothing Ensembles:

The normal operational combat clothing configuration consisted of underwear, shorts, T-shirt, socks, combat clothing and running shoes. The NBC protective clothing ensemble consisted of impermeable rubber gloves, overboots, and a mask with a respirator. The NBC overgarment was layered over the combat clothing configuration. The total thermal resistance of the combat clothing and NBC ensemble, determined with a heated copper manikin at a wind speed of 1.11 $m \cdot s^{-1}$, was 0.291 $m^2 \cdot °C \cdot W^{-1}$ (1.88 clo) (Gonzalez et al., 1993). The Woodcock vapour permeability coefficient (i_m), determined with a completely wetted manikin, was 0.33.

4.2.7 - Dressing/ Weighing Procedures:

To control for the effects of circadian rhythm on core temperature, all trials occurred at approximately 8:00 am (McLellan et al., 1999). Upon arrival, subjects inserted a rectal probe (see below) and were weighed nude on an electronic scale sensitive to the nearest 0.05 kg (Serta Systems Inc., SuperCount, Acon, MA). Skin heat flow transducers (HFT), humidity sensors and temperature thermistors, and a heart rate monitor were then applied. Subjects then dressed in the combat uniform before 3 additional humidity sensors and temperature thermistors were taped to this clothing layer. At this stage, subjects donned the NBC overgarment and rubber boots, and carried the gloves and respirator while a dressed weight was obtained. Following the ingestion of 200mL of water (see below), subjects then donned the respirator and gloves, covered the head with the hood of the overgarment and then finally zippered the overgarment to obtain full encapsulation. They were then led into the climatic chamber where the humidity sensors and thermistors, HFT, and rectal thermistor monitoring cables were connected to a computerized data acquisition system (Hewlett-Packard 3497A control unit, 236-9000 computer, and 2934A printer, Pitts, PA.). Within one minute after removal from the chamber, the subject's dressed weight was recorded. The subject's nude weight was recorded within 5 minutes after subjects undressed and toweled dry. T_{re} was monitored during and following the undressing procedures to ensure a reduction in core temperature prior to leaving the supervision of the investigator.

4.2.8 - Hydration Schedule:

Each subject ingested 200 mL of warm water at approximately 37°C prior to entering the chamber and every 15 minutes during the exercise. The temperature of the water was maintained close to body temperature in order to reduce the heat-sink effect that cooler water would have had on T_{re}. If T_{re} was above 39°C or if the subject felt that they could not continue for another 10 minutes, water was not administered for the remainder of the test. An extension tube fitted to the fluid intake port of the respirator allowed water intake with the respirator in place during exercise. Gatorade® was provided to replenish fluid loss following the exposure.

4.3 - Physiologic Measurements

4.3.1 - Temperature measurements:

Mean values over 1-min periods for T_{re}, and a 12-point weighted $\overline{T}_{sk}$ were calculated, recorded, and printed by the computerized data-acquisition system.

T_{re} was measured using a flexible vinyl-covered rectal thermistor (Pharmaseal APC 400 Series) inserted approximately 15 cm beyond the anal sphincter. $\overline{T}_{sk}$ was calculated from 12 HFT's (Concept Engineering, FR-025-TH4403S-F8-F) using a weighted equation as,

$$\overline{T}_{sk} = 0.07(\text{forehead}) + 0.085(\text{chest}) + 0.065(\text{calf}) + 0.085(\text{abdomen}) + 0.14(\text{lower arm}) + 0.05(\text{wrist}) + 0.095(\text{front thigh}) + 0.065(\text{shin}) + 0.07(\text{foot}) + 0.09(\text{upper back}) + 0.09(\text{lower back}) + 0.095(\text{rear thigh})$$ (Vallerand et al., 1989)

(Eqn: 7)

Each skin site was prepared by shaving the contact area when necessary, and then cleaning the site with an alcohol swab and wiping with Skin Prep® (Smith and Nephew United, Largo, Florida).

4.3.2 – Heart Rate Measurements:

HR was monitored using a transmitter (Polar Vantage XL) clipped to ECG leads or an elasticized belt that was fitted around the chest and taped in place. The receiver was taped to the outside of the clothing, allowing for a continuous HR display. HR was recorded manually every 5 minutes during the heat stress test.

4.3.3 - Vapour Pressure (Humidity/Temperature):

Skin and clothing vapour pressures were determined using relative humidity capacitance sensors (Vaisala Sensor Systems, Woburn, MA) and temperature thermistors taped on the skin and the outer layer of the combat clothing at the upper back, abdomen and thigh. Vapour pressures were calculated using temperature and relative humidity at each site and an unweighted average was calculated for skin and garment vapour pressure and printed each minute by the data acquisition system. The humidity sensors had an accuracy of ±3%. Saturated salt solutions of lithium chloride, sodium chloride, and potassium sulfate, with relative humidities of 12, 75, and 97%, respectively, were used to verify the linearity of response for each sensor.

4.3.4 - Gas-exchange Measurements:

Open-circuit spirometry was used to determine expired minute ventilation ($\dot{V}_E$), $\dot{V}O_2$ and carbon dioxide production ($\dot{V}CO_2$) every 15 minutes. Values were averaged from a 2-min sampling period for each subject following a 1-min washout period. In order to determine $\dot{V}_E$, an adaptor attached to the respirator directed expired air to a 5L-mixing box and then through a ventilation module (Alpha Technologies VNN 110 Series, Laguna Hill, CA). An aliquot of dried expired gases was pumped via a sampling line to an O_2 and CO_2 analyser (Amtek Instruments S-3A/I and CD-3A, respectively, Pitts, PA). Gas analyzers were calibrated using precision-analysed gas mixtures in cylinders. The ventilation meter was calibrated with a 3-L syringe. After analogue-to-digital conversion (Hewlett Packard 59313A A/D converter, Pitts, PA), $\dot{V}_E$, $\dot{V}O_2$, $\dot{V}CO_2$, and respiratory exchange ratio (RER) were calculated and printed on-line at one minute intervals (Panasonic, KX-P1092).

4.3.5 - Sweat Measurements:

Subjects were weighed nude and dressed, before and immediately after the trials, using an electronic scale (see above). Differences between nude and dressed body masses before and after each trial were corrected for respiratory and metabolic weight losses as well as fluid intake. Respiratory water loss ($\dot{m}_e$ in g·min^{-1}) was calculated using the measured $\dot{V}O_2$ (L·min^{-1}) during the trial, respired mouth water vapour pressure (P_{resp}) and P_A as,

$$\dot{m}_e = 0.1425 \cdot \dot{V}O_2 (P_{resp} - P_A)$$ (Mitchell et al., 1972) (Eqn: 8).

Based on previous work, a P_{resp} of 5.32 kPa was used (Livingstone et al., 1994); this value was measured with subjects exercising under similar experimental and ambient conditions. The value of 5.32 kPa assumes 100% saturation at a mouth temperature (T_{resp}) of 34°C for the chamber conditions (Livingstone et al., 1994). Metabolic weight

loss ($\dot{m}_r$ in g·min^{-1}) was calculated from $\dot{V}O_2$ and RER as,

$$\dot{m}_r = \dot{V}O_2\ (1.9769 \cdot RER - 1.42904) \quad \text{(Snellen, 1966)(Eqn: 9).}$$

The rate of sweat produced, SR, (kg·hr^{-1}·m^{-2}) was calculated as the sum of pre-trial nude body mass and fluid given minus post-trial (corrected) nude body mass, divided by tolerance time and body surface area.

4.3.6 - Blood Measurements:

A 5 mL blood sample was obtained by venipuncture prior to the dressing procedures to determine osmolality. An additional 5 mL sample was obtained from the women for estradiol and progesterone determination. Radioimmunoassays, in duplicate, were used to determine estradiol and progesterone levels for menstrual phase verification (DSL-4800 Ultra-Sensitive Estradiol Radioimmunoassay Kit, and KSL-3900 ACTIVE Progesterone Coated-Tube Radioimmunoassay Kit, respectively, from Diagnostics Systems Laboratories, Inc.). Blood osmolality was calculated from plasma concentrations of glucose (Glu), sodium (Na^+), and blood urea nitrogen (BUN) (Nova Ultra Stat, Nova Biomedical). This method (Nova Biomedical Corp., 1996) calculated osmolality (mOsm·kg^{-1}) as a zero-order approximation by the following equation:

$$Osm = 1.86 \cdot [Na^+] + [Glu] \cdot 18^{-1} + [BUN] 2.8^{-1} + 9 \qquad \text{(Eqn: 10)}$$

where Na^+ units are mmol·L^{-1}, Glu units are mg·dL^{-1}, and BUN units are mg·dL^{-1}.

4.4 - Subjective Measurements:

Two subjective ratings were completed every fifteen minutes following metabolic gas exchange measurements. These subjective scores were a rating of overall perceived exertion (RPE) (Borg, 1982) and a rating of thermal comfort (RTC) (McGinnis Thermal Scale). The two scales were each presented on large charts, and subjects were asked to indicate their current rating, using their index finger. The respective values for RPE and RTC ranged from 0 to 10 and 1 to 13, respectively (Aoyagi et al., 1998).

4.5 - Calculation of Heat Exchange and Heat Storage:

The rate of heat storage ($\dot{S}$, in $W{\cdot}m^2$) was calculated from the heat balance equation as previously presented (McLellan et al., 1999; McLellan, 1998):

$$\dot{S} = \dot{M} - \dot{W} + (\dot{C} + \dot{R}) + \dot{K} + \dot{C}_{resp} - \dot{E}_{resp} - \dot{E}_{sk} . \qquad \text{(Eqn: 11)}$$

The rate of metabolic heat production ($\dot{M}$) was determined from A_D, RER, and the measured $\dot{V}O_2$ as,

$$\dot{M} = 352(0.23 \cdot \text{RER} + 0.77)(\dot{V}O_2 \cdot A_D{}^{-1}) \text{ (Nishi, 1981)} \qquad \text{(Eqn: 12)}$$

The rate of external work ($\dot{W}$) and conductive heat gain ($\dot{K}$) were considered zero since subjects were walking on a level treadmill.

Chamber temperature exceeded skin temperature; therefore, the rate of radiative and convective heat exchange contributed to positive heat gain. $\dot{R}$ and $\dot{C}$ were estimated by using the total insulative value of the NBC clothing ensemble (I_T) of $0.291°C{\cdot}m^2{\cdot}W^{-1}$ (or 1.88 clo) and the difference between the chamber temperature of 40°C and $\overline{T}_{sk}$ averaged over each 5-min interval, as

$$\dot{R} + \dot{C} = (40 - \overline{T}_{sk}) \cdot 291^{-1} \text{ (Gonzalez et al., 1997)} \qquad \text{(Eqn: 13).}$$

Respiratory evaporative heat loss ($\dot{E}_{resp}$) and convective heat gain ($\dot{C}_{resp}$) were calculated from P_A of 2.21 kPa for 40°C and 30% R.H., and P_{resp} of 5.32 kPa at a T_{resp} of 34°C (Livingstone, 1994), as

$$\dot{E}_{resp} = 0.0173 \cdot \dot{M} \cdot (P_{resp} - P_A), \qquad \text{(Eqn: 14)}$$

and

$$\dot{C}_{resp} = 0.0014 \cdot (T_A - T_{resp}) \text{ (Fanger, 1970)} \qquad \text{(Eqn: 15)}$$

Evaporative heat loss from the skin ($\dot{E}_{sk}$) was determined from a model that determined mass flow rates of water vapour through the clothing layers using the skin and garment vapour pressures measured from the humidity sensors positioned above the skin surface and over the combat clothing layer together with the thermal resistances of the clothing and air layers (Cain and McLellan, 1998; McLellan et al., 1996).

Heat storage capacity (S, in $kJ \cdot kg^{-1}$) was calculated from $\dot{S}$ values averaged every 5 minutes and tolerance time (McLellan et al., 1999), as

$$S = \dot{S} \cdot A_D \cdot \text{mass}^{-1} \cdot (60 \cdot \text{time}) \cdot 1000^{-1}. \qquad \text{(Eqn: 16)}$$

4.6 - Data Analyses:

A 3-factor ANOVA with 2 grouping factors (fitness and fatness) and 1 repeated factor (time) was performed on the dependent measures sampled over time, (i.e., T_{re}, $\overline{T}_{sk}$, $\dot{S}$, $\dot{M}$, and HR). The trained and untrained groups were analyzed up to and including 75 and 60 minutes respectively, maintaining an n of 6 for all data points. In addition, a 2-factor ANOVA with two grouping factors (fitness and fatness) was calculated for the dependent measures recorded at discrete time intervals (i.e., tolerance time, SR and S). Planned post hoc comparisons were made between the groups using a Neuman Keuls adjustment for multiple comparisons. Post hoc analyses were performed only between groups matched for fitness or fatness. Thus, T_{Low} was never compared with UT_{High} and similarly T_{High} was not compared with UT_{Low}.

The planned post-hoc comparisons were,

T_{Low} vs. T_{High},
T_{High} vs. UT_{High},
T_{Low} vs. UT_{Low}, and
UT_{High} vs. UT_{Low}

All ANOVA's were performed using statistical software (SuperAnova V. 1.11 (1991), Abacus Concepts, Inc.). For all statistical analyses, an alpha level of 0.05 was used.

Chapter 5
Results

5.1- Subject Characteristics:

Physical characteristics of the groups are listed in Table 1 and body fatness and $\dot{V}O_{2peak}$ values which were used to define the groups and match subjects are presented in Table 2. UT_{Low} had a significantly greater A_D:mass compared to UT_{High}. The high fat groups combined had a significantly greater body mass and A_D, plus a lower A_D:mass compared to the low fat groups.

Table 1: *Physical measurements of age, height, mass, lean body mass (LBM), surface area (A_D), surface area to mass ratio (AD:mass), peak heart rate (HR_{peak}) peak aerobic power ($\dot{V}O_{2peak}$) for trained (T) and untrained (UT) groups with high or low body fatness. Values are means (±SE).*

Group	Age (y)	Height (cm)	Mass (kg)	LBM (kg)	A_D (m^2)	A_D:mass ($m^2 \cdot kg^{-1} \cdot (10^{-2})$)	HR_{peak} ($b \cdot min^{-1}$)	$\dot{V}O_{2peak}$ ($L \cdot min^{-1}$)	$\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)
T_{Low}	25.2	168.5	61.30	54.70	1.69	2.79	195.2	3.58	57.91 *, +
	(2.5)	(4.6)	(4.38)	(4.22)	(0.09)	(0.08)	(4.4)	(0.36)	(2.04)
T_{High}	22.5	174.1	73.80	60.00	1.88	2.58	194.2	3.92	52.92
	(0.9)	(5.1)	(6.56)	(5.37)	(0.11)	(0.09)	(3.1)	(0.45)	(1.87)
UT_{Low}	22.2	171.6	62.00 †	54.30	1.72	2.78 †	196.0	3.18	46.43 ‡
	(0.8)	(5.1)	(3.25)	(2.84)	(0.07)	(0.07)	(1.7)	(0.35)	(2.10)
UT_{High}	21.2	175.0	78.70	62.20	1.93	2.50	198.8	3.33	41.87
	(0.5)	(3.9)	(6.89)	(6.10)	(0.10)	(0.10)	(3.2)	(0.34)	(1.03)

† - UT_{Low} significantly different from UT_{High}
*- T_{High} significantly different from T_{Low}
+ - T_{Low} significantly different from UT_{Low}
‡ - T_{High} significantly different from UT_{High}

Table 2: *Peak aerobic power ($\dot{V}O_{2peak}$), expressed relative to lean body mass (LBM) and body fatness levels used to classify groups as trained (T) and untrained (UT) with low or high levels of body fatness. Values are means (±SE).*

Group	$\dot{V}O_{2peak}$ ($mL \cdot kgLBM^{-1} \cdot min^{-1}$)	Body Fatness (%BF)
T_{Low}	64.7 +	10.9
	(2.0)	(0.8)
T_{High}	64.6 ‡	18.8 *
	(2.4)	(1.0)
UT_{Low}	53.3	12.4
	(2.0)	(1.0)
UT_{High}	52.3	21.2 †
	(1.2)	(1.0)

* - T_{High} significantly different from T_{Low}
† - UT_{High} significantly different from UT_{Low}
‡ - T_{High} significantly different from UT_{High}
+ - T_{Low} significantly different from UT_{Low}

5.2- Blood:

Osmolality, estradiol and progesterone values are reported in Table 3. There were no differences in osmolality among the groups, indicating similar hydration levels prior to the heat exposure. All female estradiol (37.4 – 201 pmol·L^{-1}) and progesterone (NB = 2.99 nmol·L^{-1}) levels were within normal ranges for the early follicular phase.

Table 3: *Serum osmolality (N=24), and female estradiol and progesterone levels, before the heat-stress trial for trained (T) and untrained (UT) groups with high or low body fatness. Values are means (±SE).*

Group	Osmolality ($mOsmol{\cdot}kgH_2O^{-1}$)	Estradiol N=2 ($pmol{\cdot}L^{-1}$)	Progesterone N=2 ($nmol{\cdot}L^{-1}$)
T_{Low}	286.7	86.27	2.29
	(1.1)	(6.24)	(0.48)
T_{High}	285.7	120.04	2.23
	(1.0)	(14.68)	(0.06)
UT_{Low}	287.5	77.46	3.10
	(0.6)	(2.57)	(0.06)
UT_{High}	284.9	86.27	2.61
	(1.9)	(2.20)	(0.38)

5.3- Heat-stress Trial

5.3.1- Metabolic Rate:

The oxygen cost of exercise is depicted in absolute (L·min^{-1}) and relative (mL·kg^{-1}·min^{-1}) terms in Figure 1 and Figure 2, respectively. Because of their greater body mass, the oxygen cost of walking, expressed in L·min^{-1}, was increased for the high fatness groups early during the exercise and heat stress (Figure 1). These differences remained for T_{High} and T_{Low} throughout the heat stress whereas the differences between UT_{High} and UT_{Low} disappeared after 30 minutes. When the expression of $\dot{V}O_2$ was normalized for differences in body mass (Figure 2), the response for UT_{High} was significantly reduced compared with the other matched groups. Differences between T_{Low} and T_{High} become significant at 60 minutes (Figure 2). When the oxygen cost of exercise was expressed as a percentage of $\dot{V}O_{2peak}$, values were significantly greater for both UT_{High} and UT_{Low} compared to their trained counterparts, (26.0 ± 1.8 , 26.5 ± 1.1, 20.4 ± 1.0 , and 22.7 ± 1.6 for UT_{Low}, UT_{High}, T_{Low} and T_{High}, respectively

Figure 1: *Oxygen consumption ($L \cdot min^{-1}$) during the heat-stress trial conducted at 40°C and 30% R.H., with subjects wearing the nuclear, biological and chemical protective ensemble for trained (T) or untrained (UT) groups with low or high body fatness (T_{Low}(Δ), T_{High}(o), UT_{Low}(▲), UT_{High}(•)). Values are means (±SE). $T_{High} > T_{Low}$ throughout trial; $UT_{Low} > T_{Low}$ @ 60 mins; $UT_{High} > UT_{Low}$ @ 15 mins.*

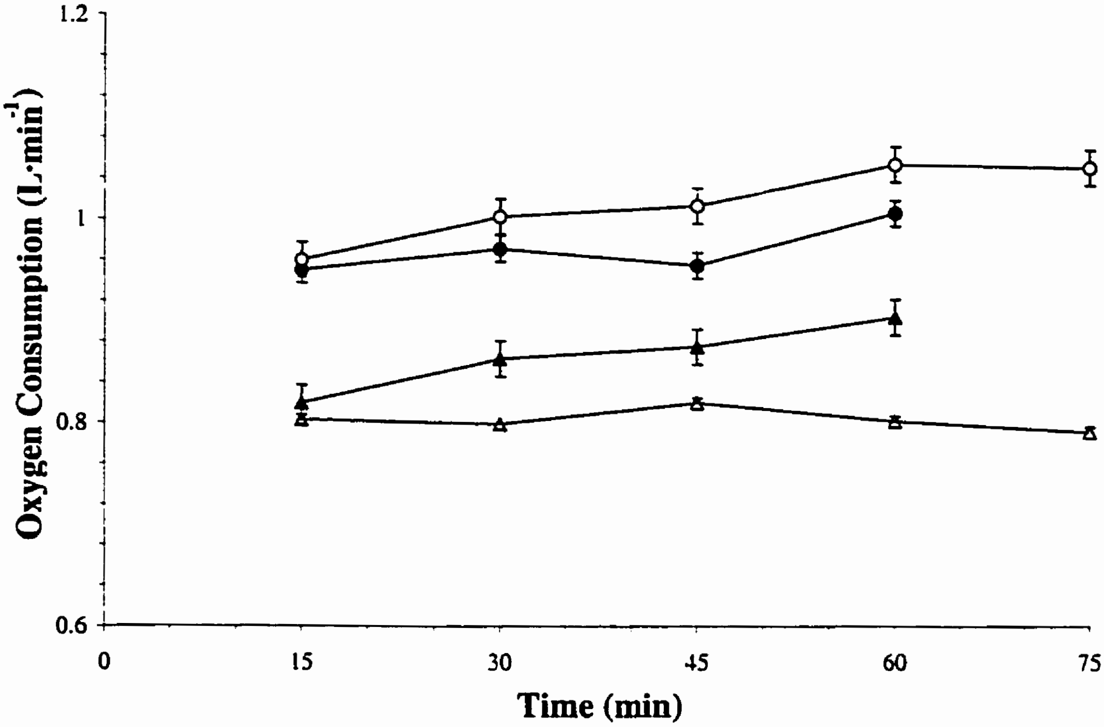
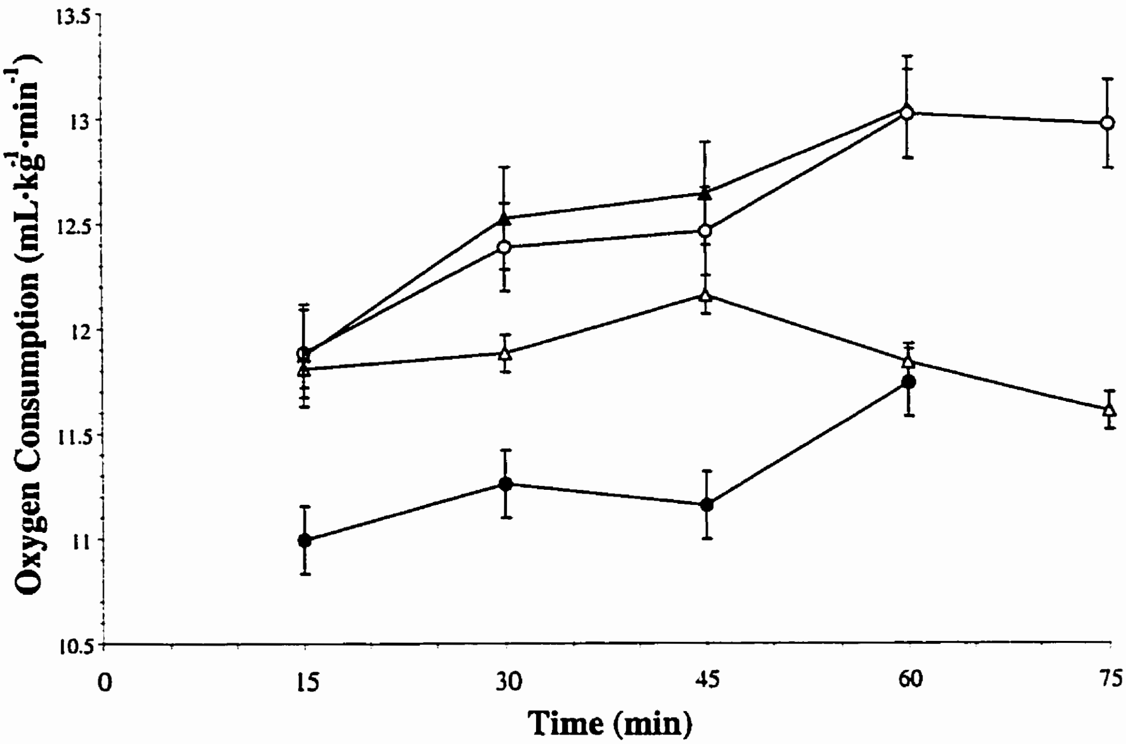


Figure 2: *Oxygen consumption (mL·kg^{-1}·min^{-1}) during the heat-stress trial conducted at 40°C and 30% R.H., with subjects wearing the nuclear, biological and chemical protective ensemble for trained (T) or untrained (UT) groups with low or high body fatness (T_{Low}(Δ), T_{High}(o), UT_{Low} (▲), UT_{High}(•)). Values are means (±SE). $T_{High} > T_{Low}$ @ 60 mins; $UT_{Low} > T_{Low}$ from 30 mins; $UT_{Low} > UT_{High}$ throughout trial; $T_{High} > UT_{High}$ from 30 mins.*



5.3.2- Rate of Sweat Production and Body Mass Loss:

Sweat rate and mass loss for the groups are reported in Table 4. The rate of sweat production, in kg·h^{-1}, was significantly different among the groups. When normalized for surface area, sweat rate was higher for T_{High} compared with UT_{High} and for UT_{Low} compared with UT_{High}. There were also observed differences in total fluid intake, total mass change, percent body mass change, and the rate of mass loss. It should be noted that the rehydration schedule was such that when T_{re} reached 39°C or when subjects felt that they could not continue for another ten minutes, rehydration was terminated. Trained subjects went longer without water in the latter stages of their trial than their untrained counterparts. Body mass changes were less than 0.8% total body mass for all groups.

Table 4: *Sweat rate (SR), total fluid intake, total and percent body mass change, and rate of mass loss during the heat-stress trial conducted at 40°C and 30% R.H., with subjects wearing nuclear, biological and chemical protective ensemble for trained (T) and untrained (UT) groups with high or low body fatness. Values are means (±SE).*

Group	*SR (kg·h^{-1})*	*SR (kg·m^{-2}·h^{-1})*	*Total Fluid Intake (kg)*	*Total Mass Loss (kg)*	*Body Mass Loss (%)*	*Rate of Mass Loss (kg·h^{-1})*
T_{Low}	0.89	0.53	1.29 +	0.42	0.70	0.22
	(0.04)	(0.03)	(0.11)	(0.06)	(0.09)	(0.04)
T_{High}	1.10 *,‡	0.59 ‡	1.02 *	0.48 ‡	0.63 ‡	0.37 ‡
	(0.09)	(0.03)	(0.04)	(0.11)	(0.16)	(0.09)
UT_{Low}	0.84 †	0.49 †	0.73	0.24	0.38	0.21
	(.05)	(0.02)	(0.07)	(0.08)	(0.14)	(0.07)
UT_{High}	0.68	0.35	0.88	0.07	0.08	0.06
	(0.06)	(0.03)	(0.05)	(0.09)	(0.13)	(0.07)

* - T_{High} significantly different from T_{Low}
† - UT_{High} significantly different from UT_{Low}
‡ - T_{High} significantly different from UT_{High}
\+ - T_{Low} significantly different from UT_{Low}

5.3.3 - Heart Rate:

Figure 3 illustrates the heart rate response for the groups in absolute (b·min^{-1}) and Figure 4 in relative (%HR_{peak}) terms. With the exception of the data at 15 minutes, HR and %HR_{peak} were significantly higher for T_{High} compared to T_{Low} throughout the HST. Similarly, UT_{Low} was significantly greater than T_{Low} over the entire exposure when

Figure 3: *Heart rate (HR) response (b·min^{-1}) during the heat-stress trial conducted at 40°C and 30% R.H., with subjects wearing the nuclear, biological and chemical protective ensemble for trained (T) or untrained (UT) groups with low or high body fatness (T_{Low}(Δ), T_{High}(o), UT_{Low}(▲), UT_{High}(●)). Values are means (±SE). T_{High} > T_{Low} throughout trial, excluding 15 mins; UT_{Low} > T_{Low} from 15 minutes.*

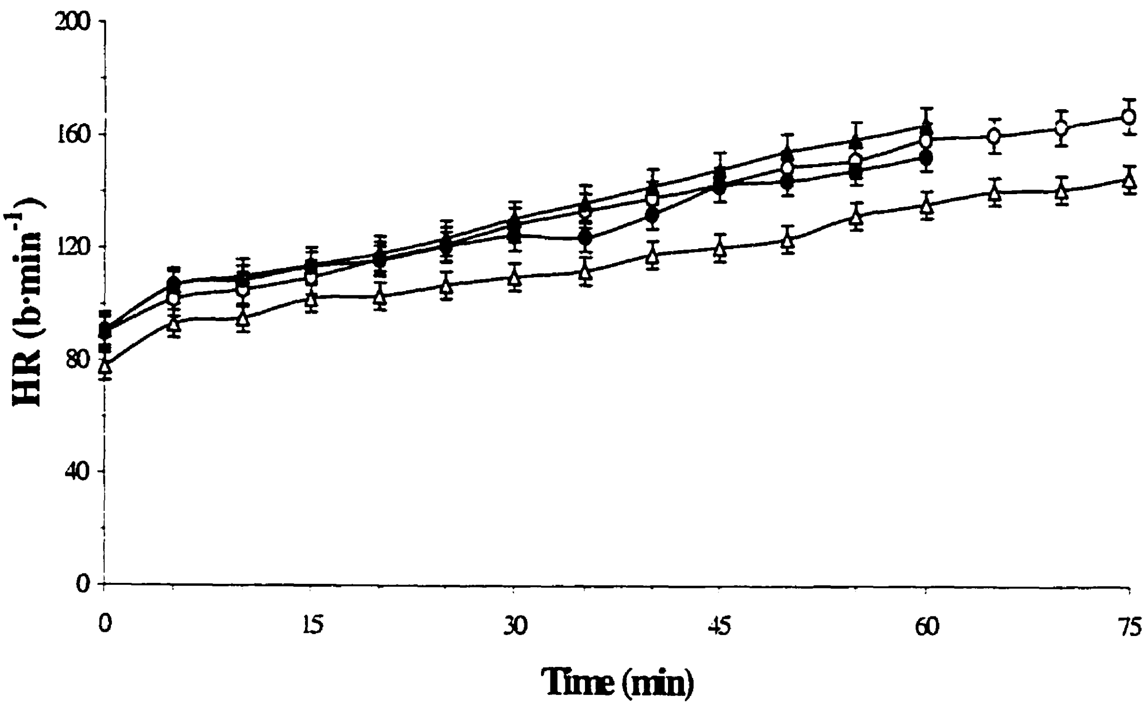
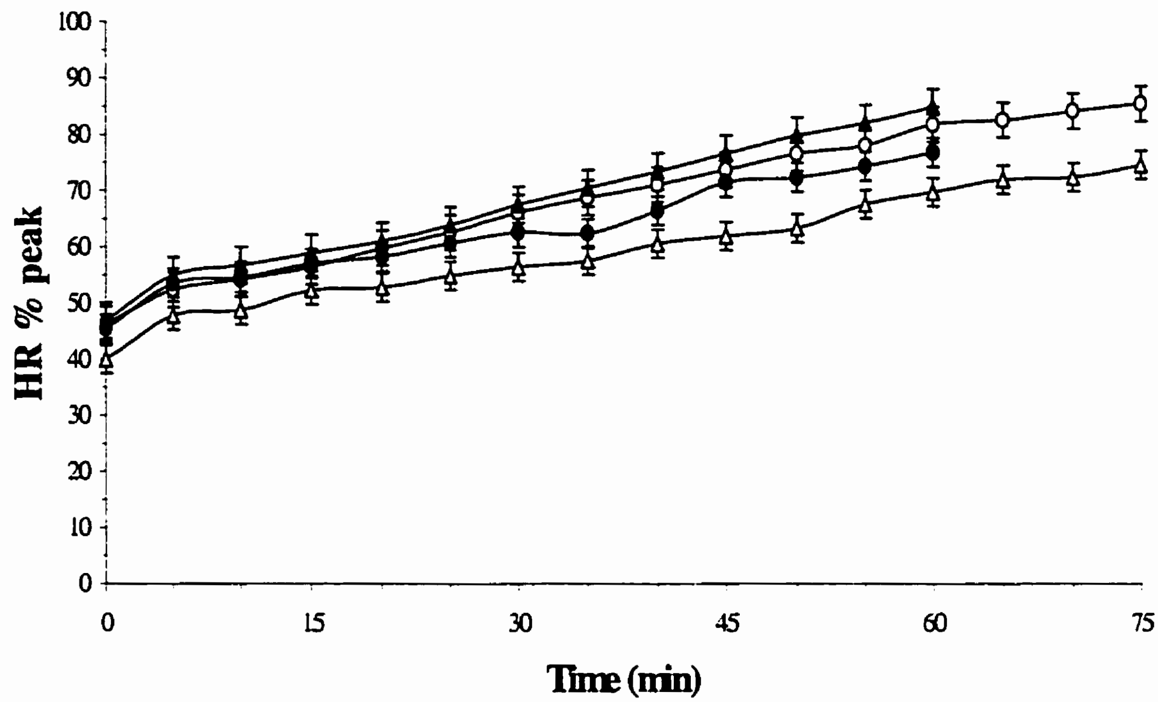


Figure 4: *Heart rate (HR) response (% HR_{peak}) during the heat-stress trial conducted at 40°C and 30% R.H., with subjects wearing the nuclear, biological and chemical protective ensemble for trained (T) or untrained (UT) groups with low or high body fatness (T_{Low}(Δ), T_{High}(○), UT_{Low}(▲), UT_{High}(●)). Values are means (±SE). T_{High} > T_{Low} throughout Trial; UT_{Low} > T_{Low} throughout trial; UT_{Low} > UT_{High} from 35 mins.*



expressed in relative terms (Figure 4). UT_{Low} was significantly greater than UT_{High} at 35 minutes with both expressions of HR. Only 2 subjects reached the heart rate cut-off during the trials. Both of these subjects were in the UT_{Low} group (see Table 6). There were no differences among the matched groups for final HR expressed in absolute or relative terms (Table 5). Final heart rate expressed as a percentage of HR_{peak} did not exceed 90 percent.

Table 5: *Heart rate response expressed in absolute ($b \cdot min^{-1}$) and relative (% HR_{peak}) terms at the end of the trial during the heat-stress trial conducted at 40°C and 30% R.H., with subjects wearing the nuclear, biological and chemical protective ensemble for trained (T) and untrained (UT) groups with high or low body fatness. Values are means (±SE).*

Group	HR_{Final} ($b \cdot min^{-1}$)	$HR_{(Final, \%peak)}$ (%)
T_{Low}	162.7 (6.5)	83.5 (2.4)
T_{High}	169.7 (6.6)	86.8 (2.6)
UT_{Low}	172.2 (5.0)	89.0 (2.7)
UT_{High}	162.3 (9.0)	81.6 (3.6)

5.3.4- Rectal Temperature:

The values for initial T_{re} ($T_{re,\,initial}$), final T_{re} ($T_{re,\,final}$), delta T_{re} (ΔT_{re}), the rate of change of T_{re} (calculated $(T_{re,\,final} - T_{re,\,initial}) \cdot TT^{-1}$) and the time for a 1°C increase in T_{re} are given in Table 6. There were no significant differences in $T_{re,\,initial}$, or the time for a 1°C increase in T_{re}. The rate of change in T_{re} was significantly greater for T_{High} compared with T_{Low} and UT_{High}. Similarly, among the groups there was a significant effect of fitness level on $T_{re,\,final}$ with values 0.9°C greater for T_{Low} compared with UT_{Low} and 0.4°C greater for T_{High} compared with UT_{High}. Both trained groups had a greater ΔT_{re}

when compared to their corresponding untrained groups. In addition, ΔT_{re} was significantly greater for T_{Low} compared with T_{High}. The T_{re} response throughout the heat-stress trial is shown in Figure 5. There were no significant differences in T_{re} (Figure 5) or ΔT_{re} (Figure 6) over the first 30 minutes. At 45 minutes, T_{re} and ΔT_{re} of T_{High} was significantly greater than T_{Low} and these differences remained for the duration of the heat-stress trial. In addition, after 60 minutes of exercise, T_{re} was significantly higher for UT_{Low} compared with T_{Low}, but this difference was not evident when expressed as ΔT_{re} (Figure 6).

Table 6: *$T_{re,\ initial}$, $T_{re,\ final}$, ΔT_{re}, rate of change T_{re} and time (min) for 1°C increase in T_{re} responses during the heat-stress trial conducted at 40°C and 30% R.H., with subjects wearing the nuclear, biological and chemical protective ensemble for trained (T) and untrained (UT) groups with high or low body fatness. Values are means (±SE).*

Group	$T_{re,\ initial}$ (°C)	$T_{re,\ final}$ (°C)	ΔT_{re} (°C)	Rate of change T_{re} ($°C \cdot h^{-1}$)	Time (min) for 1°C increase in T_{re}
T_{Low}	37.02	39.48 +	2.46 +	1.27	57.50
	(0.08)	(0.01)	(0.08)	(0.10)	(2.92)
T_{High}	37.10	39.22 ‡	2.12 *, ‡	1.55 *, ‡	52.17
	(0.09)	(0.09)	(0.12)	(0.09)	(2.98)
UT_{Low}	37.19	38.58	1.39	1.19	55.67
	(0.08)	(0.19)	(0.19)	(0.13)	(3.13)
UT_{High}	37.26	38.78	1.52	1.23	57.67
	(0.15)	(0.24)	(0.11)	(0.04)	(1.59)

* - T_{High} significantly different from T_{Low}
† - UT_{High} significantly different from UT_{Low}
‡ - T_{High} significantly different from UT_{High}
+ - T_{Low} significantly different from UT_{Low}

At the onset of the heat-stress exposure, there was an observed lag in the core temperature response, which varied among the groups. The high fat groups took longer for T_{re} to begin to increase compared to the low fat groups. T_{re} began to depict a linear increase after 30 minutes of exercise during UHS for all groups (Figure 5). By calculating the slope of each line between time 30 and 60 minutes, a representation of the rate of increase in T_{re} between the groups can be depicted (Table 7). The rate of increase in T_{re} was significantly greater for T_{High} compared with T_{Low}.

Figure 5: *Rectal temperature response during the heat-stress trial conducted at 40°C and 30% R.H., with subjects wearing nuclear, biological and chemical protective ensemble for trained (T) or untrained (UT) with low or high body fatness (T_{Low}(Δ), T_{High}(O), UT_{Low} (▲), UT_{High}(●)). Values are means (±SE). UT_{Low} > T_{Low} @ 60 mins; T_{High} > T_{Low} from 40 mins.*

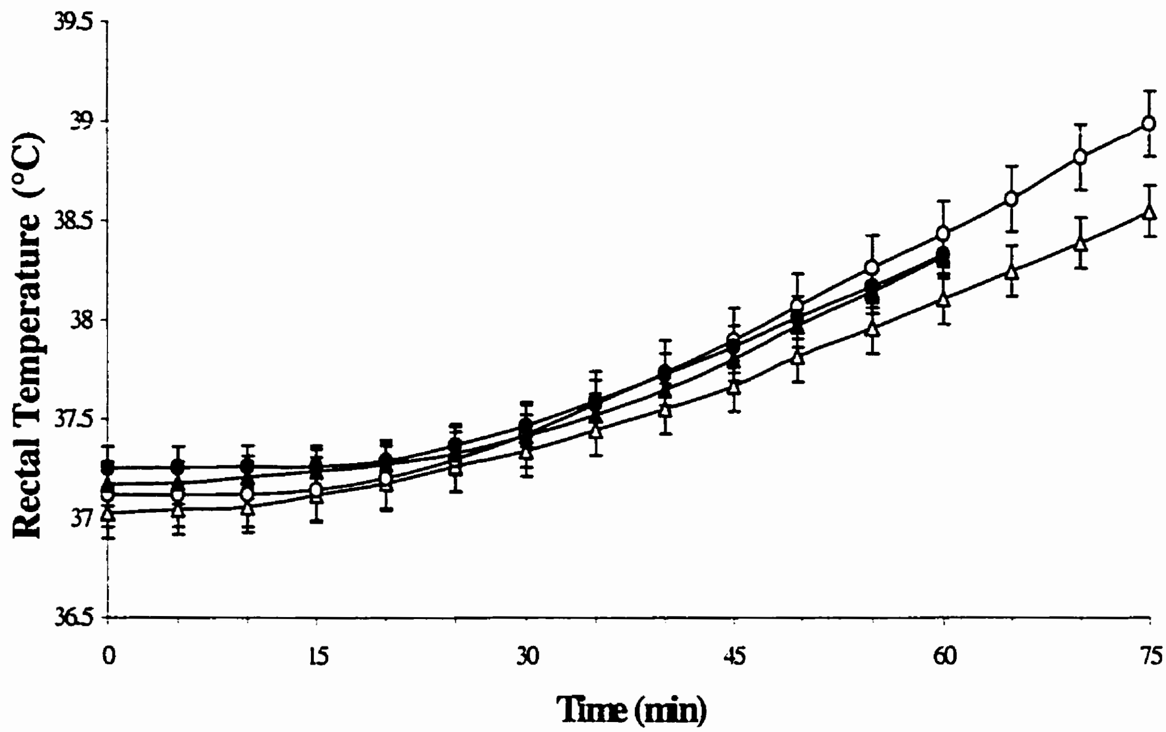


Figure 6: *Delta rectal temperature (T_{re}) response during the heat-stress trial conducted at 40°C and 30% R.H., with subjects wearing nuclear, biological and chemical protective ensemble for trained (T) or untrained (UT) with low or high body fatness (T_{Low}(Δ), T_{High}(O), UT_{Low} (▲), UT_{High}(•)). Values are means (±SE). T_{High} > T_{Low} from 50 mins; T_{High} > UT_{High} from 45 mins.*

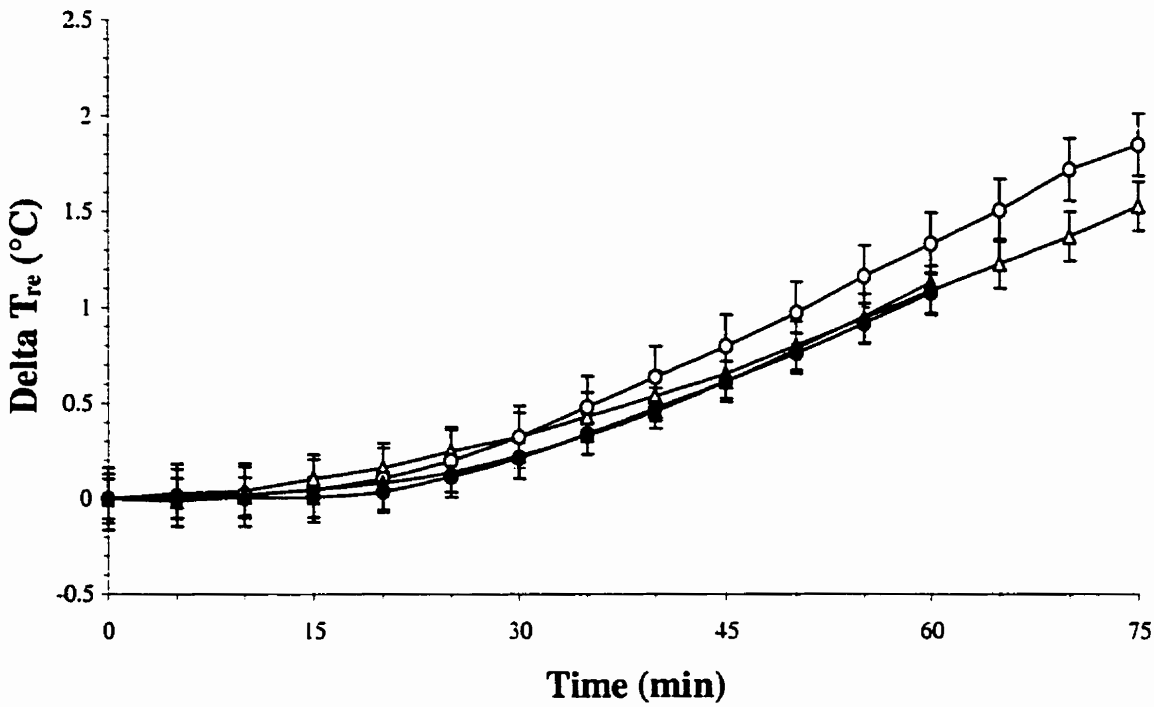


Table 7: *Calculated slope for rate of core temperature increase between 30 and 60 minutes.*

Group	*Rate of ΔTre ($°C \cdot h^{-1}$)*
T_{Low}	1.53 * (0.16)
T_{High}	2.02 (0.10)
UT_{Low}	1.81 (0.16)
UT_{High}	1.73 (0.07)

* - T_{High} significantly different from T_{Low}

5.3.5- Mean Skin Temperature:

The $\overline{T}_{sk}$ response during the heat exposure is presented in Figure 7. $\overline{T}_{sk}$ for T_{High} was significantly greater at 65 minutes compared with T_{Low}. There were no other differences in $\overline{T}_{sk}$ among the groups during the heat stress exposure. Also, there were no significant differences in initial $\overline{T}_{sk}$ or final $\overline{T}_{sk}$ among the groups (Table 10).

Table 8: *Initial and final $\overline{T}_{sk}$ responses during the heat-stress trial conducted at 40°C and 30% R.H., with subjects wearing the nuclear, biological and chemical protective ensemble for trained (T) or untrained (UT) with low or high body fatness. Values are means (±SE).*

Group	*Initial T_{sk} (°C)*	*Final T_{sk} (°C)*
T_{Low}	32.88 (0.26)	38.00 (0.23)
T_{High}	33.45 (0.23)	38.01 (0.08)
UT_{Low}	33.25 (0.19)	37.68 (0.26)
UT_{High}	33.06 (0.19)	37.78 (0.22)

5.3.6- RPE and Thermal Comfort:

RPE and Thermal Comfort (RTC) are illustrated in Figure 8 and 9, respectively. RPE was lower for T_{Low} compared with UT_{Low} at 30 minutes and beyond during the exercise. Similarly, RPE for T_{High} was significantly lower than UT_{High} after 45 minutes of the heat-stress exposure. RPE was also significantly reduced for T_{Low} compared with

Figure 7: *Mean skin temperature response during the heat-stress trial conducted at 40°C and 30% R.H., with subjects wearing the nuclear, biological and chemical protective ensemble for trained (T) or untrained (UT) with low or high body fatness (T_{Low}(Δ), T_{High}(o), UT_{Low}(▲), UT_{High}(●)). Values are means (±SE). T_{High} > T_{Low} from 65 mins.*

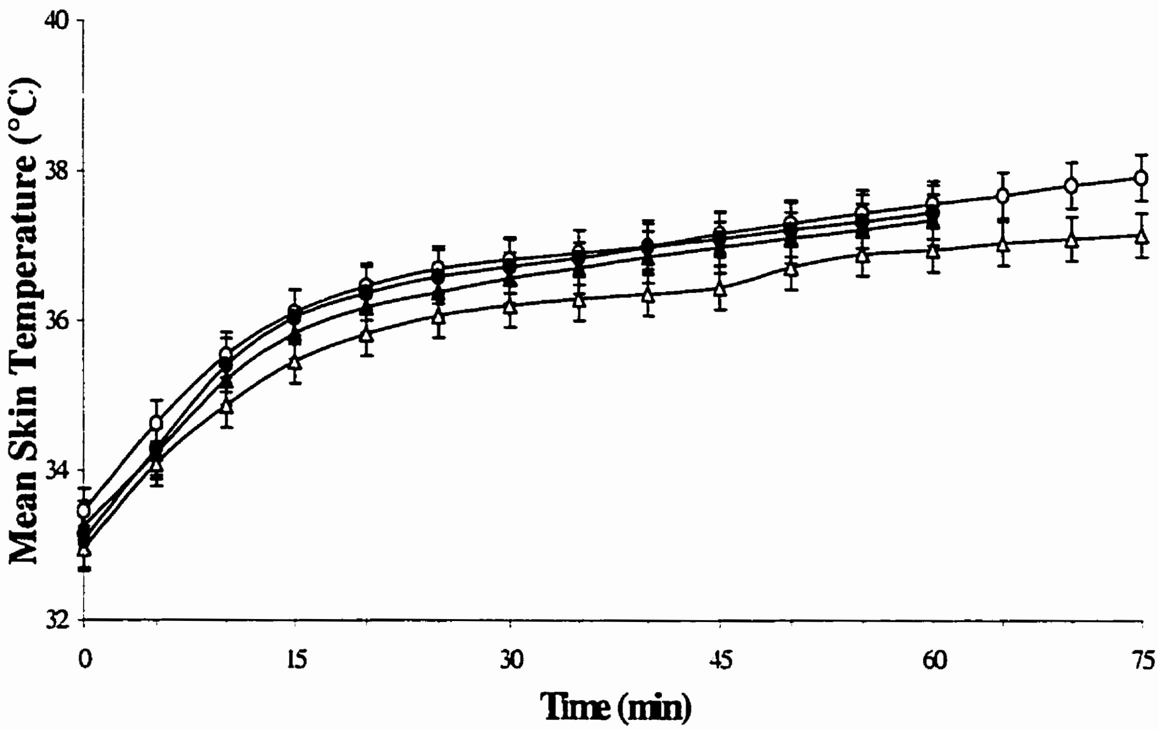


Figure 8: *Rating of Perceived Exertion (RPE) during the heat-stress trial conducted at 40°C and 30% R.H., with subjects wearing the nuclear, biological and chemical protective ensemble for trained (T) and untrained (UT) with low or high body fatness (T_{Low}(Δ), T_{High}(o), UT_{Low} (▲), UT_{High}(●)). Values are means (±SE). T_{High} > T_{Low} at 75 mins; UT_{Low} > T_{Low} from 30 mins; UT_{High} > T_{High} from 45 mins.*

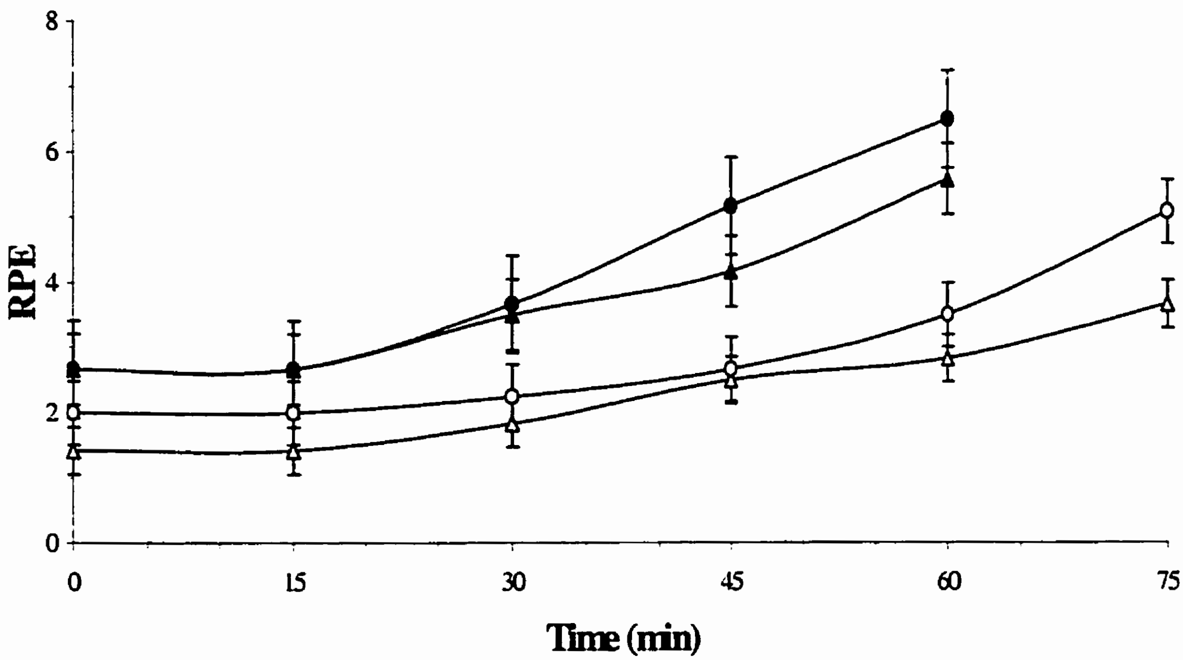
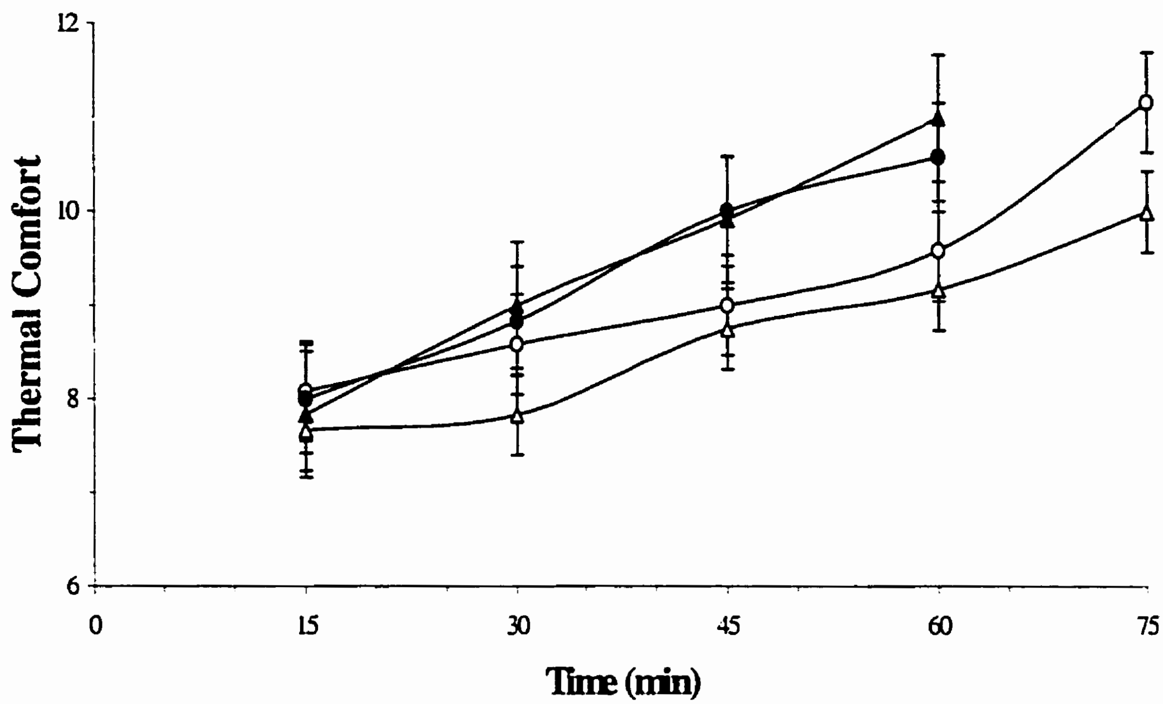


Figure 9: *Thermal Comfort between groups during the heat-stress trial conducted at 40°C and 30% R.H., with subjects wearing the nuclear, biological and chemical ensemble for trained (T) or untrained (UT) with low or high body fatness (T_{Low}(Δ), T_{High}(o), UT_{Low} (▲), UT_{High}(•)). Values are means (±SE). UT_{Low} > T_{Low} from 30 mins; T_{High} > T_{Low} at 75mins.*



T_{High} after 75 minutes of heat-stress exposure. T_{Low} displayed lower ratings of RTC than UT_{Low} after 30 minutes of exercise. There were no other significant differences among matched groups.

5.3.7- Tolerance Time:

There was an interaction of both fitness and fatness on TT ($p<0.001$). T_{Low} had a significantly greater TT compared to T_{High} and UT_{Low}, whereas no difference in TT was observed between the groups matched for a high body fatness or low aerobic fitness (Table 11). Reasons for termination of the heat-stress trial are described in Table 12. None of the trials approached the 4h time limit.

Table 9: *Tolerance time (TT) and its range of values during the heat-stress trial conducted at 40°C and 30% R.H., with subjects wearing the nuclear, biological and chemical protective ensemble for trained (T) and untrained (UT) groups with high or low body fatness. Values for tolerance time are means (±SE), with range in square parentheses.*

Group	*TT (min)*	*[Range]*
T_{Low}	116.2 + (6.5)	[100-147]
T_{High}	82.2 * (3.9)	[74-101]
UT_{Low}	69.5 (3.6)	[62-86]
UT_{High}	73.7 (4.1)	[60-85]

* - T_{High} significantly different from T_{Low}
\+ - T_{Low} significantly different from UT_{Low}

Table 10: *Reasons for test termination are presented as number of subjects for rectal temperature (T_{re}) (39.5°C); Exhaustion; Discomfort; HR, heart rate (≥95% HR_{peak} for 3 min); and Nausea, for trained (T) and untrained (UT) groups with high or low body fatness.*

Reason for Termination	T_{Low}	T_{High}	UT_{Low}	UT_{High}
T_{re}	6	1	0	2
Exhaustion	-	3	2	3
Discomfort	-	-	2	1
HR	-	-	2	-
Nausea	-	2	-	-

5.3.8- Heat Storage:

A summary of the partitional calorimetry used in the heat balance equation to calculate heat storage is depicted in Table 11. Rate of external work ($\dot{W}$) and conductive heat exchange ($\dot{K}$) were considered to be zero since subjects were walking on a level treadmill. There were no differences in metabolic rate, evaporation at the skin, radiative and convective heat gain, or respiratory heat loss. The rate of heat storage, in $W \cdot kg^{-1}$, was significantly greater in UT_{Low} and T_{High} compared to UT_{High} (Table 11). As well,

Table 11: *Metabolic heat production ($\dot{M}$), skin evaporation rate ($\dot{E}_{sk}$), radiative and convective heat loss ($\dot{R} + \dot{C}$), respiratory heat loss and convective heat gain ($\dot{E}_{resp} + \dot{C}_{resp}$), rate of heat storage ($\dot{S}$) and heat capacity (S) during heat-stress trial conducted at 40°C and 30% R.H., with subjects wearing nuclear, biological and chemical protective ensemble for trained (T) or untrained (UT) with low or high body fatness. Rate of external work ($\dot{W}$) and conductive heat gain ($\dot{K}$) were considered zero since subjects were walking on a level treadmill. Values are means (±SE).*

Group	$\dot{M}$ ($W \cdot m^{-2}$)	$\dot{E}_{sk}$ ($W \cdot m^{-2}$)	$\dot{R} + \dot{C}$ ($W \cdot m^{-2}$)	$\dot{E}_{resp} + \dot{C}_{resp}$ ($W \cdot m^{-2}$)	$\dot{S}$ ($W \cdot m^{-2}$)	$\dot{S}$ ($W \cdot kg^{-1}$)	S ($KJ \cdot kg^{-1}$)
T_{Low}	165.30	50.29	12.08	13.40	116.45	3.27	22.20 +
	(3.91)	(4.58)	(1.35)	(0.32)	(8.01)	(0.18)	(1.17)
T_{High}	181.20	50.92	11.18	14.61	129.80	3.41	16.96 *, ‡
	(6.02)	(5.76)	(0.21)	(0.51)	(10.50)	(0.16)	(0.75)
UT_{Low}	175.20	51.09	12.39	14.25	125.24	3.52 †	14.46
	(8.03)	(6.56)	(0.72)	(0.65)	(6.99)	(0.19)	(0.71)
UT_{High}	173.30	59.76	12.02	13.98	114.41	2.87	12.70
	(6.61)	(3.22)	(0.56)	(0.51)	(8.44)	(0.19)	(1.27)

* - T_{High} significantly different from T_{Low}
† - UT_{High} significantly different from UT_{Low}
‡ - T_{High} significantly different from UT_{High}
\+ - T_{Low} significantly different from UT_{Low}

there was an interaction of fitness and fatness on the heat storage capacity expressed per unit of total mass. Heat storage for T_{Low} was greater than both its matched fitness (T_{High}) and fatness (UT_{Low}) counterpart, and T_{High} was greater than UT_{High}. However, there was no difference in S between the UT groups.

Chapter 6

Discussion

This study quantified and documented the separate and combined influence of aerobic fitness and body fatness on the heat strain and physical work tolerance times associated with light exercise during UHS. It has been shown that increases in environmental temperature and/or humidity lead to decreases in tolerance time (McLellan et al., 1996). Therefore, environmental conditions of 40°C and 30% relative humidity were chosen to correspond to previous work by Cheung and McLellan (1998abc) that evaluated heat strain and tolerance during UHS. Furthermore, exercise tolerance during UHS has been shown to follow a hyperbolic function in relation to exercise intensity (McLellan, 1993; McLellan et al., 1996). Therefore, light intensity exercise of 0.97 $m \cdot s^{-1}$ (3.5 $km \cdot h^{-1}$) at 0% incline was utilized similar to Cheung and McLellan (1998abc), in an attempt to allow factors other than intensity to affect the variance among the observed physiological responses. The light exercise employed was sufficient to produce a heat strain index of approximately 2.5 ($HSI = E_{req} \cdot E_{max}^{-1}$) (Cheung and McLellan, 1998a). Therefore, several possible confounding factors must be reviewed before any conclusions can be drawn on the influence of aerobic fitness and body fatness on heat strain and tolerance time to UHS.

6.1- Subjects:

Twenty-four subjects were chosen from a subject pool of 49 volunteers and matched for both body composition and aerobic fitness. It was hypothesized that a high aerobic fitness as well as a low body fatness would enhance tolerance during UHS. Each group (T_{High}, T_{Low}, UT_{High}, and UT_{Low}) consisted of 6 subjects (4 male, 2 female) correspondingly matched to specified fitness and fatness levels. The difficulty of finding T_{High} and UT_{Low} subjects precluded a greater sample size.

6.2 - Confounding Factors

6.2.1 - Fitness definition:

Aerobic fitness was defined relative to lean rather than total body mass in order to remove the influence of body fatness on the expression of fitness. High fat subjects had a significantly higher body mass compared to the low fat groups. Thus, the expression of $\dot{V}O_{2peak}$ relative to total mass was significantly reduced for these high fat groups compared with their matched counterparts. For example, T_{High} had a matched $\dot{V}O_{2peak}$ of 65 $mL \cdot kgLBM^{-1} \cdot min^{-1}$ which corresponded to 53 $mL \cdot kg^{-1} \cdot min^{-1}$ based on total body mass. However, the corresponding $\dot{V}O_{2peak}$ of 65 $mL \cdot kgLBM^{-1} \cdot min^{-1}$ for T_{Low} corresponded to a $\dot{V}O_{2peak}$ of 58 $mL \cdot kg^{-1} \cdot min^{-1}$ based on total body mass. Therefore, by defining aerobic power in terms of LBM, a confounding influence of body fatness was eliminated. The inclusion of activity level as an additional grouping criterion was used due to the observation that $\dot{V}O_{2peak}$ alone, correlates only moderately with heat tolerance and the presence of training-induced adaptations to heat exposure (Avellini et al., 1982; Kielblock, 1987). Hence, classifying a sedentary subject with a naturally high $\dot{V}O_{2peak}$ as trained was undesirable.

6.2.2 - Hydration:

Hypohydration is associated with increased HR, T_{re} and RPE during exercise (Candas et al., 1988; Sawka, 1988). Furthermore, in the NBC condition, hypohydration leads to a decreased tolerance time regardless of fitness and an increase in both the rate of increase of T_{re} and resting T_{re} (Cheung and McLellan, 1998a). In the present heat trials, all of the subjects pre-exercise osmolality values corresponded to normal hydration levels prior to the heat stress exposure, removing an influence of hypohydration among the trials.

It has been previously suggested that increased sweat rates without increases in sweat evaporation can lead to an increase in the rate of dehydration and thermal strain (Nunneley, 1989; Cheung and McLellan, 1998a). Furthermore, dehydration of 2.2% or greater has been found to have deleterious effects on heat tolerance during UHS (Cheung and McLellan, 1998b). These findings accentuated the importance of a regular fluid replacement schedule on tolerance time. Fluid replacement decreased physiological strain during exercise in the heat (Candas et al., 1986), and has also been shown to produce a decreased cardiovascular strain while exercising in NBC protective clothing (Cheung and McLellan, 1998b). In the present study, T_{High} had a significantly greater loss in body mass compared to UT_{High}. This was probably due to the hydration protocol. If subjects reached 39°C or were within 10 minutes of exhaustion, the rehydration protocol was terminated. The trained subjects had a greater time period with a T_{re} over 39°C, sometimes 30-35 minutes longer than the untrained. This extended time created a situation that, when combined with the increased sweat rates, produced a greater loss in body mass. However, the percentage of body mass lost due to dehydration did not exceed 0.8% for any group, thus minimizing the deleterious effects of dehydration. Nonetheless, differences in TT between T and UT groups may have been even greater had all subjects remained euhydrated throughout the heat stress.

6.2.3 - Circadian Effects:

Core temperature values can vary substantially from early morning to mid afternoon, with differences ranging up to 0.5°C (Krauchi, K. and Wirz-Justice, 1994). In order to control for the circadian effect on resting core temperature values, all subjects were tested in the early morning (8:00am). As well, taking into consideration the observed increase in $T_{re,\ final}$ throughout the day (McLellan et al., 1999), testing in the early morning maximized the potential to demonstrate differences in ΔT_{re} between the groups. If testing had been done later in the day, resting core temperatures would have been higher which would have resulted in a reduction in ΔT_{re} obtained for T_{Low} before reaching the ethical core temperature cut-off of 39.5°C. Thus differences in TT between T_{Low} and UT_{Low} may have been less than those observed in the present study.

6.2.4 - Menstrual Phase:

Elevations in $T_{re,\ initial}$ in female subjects have been found during the mid-luteal phase compared to the early follicular phase (Tenaglia et al., 1999; Kolka and Stephenson 1989). To remove the confounding variable of menstrual phase, all women were tested in the early follicular phase of their menstrual cycle. Menstrual phase was verified by radioimmunoassays of both estradiol and progesterone levels to confirm correct phase. One female subject in T_{High} was an oral contraceptive user. However, Tenaglia et al. (1999) found that tolerance times did not differ between non-users and users of oral contraceptives during the early follicular or quasi-early follicular phase of the menstrual cycle. It has been found that females are at a thermoregulatory disadvantage compared with males when wearing protective clothing and exercising in the heat (McLellan, 1998). This disadvantage was due to the lower specific heat of adipose tissue and a higher percentage body fatness in females. However, when the men and women were matched for both body composition and aerobic fitness, heat storage, tolerance times, average metabolic rates, sweat rates and HR responses were all similar (McLellan, 1998). It was these latter findings, which supplied the justification for inclusion of both men and women in the groups.

6.2.5 - Heat Acclimation:

Heat acclimation has been shown to increase tolerance time while exercising at low metabolic rates of 300 W during UHS (Aoyagi et al., 1995). In order to reduce any confounding effects of heat acclimation, testing was conducted during the months between January and June when climate temperatures are at a moderate level. Also, the familiarisation and experimental trials were conducted one week apart to reduce the acute effect of an UHS exposure. Furthermore, recent literature has illustrated that although heat acclimation is beneficial during UHS, when combined with fluid replacement, there is no added benefit of acclimation (Cheung and McLellan, 1998a). Therefore, the spacing of the two trials, combined with the fluid replacement protocol, likely controlled any possible effects of heat acclimation.

6.2.6 - Clothing Fit:

Air trapped between clothing layers acts as a barrier against convective and evaporative heat transfer between the environment and skin (Havenith, 1999). Since air is an excellent insulator, clothing fit is an important factor when examining human heat response to UHS. At present, there is a debate over loose versus tight fitting clothing. Looser clothing would theoretically have greater air pockets and thus a greater insulation (Havenith et al., 1990b). However, the greater air pockets would also create a bellowing effect during motion, increasing the effective air velocity within the ensemble (Havenith et al., 1990b; Givoni and Goldman, 1972). The microclimate that was created due to the high thermal insulation and low water vapour permeability of the clothing ensemble affected heat exchange at the skin surface (Holmer, 1995). Therefore, if the subject had a looser fitting ensemble with greater air pockets, there was a potential for that subject to have evaporated more sweat before the microclimate became saturated. Although this may have been a potential factor in the present study, further research is necessary to clarify the effects of air pockets on convective and evaporative heat transfer.

6.2.7 - Accuracy of Body Fatness Measurements:

In the present study, body fatness was determined using helium dilution for residual lung volumes combined with hydrostatic weighing to determine body density. The error in this method has been shown to follow a curvilinear relationship, increasing at either end (Jackson and Pollock, 1985). Brodie (1988) reported a 3.8% error when determining body density through hydrostatic weighing, and an additional 2.6% error when estimating percentage fat from body density measurements in a restricted population. This tabulated to a combined error of 6.4%. Furthermore it had been suggested that athletes, such as in the trained groups of the present study, have a higher bone and muscle density that might lead to an overestimation of body fatness (Macdougal, 1983). Skinfold measurements were used for 2 subjects to estimate body fatness. It has been found that there is a 3% to 9% error using skinfold measurements to estimate body composition (Lohnman, 1981; Jackson and Pollock, 1977). To increase internal validity, all body fatness measurements were taken by the same experimenter. It could be postulated that if error did exist in the fatness measurement, each subject would still have a value relative to one another. Consequently, if the actual body fatness percentage was erroneous, the separation between the groups would remain intact. As well, the hydrostatic weighing method was repeated numerous times in order to increase subject familiarity before a consistent measurement was obtained.

6.2.8 - Ethical vs. Non-ethical criteria:

Due to the extreme condition created by wearing the NBC protective clothing there are specific physiological end-point criteria employed to ensure subject safety. It has been suggested that ethical limits are not valid indicators of true tolerance time. However, when comparing similar uncompensable environments, final rectal temperatures of 39.6°C have been observed (Latzka et al., 1998). Therefore, in the present study subjects reaching the ethical T_{re} cut-off of 39.5°C could have continued for another 0.1°C. This 0.1°C translates to approximately 4.6 minutes given the rate of increase in T_{re} of 1.3°C·h^{-1} in T_{Low}. As a result the ethical cut-off probably had minimal effects on the observed tolerance time in the present study.

6.3 - Grouping comparisons:

When examining the differences between the matched groups it is important to remember those factors which influence tolerance time during UHS, as was shown in equation 1 :

$$\text{Tolerance Time (TT)} = (T_{re,Final} - T_{re,Initial}) \cdot C_{p,b} \cdot \text{mass} \cdot (\dot{S} \cdot 60 \cdot A_D)^{-1}$$

6.3.1- Fitness Comparisons

6.3.1.1 - T_{Low} vs UT_{Low}

T_{Low} and UT_{Low} had similar rates of heat storage, and rates of T_{re} increase.

Therefore, the difference in TT (116 vs. 69) could possibly be attributed to the significantly greater tolerance to elevated T_{re} as reflected by the significantly higher $T_{re,final}$ for T_{Low}. Although not significant, T_{Low} also had a decrease in $T_{re, initial}$. This increased the absolute change in T_{re}. Combined differences between $T_{re,final}$ and $T_{re, initial}$ produced a 1.07°C difference in ΔT_{re} between the groups. This difference accounts for 36 minutes or 76% of the difference in TT between the groups using a rate of increase in T_{re} of 1.8°C·h^{-1} (see Table 7). The remaining difference in TT between the groups could potentially be attributed to the small difference in the rate of heat storage, which reflected differences in the metabolic costs of exercise. After 15 minutes, UT_{Low} had a significantly greater oxygen cost of exercise and metabolic heat production. Although the rates of heat storage were not significantly different, T_{re} was significantly different after 60 minutes of exercise.

Perfusion of skin capillaries and active skeletal muscle during exercise compromise central blood volume and subsequently reduce venous return (Roberts et al., 1977). This phenomenon, referred to as cardiovascular strain, may be responsible for the lower T_{re} tolerated by the untrained groups. An increased cardiovascular strain in UT_{Low} can be seen in the HR and % VO_{2peak} responses (Figure 3 and 4). The lower tolerance to the heat stress was further supported by the thermal comfort and RPE ratings. UT_{Low} showed a significantly higher rating of thermal comfort (ie., greater discomfort)) and RPE after 30 minutes of exercise compared to T_{Low}. These findings, coupled with the reasons for termination, suggested that UT_{Low} experienced a greater subjective strain, and that termination was due to voluntary exhaustion, as opposed to ethical T_{re} constraints as was seen in T_{Low}.

6.3.1.2 - T_{High} vs UT_{High}

A similar effect of fitness might be expected in the high fat groups as was seen in the low fat groups. However, it appeared that the increase in body fatness masked the effect of fitness on tolerance time. T_{High} had a significantly greater $T_{re,\ final}$ of 0.43°C. This difference in $T_{re,\ final}$ theoretically accounted for 14 minutes or 175% of the observed difference between the groups using a rate of T_{re} increase of 1.7°C·h^{-1} (Table 7). A portion of this theoretical advantage, however, was negated by the lower $\dot{S}$ for UT_{High} attributed to their lower metabolic cost of walking (see Table 11). Differences in TT between these two groups approached significance. A critical difference of 12.5 minutes or an increase in sample size to 10 was required to achieve statistical significance. Thus, despite the increased metabolic cost of walking compared to UT_{High}, T_{High} was still able to approach a significantly longer tolerance time, potentially further illustrating the benefits of a high training level.

6.3.2 - Fatness Comparisons

6.3.2.1 - T_{High} vs. T_{Low}

T_{High} and T_{Low} had similar rates of heat storage, but displayed a significant difference in tolerance time, rate of T_{re} increase and heat storage capacity. These findings are illustrative of the role of body fatness when rates of heat storage are similar. With a lower body fatness, there is a greater capacity to store heat due to the difference in the heat capacity of fat versus lean tissue (Gephart and DuBois, 1915).

T_{Low} tolerated a significantly greater change of 0.35°C in T_{re} compared to T_{High}. This additional change in T_{re} could account for 10 minutes or 30% of the difference in TT between groups. This calculation was done using a rate of increase in T_{re} of 2.0°C·hr^{-1} for

T_{High} (Table 7). Therefore, 70% of the differences in TT between groups potentially reflected the impact of adipose tissue on the change in tissue temperature for a given rate of heat storage.

T_{High} displayed a higher HR throughout the heat trial when expressed as a percentage of HR_{peak}. Since $\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$) was reduced for T_{High} compared to T_{Low}, T_{High} was working at a greater percent $\dot{V}O_{2peak}$ while walking at 0.97 $m \cdot s^{-1}$, thus helping to potentially explain the observed differences in HR response.

Cheung and McLellan (1999) suggested that the true tolerance time for their high fit group (HF) was underestimated due to the ethical constraint on T_{re}. All of their HF subjects terminated the trial once T_{re} reached 39.3°C. There was a similar phenomenon present in the current study. All six of the T_{Low} subjects reached the T_{re} limit, despite the fact that this limit was raised to 39.5°C for this study. Thus, differences in TT between T_{High} and T_{Low} may have been underestimated in the present study.

6.3.2.2 - UT_{Low} vs UT_{High}

In the untrained subjects, the lean individual would be expected to have a greater heat storage capacity. However, UT_{Low} had a lower $T_{re,\ final}$ and an increased heat production, which offset any advantage of body composition. Thus, tolerance times were similar between low fit groups. Potentially, UT_{Low} could have a naturally higher rate of heat production, which might explain why these individuals fall in the low fat, untrained category. However, whether differences in metabolic rate that may be evident at rest are also evident during exercise requires further investigation. Body composition still played an important role between these two untrained groups. Although UT_{Low} had a significantly greater rate of heat storage, the increase in T_{re} was similar. These findings support the potential advantage provided by a lower fatness level.

6.4 - Implications of Fitness:

The major impact of fitness on heat tolerance during UHS was the $T_{re,\ final}$ tolerated at exhaustion. When endurance-trained subjects were compared to their sedentary counterparts the observed difference in $T_{re,\ final}$ was as great as (or greater than) 0.9°C. This finding is similar to the 0.7°C difference in $T_{re,\ final}$ observed by Cheung and McLellan (1998a). It appears that habitual aerobic activity allows an individual to tolerate higher levels of T_{re} and discomfort at exhaustion (Cheung and McLellan, 1999). When comparing the present responses in T_{Low} and UT_{High} with those of the corresponding high and moderate fitness groups of Cheung and McLellan (1999), the moderate and UT_{High} groups had similar T_{re} changes, 1.62°C and 1.52°C, respectively. Slight variations in ΔT_{re} accounted for 21% of the difference in tolerance time between the groups. The moderate fitness subjects had a 2% body fat advantage and an increased sweat rate. These findings illustrate the importance of not over-emphasizing the dependent measure of tolerance time. While it may be the most practical measure, its reliability and reproducibility have been questioned in the uncompensable environment (Montain et al., 1994). It appears that this was more the case in untrained subjects, where the end-point criteria are much more subjective compared to trained individuals. The T_{re} tolerated at exhaustion has been found to occur at similar high values of 40°C despite different rates of heat storage or initial T_{re} in highly trained cyclists (Gonzalez-Alonso et al., 1999). In the present study, exhaustion occurred due to any number of factors (Table 10). However, in the trained groups, the predominant reason for termination was reaching the ethical limit for core temperature (7 out of 12 trained). Contrary to the findings in the trained individuals, 10 of 12 untrained subjects reached exhaustion for reasons other than the ethical T_{re} criteria. There have been findings indicating that some untrained subjects fatigued during light exercise in uncompensable environments with body temperatures of approximately 38°C (Gonalez-Alonso et al., 1999; Latzka et al., 1998; Montain et al., 1994). This might suggest that the high T_{re} may be the main factor leading to fatigue in trained subjects, and in some, but not all untrained subjects. Cheung and McLellan, (1999) found that subjects with a moderate fitness level (54 mL·kgLBM^{-1}·min^{-1}) reached exhaustion at a $T_{re, final}$ of 38.7°C. These findings are comparable to the untrained groups of the present study with $T_{re, final}$ of 38.8°C and 38.6°C for UT_{High} and UT_{Low}, respectively.

An increased aerobic fitness had been shown to elicit a reduction in $T_{re,initial}$ among subjects (Armstrong and Pandolf, 1988). In an UHS situation, a lower starting T_{re} and higher T_{re} at exhaustion were observed when comparing subjects with high and low fitness levels, resulting in extended tolerance times (Cheung and McLellan, 1998b). Similarly, $T_{re, initial}$ was inversely related to TT when the rate of heat storage and $T_{re, final}$ were held constant (Gonzlez-Alonso et al., 1999). In the present study, trained subjects did show a trend towards a lower $T_{re, initial}$; however, the values were not significantly different from their untrained counterparts. This lack of significance in $T_{re, initial}$ might be attributed to the experimental protocol. $T_{re, initial}$ represented the recorded value at the onset of exercise in the environmental chamber, and did not correspond to T_{re} prior to the dressing and weighing procedures.

It has been suggested that the observed heat adaptations with training are due to both the exercise stimulus itself and the exercise induced hyperthermia (Convertino et al., 1980). Work by Avellini et al. (1982) comparing land versus warm and cold-water training, suggests that regular sessions of exercise which produce an elevation in $T_{re,}$ produce an improved thermoregulatory response to subsequent heat-stress. Similar conclusions are drawn by Henane et al. (1977) which proposed that both local and body core heating are necessary to elicit an increase in local sweat rates. Also, heat acclimation while wearing the NBC protective ensemble has been found to produce a greater thermoregulatory response when compared to dry-heat alone (Cheung and McLellan, 1999; McLellan et al., 1996). In light of these findings, it is possible that short-term training protocols may not have produced the levels of core temperature necessary to produce physiological adaptations (Cheung and McLellan, 1999).

However, wearing the NBC protective ensemble during training could potentially have multiple advantages. First, regular training sessions wearing the NBC clothing could acclimate the subject to the hot-wet environment of the ensemble. Secondly, the increased heat strain during exercise while wearing the NBC protective ensemble could further elevate core and skin temperatures. Finally, through daily and/or weekly exposures to the NBC protective ensemble, untrained subjects may become accustomed to the psychological strain and discomfort of wearing encapsulating clothing. It is noteworthy that runners display an increased thermoregulatory tolerance to heat-stress when compared to trained swimmers with comparable $\dot{V}O_{2peak}$ (Henane et al., 1977). The mechanism behind the observed response was attributed to the training medium. During training, the increase in core temperature was smaller for swimmers than for runners. These findings indicate that a repeated hyperthermic response during training may be necessary before the advantage of an increased $\dot{V}O_{2peak}$ is realized during heat stress exposure.

6.5 - Implications of Fatness:

As shown in Table 12 (below), for a given rate of heat storage, a 10% decrease in body fatness (T_{High} vs T_{Low}) slowed the rate of increase in T_{re} by approximately 0.3°C·h^{-1}. This slower rate of increase in T_{re} could be attributed to the advantage of the increased heat capacity of lean tissue. However, despite similar levels of body fatness, individual differences in $\dot{S}$ can also alter the rate of increase in T_{re}. This effect also appears to be 0.3°C·h^{-1} when T_{High} and UT_{High} are compared. Thus, the effects of body fatness may be offset by individual differences in the rate of heat storage, thus leading to similar rates of change in T_{re}, as was observed for UT_{High} and UT_{Low}.

Table 12: *Groupings differences seen in Heat storage ($\dot{S}$) expressed in W·kg^{-1} and Rate of change in T_{re} (ΔT_{re}) over the entire exposure between the groups.*

Group	$\dot{S}$ *(W·kg^{-1})*	ΔT_{re} *(°C·hr^{-1})*
T_{Low}	3.3	1.27
T_{High}	3.4	1.55
UT_{Low}	3.5	1.19
UT_{High}	2.9	1.23

Theoretically, the effects of body fatness and $\dot{S}$ on the rate of increase in T_{re} could be additive leading to an increase tolerance time for the leaner individual by slowing the rate of increase in T_{re} (by a combined 0.6°C·h^{-1}).

The present study compared groups with 10% body fatness and 20% body fatness which produced a 0.3°C·h^{-1} difference in the rate of increase in T_{re}. Greater differences in body fatness would be expected to have a greater effect on the rate of increase in T_{re}

for a given $\dot{S}$.

6.6 - Interaction Between Fitness, Fatness and the Rate of Heat Storage:

The present study has shown that fitness, fatness and the rate of heat storage may confound the interpretation of the response to UHS. Therefore, it is important to note the relative importance of these factors. The factors act independently of one another, while at the same time their effects can be either additive or antagonistic. Efficiency of movement indicated as oxygen cost of walking determined either a high or low $\dot{S}$. Similarly, high fitness produced an elevated T_{re} at exhaustion increasing heat storage capacity. Analyses of the rates of heat storage amongst the groups showed that UT_{High} had a significantly lower metabolic rate compared to UT_{Low}. Consequently, UT_{High} was given a positive weighting for $\dot{S}$, and the other three observed groups were given a negative weighting for $\dot{S}$. The same was done for fitness and fatness using a positive value for trained and low fatness and a negative value for untrained and high fatness. T_{Low}, for example, was considered to have a positive weighting for body composition and training status, but a negative weighting for the rate of heat storage (see Table 13). An asterisk represents the actual observed tolerance times for the 4 groups in the present study (Table 13). Tolerance times for the other 4 theoretical groups were determined by increasing or decreasing the rate of ΔT_{re} by 0.3°C·h^{-1}, depending on whether fatness and/or $\dot{S}$ were positive or negative in relation to the corresponding observed group. Thus, TT for T_{Low} was 116 min with a rate of increase in T_{re} of 1.27°C·h^{-1} and a ΔT_{re} of 2.46°C from beginning to end of the HST. If T_{Low} had a positive weighting for $\dot{S}$, the rate of T_{re} increase would be slowed to 0.97°C·h^{-1} and TT would increase to 152 min for the same 2.46°C increase in T_{re}. Different variations in fitness, fatness and rates of heat storage can produce up to a 100 minute difference in tolerance time. For example, an untrained subject with advantages in both body fatness and $\dot{S}$, could potentially have a greater tolerance to the UHS compared to a trained subject that is disadvantaged by having an increased body fatness and high rate of heat storage (Table 13).

Table 13: *Theoretical Tolerance with different manipulations of trained (+), untrained (-); High fat (-), Low fat (+); and high (-) and low (+)* $\dot{S}$

Training	*Fatness*	$\dot{S}$	*Tolerance Time (min)*
+	+	+	152 (T_{Low})
+	+	-	116 (T_{Low})*
+	-	+	101 (T_{High})
+	-	-	82 (T_{High})*
-	+	+	95 (UT_{Low})
-	-	+	73 (UT_{High})*
-	+	-	71 (UT_{Low})*
-	-	-	58 (UT_{High})

* represents observed group response.

Chapter 7

Limitations

Factors which have limited interpretation of the results of this study follow:

1. During an operational scenario there are further extenuating stressors present, such as an increased psychological stress, malnutrition and sleep deprivation. Subsequently these added stressors have the potential to affect performance outcomes.
2. Temperatures reported for $T_{re,initial}$ and $\overline{T}_{sk}$ represent values following dressing procedures after being connected to the data acquisition system within the chamber. These values of $T_{re,initial}$ and $\overline{T}_{sk}$ may not be representative of a thermoneutral environment under controlled resting conditions.
3. In order to have the desired separation between groups for fitness and fatness levels, subject suitability was severely hindered. The small sample size in each group lowered the power of the experimental design, and therefore may have influenced the interpretation of the findings.
4. The present experiment included the use of treadmill exercise, a weight-bearing activity. Heat storage was expressed, therefore, per unit of mass. For non weight-bearing activities, such as cycling or rowing, total mass, in addition to body composition, will impact on heat storage capacity. Thus, allowing an individual with a greater overall mass to have a greater absolute heat storage capacity.
5. Data interpretation is restricted to the differences in fitness (approximately 65 vs 53 $mL \cdot kgLBM^{-1} \cdot min^{-1}$) and fatness (10% versus 20%) that were used to establish the groupings.

Chapter 8

Conclusions

1. For light exercise in the heat while wearing NBC protective clothing, tolerance times varied approximately 2-fold between aerobically fit and sedentary lean individuals. Tolerance time showed less variation for subjects with higher body fatness regardless of fitness.
2. The main benefit of an increased aerobic fitness is the ability to tolerate a higher core temperature at exhaustion. Temperatures at exhaustion may be 0.9°C or higher for trained compared with untrained subjects.
3. Trained individuals are more capable of tolerating a higher level of subjective discomfort of physiological strain due to habitual physical activity.
4. For a given rate of heat storage, a 10% change in body fatness alters the rate of increase in T_{re} by $0.3°C \cdot h^{-1}$ for the exercise and heat-stress used in this study.
5. For a given body fatness, differences in the rate of heat storage due to differences in oxygen cost of walking may equally alter the rate of change in T_{re} by $0.3°C \cdot h^{-1}$. These effects are independent of the effects of body fatness.
6. Approximately 50% of the individual variations in tolerance time can be attributed to differences in fitness, 25% to differences in fatness, and 25% to differences in the rate of heat storage.

Chapter 9

Recommendations for Future Study

Directions for further study should include the following:

1. To further investigate the rate of heat storage and its interaction with fitness and fatness.
2. To investigate the role of loose- versus tight-fitting clothing on tolerance to UHS.
3. To investigate the separate effects of training history and maximal aerobic power on tolerance to UHS.

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Appendix A
Raw Data

Single Measures

2 females (subject 1,2), 4 males (3-6) in each group.

	Age	Height (cm)	Weight (kg)	% Fatness	Lean Mass (Kg)	A_D (m^2)	A_D:Mass ($m^2 \cdot kg^{-1} \cdot (10^2)^{-1}$)
UT_{High}							
1	21	171.00	61.50	20.57	48.85	1.72	2.79
2	21	172.00	65.50	23.29	50.25	1.77	2.70
3	22	180.00	78.50	19.49	63.20	1.98	2.52
4	23	168.00	70.00	24.25	52.79	1.79	2.56
5	19	192.00	105.80	17.53	87.30	2.35	2.22
6	21	167.00	90.70	21.89	70.85	1.99	2.19
Average	21.17	175.00	78.67	21.17	62.21	1.93	2.50
UT_{Low}							
1	22	155.00	51.00	13.85	43.94	1.48	2.89
2	24	170.00	62.10	14.14	53.32	1.72	2.76
3	21	159.00	60.50	13.81	52.14	1.62	2.67
4	21	181.00	59.50	9.50	53.85	1.73	2.89
5	25	179.70	75.60	13.83	65.15	1.94	2.57
6	20	185.00	63.50	9.19	57.66	1.84	2.90
Average	22.17	171.62	62.03	12.39	54.34	1.72	2.78
T_{High}							
1	22	155.00	52.70	15.48	44.54	1.50	2.84
2	26	163.00	56.50	22.25	44.13	1.60	2.83
3	23	175.00	76.70	20.62	60.89	1.92	2.50
4	23	183.00	89.10	19.62	71.65	2.11	2.37
5	20	186.00	91.00	17.76	74.97	2.15	2.37
6	21	182.40	76.50	16.85	63.67	1.97	2.58
Average	22.50	174.07	73.75	18.76	59.98	1.88	2.58
T_{Low}							
1	37	162.00	56.80	12.04	49.96	1.60	2.81
2	24	151.00	42.00	12.76	36.64	1.33	3.18
3	23	179.00	70.50	8.18	64.73	1.88	2.67
4	25	167.00	63.90	9.53	57.81	1.72	2.68
5	22	171.00	64.00	12.64	55.91	1.75	2.73
6	20	181.00	70.50	10.20	63.31	1.90	2.69
Average	25.17	168.50	61.28	10.89	54.73	1.69	2.79

Single measures raw data con'd. 2 females (subject 1,2), 4 males (subject 3-6) in each group.

	HR_{Peak} ($b \cdot min^{-1}$)	$\dot{V}O_{2peak}$ ($L \cdot min^{-1}$)	$\dot{V}O_{2peak}$ ($mL \cdot KgLBM^{-1} \cdot min^{-1}$)	Osmolality ($mOsmol \cdot kgH2O^{-1}$)
UT_{High}				
1	196	2.47	50.56	285.5
2	204	2.60	51.74	286
3	187	3.52	55.70	276
4	208	2.84	53.79	289.5
5	204	4.45	50.97	286.5
6	194	4.11	58.01	286
Average	198.83	3.33	52.30	284.92
UT_{Low}				
1	198	2.20	50.53	286
2	190	2.40	45.01	285.5
3	203	4.61	55.43	289
4	196	3.20	59.43	288.5
5	194	3.48	53.42	289
6	195	3.20	56.02	287
Average	196.00	3.18	53.30	287.50
T_{High}				
1	190	2.53	56.80	289.5
2	190	2.69	60.95	287
3	185	4.22	69.31	285
4	194	5.25	73.27	283.5
5	200	4.80	64.02	286.5
6	206	4.04	63.45	282.5
Average	194.17	3.92	64.63	285.67
T_{Low}				
1	180	2.83	56.65	284
2	212	2.24	61.13	291
3	197	4.50	69.52	288
4	197	3.80	65.73	286.5
5	188	3.70	66.17	283.5
6	197	4.38	69.18	287
Average	195.17	3.58	64.73	286.67

Single measures raw con'd. 2 females (subject 1,2), 4 males (3-6) in each group.

	$T_{re,\,initial}$ (°C)	$T_{re,\,final}$ (°C)	ΔT_{re} (°C)	Rate of Change of T_{re} (°C·h^{-1})	Time (min) for 1°C increase in T_{re}	Rate of ΔT_{re} (30-60min) (°C·h^{-1})
UT_{High}						
1	36.88	38.46	1.58	1.19	60	1.54
2	36.85	38.02	1.17	1.17	55	2
3	37.43	38.81	1.38	1.27	53	1.6
4	37.58	39.47	1.89	1.38	55	1.66
5	37.71	39.49	1.78	1.26	63	1.78
6	37.09	38.42	1.33	1.14	60	1.78
Average	37.26	38.78	1.52	1.23	57.67	1.73
UT_{Low}						
1	37.42	39.26	1.84	1.70	44	2.36
2	37.21	38.16	0.95	0.92	60	1.66
3	37.24	38.17	0.93	0.89	60	1.88
4	37.34	38.47	1.13	0.97	65	1.4
5	37.08	39.09	2.01	1.40	55	1.42
6	36.87	38.35	1.48	1.25	50	2.14
Average	37.19	38.58	1.39	1.19	55.67	1.81
T_{High}						
1	36.75	39.21	2.46	1.81	43	1.92
2	37.15	39.50	2.35	1.39	60	1.44
3	36.92	38.94	2.02	1.64	50	2.5
4	37.39	39.00	1.61	1.22	62	1.76
5	37.21	39.32	2.11	1.64	49	2.32
6	37.20	39.35	2.15	1.57	49	2.18
Average	37.10	39.22	2.12	1.55	52.17	2.02
T_{Low}						
1	37.14	39.46	2.32	1.23	57	1.44
2	37.13	39.50	2.37	0.97	55	1.94
3	36.62	39.47	2.85	1.71	45	1.7
4	37.14	39.49	2.35	1.24	65	1.36
5	36.97	39.50	2.53	1.33	63	1.52
6	37.12	39.48	2.36	1.24	60	1.24
Average	37.02	39.48	2.46	1.27	57.50	1.53

Single measures raw con'd. 2 females (subject 1,2), 4 males (3-6) in each group.

	Tolerance Time	HR Final ($b \cdot min^{-1}$)	HR Final, %peak	SR ($kg \cdot h^{-1}$)	SR ($kg \cdot m^{-2} \cdot h^{-1}$)
UT_{High}					
1	80.00	176	89.80	0.78	0.45
2	60.00	159	77.94	0.62	0.42
3	65.00	121	65.41	0.87	0.45
4	82.00	181	87.02	0.97	0.52
5	85.00	176	86.28	0.89	0.55
6	70.00	161	82.99	0.89	0.52
Average	73.67	162.33	81.57	0.84	0.49
UT_{Low}					
1	65.00	181	91.88	0.60	0.34
2	62.00	179	93.72	0.54	0.31
3	63.00	166	87.83	0.60	0.34
4	70.00	150	76.53	0.73	0.37
5	86.00	182	94.30	0.67	0.28
6	71.00	175	89.74	0.94	0.47
Average	69.50	172.17	89.00	0.68	0.35
T_{High}					
1	80.00	166	87.37	1.05	0.53
2	101.00	187	94.21	1.12	0.52
3	74.00	157	85.33	0.75	0.50
4	79.00	146	75.26	1.09	0.68
5	77.00	177	88.50	1.40	0.67
6	82.00	185	89.81	1.15	0.60
Average	82.17	169.67	86.74	1.10	0.58
T_{Low}					
1	113.00	155	86.59	0.89	0.56
2	147.00	191	89.67	1.05	0.56
3	100.00	143	72.59	0.88	0.46
4	114.00	164	83.25	0.78	0.45
5	114.00	158	84.95	0.87	0.50
6	109.00	165	83.76	0.86	0.64
Average	116.17	162.67	83.47	0.89	0.53

Single measures raw con'd. 2 females (subject 1,2), 4 males (3-6) in each group.

	Total Fluid Intake (kg)	Total Mass Loss (kg)	Body Mass Loss (%)	Rate of Mass Loss ($kg \cdot h^{-1}$)
UT_{High}				
1	0.98	-0.26	-0.43	-0.20
2	0.77	0.00	0.00	0.00
3	0.68	0.11	0.14	0.10
4	0.98	0.36	0.54	0.26
5	0.98	-0.03	-0.03	-0.02
6	0.88	0.22	0.24	0.19
Average	0.88	0.07	0.08	0.06
UT_{Low}				
1	0.78	-0.10	-0.20	-0.09
2	0.48	0.32	0.51	0.31
3	0.78	0.15	0.27	0.14
4	0.59	0.45	0.75	0.39
5	0.99	0.26	0.34	0.18
6	0.76	0.38	0.61	0.32
Average	0.73	0.24	0.38	0.21
T_{High}				
1	0.97	0.03	0.06	0.02
2	1.21	0.63	1.12	0.49
3	0.98	0.45	0.58	0.36
4	0.99	0.86	0.98	0.66
5	0.98	0.46	0.51	0.36
6	1.01	0.42	0.54	0.31
Average	1.02	0.48	0.63	0.37
T_{Low}				
1	1.17	0.52	0.94	0.27
2	1.79	0.31	0.74	0.13
3	1.25	0.50	0.72	0.30
4	1.12	0.52	0.82	0.28
5	1.31	0.18	0.28	0.09
6	1.10	0.50	0.73	0.27
Average	1.29	0.42	0.70	0.22

Single measures raw con'd. 2 females (subject 1,2), 4 males (3-6) in each group.

	$\dot{M}$ ($W \cdot m^{-2}$)	$\dot{E}_{sk}$ ($W \cdot m^{-2}$)	$\dot{R} + \dot{C}$ ($W \cdot m^{-2}$)	$\dot{E}_{resp} + \dot{C}_{re}$ ($W \cdot m^{-2}$)	$\dot{S}$ ($W \cdot m^{-2}$)	$\dot{S}$ ($W \cdot kg^{-1}$)	S ($Kj \cdot kg^{-1}$)
UT_{High}							
1	160.43	23.64	12.92	13.28	140.45	2.81	14.40
2	203.48	62.88	9.84	14.99	138.03	2.48	15.58
3	190.92	59.09	13.13	12.17	129.32	3.23	17.17
4	171.79	66.60	12.18	13.46	107.38	3.35	13.53
5	149.54	52.85	13.14	14.42	100.33	3.17	12.15
6	175.24	41.50	10.92	15.54	135.91	2.20	13.91
Average	175.23	51.09	12.02	13.98	125.24	2.87	14.46
UT_{Low}							
1	149.67	61.64	10.56	16.54	91.51	4.10	9.02
2	165.58	66.43	14.00	13.04	100.65	3.90	13.53
3	163.42	68.07	13.46	14.25	97.73	3.69	9.20
4	184.43	56.94	9.80	15.52	125.45	2.92	15.78
5	191.11	46.16	13.27	13.97	143.55	3.35	16.18
6	185.74	59.32	13.29	12.16	127.58	3.14	12.52
Average	173.32	59.76	12.39	14.25	114.41	3.52	12.70
T_{High}							
1	172.30	50.65	11.64	15.02	121.66	3.25	13.79
2	188.25	48.38	11.12	14.01	139.06	3.11	17.65
3	178.64	73.79	10.81	13.01	103.73	3.59	17.46
4	160.06	58.36	10.40	13.79	102.18	2.95	18.54
5	203.35	33.07	11.76	16.53	168.92	4.01	18.47
6	184.78	41.26	11.34	15.30	143.24	3.54	15.84
Average	181.23	50.92	11.18	14.61	129.80	3.41	16.96
T_{Low}							
1	169.09	37.52	9.65	11.97	133.10	3.84	25.82
2	175.86	52.11	18.50	13.30	122.42	2.70	22.84
3	166.12	36.68	11.45	13.48	137.23	2.95	22.63
4	165.83	51.99	10.46	13.63	114.60	3.10	20.96
5	167.70	59.20	10.00	14.30	108.14	3.34	17.30
6	147.24	64.21	12.43	13.75	83.19	3.70	23.63
Average	165.31	50.28	12.08	13.40	116.45	3.27	22.20

Repeated Measures

Oxygen Consumption ($L \cdot min^{-1}$) raw data. 2 females (subject 1,2), 4 males (subject 3-6) in each group overtime.

Time (min)		0	15	30	45	60	75
UT_{High}							
	1	0	0.732	0.791	0.82	0.865	
	2	0	0.785	0.785	0.734	0.81	
	3	0	1.275	1.293	1.283	1.2705	
	4	0	0.909	0.932	0.935	1.008	
	5	0	1.037	1.0525	1.0211	1.119	
	6	0	0.9595	0.9695	0.932	0.96	
Average		0	0.99	1.01	0.98	1.03	
UT_{Low}							
	1	0	0.718	0.744	0.737	0.777	
	2	0	0.761	0.818	0.837	0.84	
	3	0	0.8825	0.8825	0.899	0.909	
	4	0	0.8545	0.874	0.872	0.871	
	5	0	0.724	0.883	0.826	0.896	
	6	0	0.975	0.974	1.075	1.128	
Average		0	0.82	0.86	0.87	0.90	
T_{High}							
	1	0	0.83	0.83	0.83	0.863	0.882
	2	0	0.7365	0.781	0.744	0.851	0.815
	3	0	0.9795	1.047	1.0575	1.0955	1.0775
	4	0	1.022	1.079	1.11	1.112	1.113
	5	0	1.196	1.226	1.3	1.343	1.379
	6	0	0.993	1.049	1.0341	1.055	1.036
Average		0	0.96	1.00	1.01	1.05	1.05
T_{Low}							
	1	0	0.798	0.8225	0.8225	0.866	0.733
	2	0	0.569	0.647	0.649	0.575	0.539
	3	0	0.908	0.811	0.871	0.8605	0.8485
	4	0	0.824	0.848	0.839	0.783	0.85
	5	0	0.9425	0.8385	0.864	0.8385	0.8515
	6	0	0.775	0.824	0.87	0.885	0.924
Average		0	0.80	0.80	0.82	0.80	0.79

Oxygen Consumption (mL·kg^{-1}·min^{-1}) raw data. 2 females (subject 1,2), 4 males (3-6) in each group overtime.

Time (min)	0	15	30	45	60	75
UT_{High}						
1	0.00	10.61	10.61	9.92	10.95	
2	0.00	10.63	11.49	11.91	12.56	13.25
3	0.00	11.84	12.02	11.66	12.78	
4	0.00	10.97	11.12	11.14	10.93	11.79
5	0.00	12.13	12.43	12.47	13.45	13.30
6	0.00	9.79	9.89	9.85	9.79	
Average	0.00	10.99	11.26	11.16	11.74	
UT_{Low}						
1	0.00	14.96	15.30	15.26	15.25	
2	0.00	10.78	11.58	11.85	11.89	
3	0.00	10.89	13.29	12.43	13.48	
4	0.00	12.47	12.47	12.70	12.84	
5	0.00	10.56	10.94	10.84	11.43	
6	0.00	11.59	11.58	12.78	13.41	14.51
Average	0.00	11.87	12.53	12.64	13.05	
T_{High}						
1	0.00	13.90	13.90	13.90	14.45	14.77
2	0.00	11.74	12.44	11.85	13.56	12.99
3	0.00	10.20	10.90	11.01	11.41	11.22
4	0.00	11.86	12.52	12.88	12.90	12.91
5	0.00	12.04	12.34	13.09	13.52	13.88
6	0.00	11.57	12.22	12.05	12.29	12.07
Average	0.00	11.88	12.39	12.46	13.02	12.97
T_{Low}						
1	0.00	12.07	13.73	13.77	12.20	11.44
2	0.00	12.63	13.02	13.02	13.71	11.60
3	0.00	11.73	10.48	11.26	11.12	10.96
4	0.00	11.38	11.71	11.59	10.81	11.74
5	0.00	12.30	10.95	11.28	10.95	11.12
6	0.00	10.74	11.42	12.05	12.26	12.80
Average	0.00	11.81	11.88	12.16	11.84	11.61

Heart Rate (b·min^{-1}) raw data. 2 females (subject 1,2), 4 males (3-6) in each group overtime.

Time (min)		0	5	10	15	20	25	30	35
UT_{High}									
	1	90	99	103	118	113	116	125	119
	2	90	135	132	152	144	147	151	148
	3	110	113	114	122	125	135	138	140
	4	80	88	92	94	102	103	104	105
	5	90	102	110	97	103	110	115	118
	6	82	102	100	98	108	114	114	115
Average		90.33	106.50	108.50	113.50	115.83	120.83	124.50	124.17
UT_{Low}									
	1	106	113	125	123	131	140	152	155
	2	108	136	138	139	140	147	151	155
	3	83	103	101	108	115	118	121	130
	4	95	102	104	106	107	110	115	120
	5	77	99	104	115	121	127	125	133
	6	75	85	87	93	95	100	120	125
Average		90.67	106.33	109.83	114.00	118.17	123.67	130.67	136.33
T_{High}									
	1	85	112	108	111	128	122	130	142
	2	105	110	116	119	125	129	140	141
	3	86	78	88	98	98	110	110	114
	4	93	109	114	118	120	126	136	142
	5	90	109	113	120	127	137	142	147
	6	80	92	92	92	99	105	113	115
Average		89.83	101.67	105.17	109.67	116.17	121.50	128.50	133.50
T_{Low}									
	1	89	104	113	130	121	125	123	122
	2	81	93	91	95	94	97	103	107
	3	71	92	96	100	103	110	111	114
	4	78	89	90	95	101	105	107	108
	5	75	93	91	97	101	105	109	111
	6	73	87	89	96	98	100	107	111
Average		77.83	93.00	95.00	102.17	103.00	107.00	110.00	112.17

Heart Rate (b·min^{-1}) raw data con'd. 2 females (subject 1,2), 4 males (subject 3-6) in each group overtime.

Time (min)		40	45	50	55	60	65	70	75
UT_{High}									
	1	135	143	148	151	154	151	160	161
	2	159	162	162	159	160			
	3	151	152	152	156	169	175	177	179
	4	105	114	110	117	121			
	5	119	148	153	157	164	165	166	172
	6	125	135	140	148	150	157	161	
Average		132.33	142.33	144.17	148.00	153.00			
UT_{Low}									
	1	162	165	171	176	179			
	2	161	172	174	175	180	181		
	3	138	143	150	158	166			
	4	121	131	141	145	158	165	175	
	5	141	141	149	154	157	160	167	168
	6	130	138	142	145	146	149	150	
Average		142.17	148.33	154.50	158.83	164.33			
T_{High}									
	1	147	152	156	160	169	171	172	171
	2	147	152	154	153	152	153	156	166
	3	116	123	130	140	141	144	145	146
	4	141	146	157	157	171	171	173	179
	5	155	161	164	164	171	177	178	177
	6	122	125	132	136	149	147	157	
Average		138.00	143.17	148.83	151.67	158.83	160.50	163.50	
T_{Low}									
	1	130	121	135	140	148	158	160	154
	2	114	118	119	121	128	133	136	138
	3	118	127	126	130	133	136	134	141
	4	110	115	116	124	133	132	130	144
	5	119	121	122	134	137	146	148	150
	6	117	121	123	142	137	138	140	145
Average		118.00	120.50	123.50	131.83	136.00	140.50	141.33	145.33

Heart Rate (% max) raw data. 2 females (subject 1,2), 4 males (3-6) in each group overtime.

Time (min)		0	5	10	15	20	25	30	35
UT_{High}									
	1	45.92	50.51	52.55	60.20	57.65	59.18	63.78	60.71
	2	44.12	66.18	64.71	74.51	70.59	72.06	74.02	72.55
	3	52.88	54.33	54.81	58.65	60.10	64.90	66.35	67.31
	4	43.24	47.57	49.73	50.81	55.14	55.68	56.22	56.76
	5	44.12	50.00	53.92	47.55	50.49	53.92	56.37	57.84
	6	42.27	52.58	51.55	50.52	55.67	58.76	58.76	59.28
Average		45.42	53.53	54.54	57.04	58.27	60.75	62.58	62.41
UT_{Low}									
	1	55.50	59.16	65.45	64.40	68.59	73.30	79.58	81.15
	2	54.82	69.04	70.05	70.56	71.07	74.62	76.65	78.68
	3	43.92	54.50	53.44	57.14	60.85	62.43	64.02	68.78
	4	48.72	52.31	53.33	54.36	54.87	56.41	58.97	61.54
	5	39.90	51.30	53.89	59.59	62.69	65.80	64.77	68.91
	6	38.27	43.37	44.39	47.45	48.47	51.02	61.22	63.78
Average		46.85	54.94	56.76	58.92	61.09	63.93	67.54	70.47
T_{High}									
	1	44.74	58.95	56.84	58.42	67.37	64.21	68.42	74.74
	2	55.26	57.89	61.05	62.63	65.79	67.89	73.68	74.21
	3	44.33	40.21	45.36	50.52	50.52	56.70	56.70	58.76
	4	45.15	52.91	55.34	57.28	58.25	61.17	66.02	68.93
	5	45.00	54.50	56.50	60.00	63.50	68.50	71.00	73.50
	6	43.48	50.00	50.00	50.00	53.80	57.07	61.41	62.50
Average		46.33	52.41	54.18	56.47	59.87	62.59	66.21	68.77
T_{Low}									
	1	41.78	48.83	53.05	61.03	56.81	58.69	57.75	57.28
	2	45.25	51.96	50.84	53.07	52.51	54.19	57.54	59.78
	3	36.04	46.70	48.73	50.76	52.28	55.84	56.35	57.87
	4	41.94	47.85	48.39	51.08	54.30	56.45	57.53	58.06
	5	38.07	47.21	46.19	49.24	51.27	53.30	55.33	56.35
	6	37.06	44.16	45.18	48.73	49.75	50.76	54.31	56.35
Average		40.02	47.78	48.73	52.32	52.82	54.87	56.47	57.61

Heart Rate (% max) raw data con'd. 2 females (subject 1,2), 4 males (subject 3-6) in each group overtime.

Time (min)		40	45	50	55	60	65	70	75
UT_{High}									
	1	68.88	72.96	75.51	77.04	78.57	77.04	81.63	82.14
	2	77.94	79.41	79.41	77.94	78.43			
	3	72.60	73.08	73.08	75.00	81.25	84.13	85.10	86.06
	4	56.76	61.62	59.46	63.24	65.41			
	5	58.33	72.55	75.00	76.96	80.39	80.88	81.37	84.31
	6	64.43	69.59	72.16	76.29	77.32	80.93	82.99	
Average		66.49	71.53	72.44	74.41	76.89			
UT_{Low}									
	1	84.82	86.39	89.53	92.15	93.72			
	2	81.73	87.31	88.32	88.83	91.37	91.88		
	3	73.02	75.66	79.37	83.60	87.83			
	4	62.05	67.18	72.31	74.36	81.03	84.62	89.74	
	5	73.06	73.06	77.20	79.79	81.35	82.90	86.53	87.05
	6	66.33	70.41	72.45	73.98	74.49	76.02	76.53	
Average		73.50	76.67	79.86	82.12	84.96			
T_{High}									
	1	77.37	80.00	82.11	84.21	88.95	90.00	90.53	90.00
	2	77.37	80.00	81.05	80.53	80.00	80.53	82.11	87.37
	3	59.79	63.40	67.01	72.16	72.68	74.23	74.74	75.26
	4	68.45	70.87	76.21	76.21	83.01	83.01	83.98	86.89
	5	77.50	80.50	82.00	82.00	85.50	88.50	89.00	88.50
	6	66.30	67.93	71.74	73.91	80.98	79.89	85.33	
Average		71.13	73.79	76.69	78.17	81.85	82.69	84.28	
T_{Low}									
	1	61.03	56.81	63.38	65.73	69.48	74.18	75.12	72.30
	2	63.69	65.92	66.48	67.60	71.51	74.30	75.98	77.09
	3	59.90	64.47	63.96	65.99	67.51	69.04	68.02	71.57
	4	59.14	61.83	62.37	66.67	71.51	70.97	69.89	77.42
	5	60.41	61.42	61.93	68.02	69.54	74.11	75.13	76.14
	6	59.39	61.42	62.44	72.08	69.54	70.05	71.07	73.60
Average		60.59	61.98	63.43	67.68	69.85	72.11	72.53	74.69

T_{re} (°C) raw data. 2 females (subject 1,2), 4 males (3-6) in each group overtime.

Time (min)		0	5	10	15	20	25	30	35
UT_{High}									
	1	36.88	36.85	36.86	36.9	36.95	37.02	37.12	37.22
	2	36.85	36.86	36.85	36.75	36.75	36.91	37.02	37.18
	3	37.09	37.1	37.1	37.12	37.17	37.23	37.33	37.45
	4	37.43	37.5	37.57	37.62	37.65	37.72	37.78	37.88
	5	37.58	37.56	37.55	37.58	37.64	37.73	37.85	37.98
	6	37.71	37.68	37.64	37.61	37.59	37.61	37.71	37.85
Average		37.26	37.26	37.26	37.26	37.29	37.37	37.47	37.59
UT_{Low}									
	1	37.42	37.42	37.46	37.52	37.6	37.73	37.88	38.05
	2	37.21	37.15	37.14	37.1	37.13	37.16	37.23	37.33
	3	36.95	36.96	37.02	37.12	37.19	37.28	37.39	37.53
	4	37.34	37.36	37.36	37.38	37.39	37.41	37.46	37.53
	5	37.23	37.25	37.27	37.28	37.27	37.29	37.34	37.4
	6	36.89	36.94	37	37.05	37.07	37.11	37.2	37.3
Average		37.17	37.18	37.21	37.24	37.28	37.33	37.42	37.52
T_{High}									
	1	37.15	37.11	37.13	37.18	37.23	37.28	37.36	37.47
	2	36.86	36.83	36.82	36.83	36.92	37.07	37.24	37.43
	3	37.2	37.23	37.24	37.3	37.39	37.5	37.64	37.79
	4	36.92	36.92	36.9	36.9	36.93	37.02	37.16	37.38
	5	37.21	37.23	37.25	37.26	37.33	37.45	37.59	37.78
	6	37.39	37.41	37.4	37.4	37.43	37.48	37.56	37.63
Average		37.12	37.12	37.12	37.15	37.21	37.30	37.43	37.58
T_{Low}									
	1	37.13	37.19	37.24	37.36	37.46	37.56	37.67	37.76
	2	37.14	37.17	37.23	37.33	37.39	37.46	37.5	37.63
	3	36.62	36.64	36.71	36.8	36.9	37.03	37.18	37.32
	4	37.17	37.19	37.14	37.12	37.13	37.2	37.27	37.4
	5	37.14	37.14	37.11	37.17	37.2	37.25	37.31	37.38
	6	36.97	36.95	36.93	36.95	37	37.09	37.12	37.19
Average		37.03	37.05	37.06	37.12	37.18	37.27	37.34	37.45

T_{re} (°C) raw data con'd. 2 females (subject 1,2), 4 males (subject 3-6) in each group overtime.

Time (min)	40	45	50	55	60	65	70	75
UT_{High}								
1	37.35	37.47	37.61	37.75	37.89	38.03	38.18	38.33
2	37.34	37.5	37.67	37.84	38.02			
3	37.58	37.71	37.84	37.98	38.13	38.28	38.42	
4	38	38.14	38.28	38.45	38.61	38.81		
5	38.12	38.27	38.43	38.58	38.74	38.9	39.07	39.23
6	37.98	38.12	38.27	38.43	38.6	38.78	38.95	39.13
Average	37.73	37.87	38.02	38.17	38.33			
UT_{Low}								
1	38.24	38.45	38.66	38.87	39.06	39.26		
2	37.45	37.6	37.74	37.9	38.06			
3	37.67	37.82	37.97	38.13	38.33	38.5	38.64	38.79
4	37.64	37.76	37.88	38.01	38.16	38.31	38.47	
5	37.49	37.6	37.74	37.88	38.05			
6	37.41	37.6	37.86	38.08	38.27	38.41	38.33	
Average	37.65	37.81	37.98	38.15	38.32			
T_{High}								
1	37.6	37.74	37.89	38.07	38.24	38.41	38.58	38.75
2	37.66	37.88	38.09	38.3	38.49	38.67	38.84	39.03
3	37.93	38.08	38.26	38.43	38.6	38.77	38.96	39.13
4	37.56	37.73	37.9	38.11	38.32	38.5	38.7	
5	37.94	38.12	38.3	38.49	38.68	38.87	39.06	39.25
6	37.73	37.85	38	38.19	38.28	38.45	38.8	38.8
Average	37.74	37.90	38.07	38.27	38.44	38.61	38.82	
T_{Low}								
1	37.87	37.96	38.07	38.17	38.29	38.39	38.51	38.58
2	37.67	37.75	37.92	38.05	38.22	38.33	38.44	38.7
3	37.48	37.64	37.83	38	38.15	38.33	38.49	38.66
4	37.53	37.67	37.81	37.97	38.12	38.25	38.42	38.6
5	37.49	37.59	37.73	37.86	37.99	38.14	38.28	38.41
6	37.29	37.41	37.56	37.72	37.88	38.05	38.21	38.36
Average	37.56	37.67	37.82	37.96	38.11	38.25	38.39	38.55

ΔT_{re} (°C) raw data. 2 females (subject 1,2), 4 males (3-6) in each group overtime.

Time (min)	0	5	10	15	20	25	30	35
UT_{High}								
1	0	-0.03	-0.02	0.02	0.07	0.14	0.24	0.34
2	0	0.01	0	-0.1	-0.1	0.06	0.17	0.33
3	0	-0.02	-0.03	0	0.06	0.15	0.27	0.4
4	0	0.07	0.14	0.19	0.22	0.29	0.35	0.45
5	0	-0.03	-0.07	-0.1	-0.12	-0.1	0	0.14
6	0	0.01	0.01	0.03	0.08	0.14	0.24	0.36
Average	0.00	0.00	0.00	0.01	0.04	0.11	0.21	0.34
UT_{Low}								
1	0	-0.06	-0.07	-0.11	-0.08	-0.05	0.02	0.12
2	0	0	0.04	0.1	0.18	0.31	0.46	0.63
3	0	0.01	0.03	0.04	0.03	0.05	0.1	0.16
4	0	0.07	0.13	0.18	0.2	0.24	0.33	0.43
5	0	-0.12	-0.06	0.04	0.11	0.2	0.31	0.45
6	0	0.02	0.02	0.04	0.05	0.07	0.12	0.19
Average	0.00	-0.01	0.02	0.05	0.08	0.14	0.22	0.33
T_{High}								
1	0	-0.04	-0.02	0.03	0.08	0.13	0.21	0.32
2	0	0.08	0.07	0.08	0.17	0.32	0.49	0.68
3	0	0.02	0.01	0.01	0.04	0.09	0.17	0.24
4	0	0.03	0.04	0.1	0.19	0.3	0.44	0.59
5	0	0.02	0.04	0.05	0.12	0.24	0.38	0.57
6	0	0	-0.02	-0.02	0.01	0.1	0.24	0.46
Average	0.00	0.02	0.02	0.04	0.10	0.20	0.32	0.48
T_{Low}								
1	0	0.06	0.11	0.23	0.33	0.43	0.54	0.63
2	0	0.03	0.09	0.19	0.25	0.32	0.36	0.49
3	0	0.02	0.09	0.18	0.28	0.41	0.56	0.7
4	0	-0.02	-0.04	-0.02	0.03	0.12	0.15	0.22
5	0	0.07	0.02	0	0.01	0.08	0.15	0.28
6	0	0	-0.03	0.03	0.06	0.11	0.17	0.24
Average	0.00	0.03	0.04	0.10	0.16	0.25	0.32	0.43

ΔT_{re} (°C) raw data con'd. 2 females (subject 1,2), 4 males (subject 3-6) in each group overtime.

Time (min)		40	45	50	55	60	65	70	75
UT_{High}									
	1	0.47	0.59	0.73	0.87	1.01	1.15	1.3	1.45
	2	0.49	0.65	0.82	0.99	1.17			
	3	0.54	0.69	0.85	1	1.16	1.32	1.49	1.65
	4	0.57	0.71	0.85	1.02	1.18	1.38		
	5	0.27	0.41	0.56	0.72	0.89	1.07	1.24	1.42
	6	0.49	0.62	0.75	0.89	1.04	1.19	1.33	
Average		0.47	0.61	0.76	0.91	1.08			
UT_{Low}									
	1	0.24	0.39	0.53	0.69	0.85			
	2	0.82	1.03	1.24	1.45	1.64	1.84		
	3	0.25	0.36	0.5	0.64	0.81			
	4	0.54	0.73	0.99	1.21	1.4	1.54	1.46	
	5	0.59	0.74	0.89	1.05	1.25	1.42	1.56	1.71
	6	0.3	0.42	0.54	0.67	0.82	0.97	1.13	
Average		0.46	0.61	0.78	0.95	1.13			
T_{High}									
	1	0.45	0.59	0.74	0.92	1.09	1.26	1.43	1.6
	2	0.91	1.13	1.34	1.55	1.74	1.92	2.09	2.28
	3	0.34	0.46	0.61	0.8	0.89	1.06	1.41	1.41
	4	0.73	0.88	1.06	1.23	1.4	1.57	1.76	1.93
	5	0.73	0.91	1.09	1.28	1.47	1.66	1.85	2.04
	6	0.64	0.81	0.98	1.19	1.4	1.58	1.78	
Average		0.63	0.80	0.97	1.16	1.33	1.51	1.72	
T_{Low}									
	1	0.74	0.83	0.94	1.04	1.16	1.26	1.38	1.45
	2	0.53	0.61	0.78	0.91	1.08	1.19	1.3	1.56
	3	0.86	1.02	1.21	1.38	1.53	1.71	1.87	2.04
	4	0.32	0.44	0.59	0.75	0.91	1.08	1.24	1.39
	5	0.41	0.55	0.69	0.85	1	1.13	1.3	1.48
	6	0.35	0.45	0.59	0.72	0.85	1	1.14	1.27
Average		0.54	0.65	0.80	0.94	1.09	1.23	1.37	1.53

Skin Temperature raw data. 2 females (subject 1,2), 4 males (3-6) in each group overtime.

Time (min)		0	5	10	15	20	25	30	35
UT_{High}									
	1	32.2	33.5	34.78	35.75	36.29	36.63	36.83	37.01
	2	33.02	34.01	35.21	35.81	36.2	36.45	36.63	36.75
	3	33.46	34.83	35.9	36.5	36.9	37.17	37.28	37.42
	4	33.04	33.96	35.08	35.78	36.16	36.44	36.58	36.71
	5	33.43	34.89	35.72	36.17	36.3	36.5	36.66	36.75
	6	33.21	34.55	35.77	36.27	36.37	36.37	36.41	36.44
Average		33.06	34.29	35.41	36.05	36.37	36.59	36.73	36.85
UT_{Low}									
	1	32.68	33.59	34.7	35.57	36	36.16	36.43	36.62
	2	33.92	34.88	35.76	36.33	36.66	36.9	37.2	37.36
	3	33.04	34.05	35.13	35.83	36.19	36.4	36.52	36.63
	4	33.68	34.42	35.16	35.6	35.87	36.1	36.32	36.52
	5	33.22	34.41	35.46	35.96	36.31	36.45	36.53	36.52
	6	32.94	34.02	35.08	35.7	36.05	36.29	36.45	36.59
Average		33.25	34.23	35.22	35.83	36.18	36.38	36.58	36.71
T_{High}									
	1	32.74	33.74	34.66	35.55	36.23	36.61	36.79	36.91
	2	33.95	35	35.73	36.22	36.6	36.82	36.97	37.13
	3	34.18	35.3	36.05	36.44	36.63	36.76	36.74	36.84
	4	33.88	34.7	35.47	36.06	36.41	36.65	36.77	36.85
	5	33.13	34.68	35.74	36.24	36.49	36.65	36.79	36.78
	6	32.84	34.36	35.61	36.15	36.42	36.67	36.84	36.95
Average		33.45	34.63	35.54	36.11	36.46	36.69	36.82	36.91
T_{Low}									
	1	33.55	34.47	35.41	36.16	36.73	36.95	37.07	37.14
	2	32.24	33.13	34.01	34.95	35.71	36.15	36.38	36.48
	3	33.43	34.8	35.68	36.18	36.42	36.57	36.63	36.75
	4	33.23	34.47	35.5	36.19	36.45	36.83	36.98	37.02
	5	32.46	33.58	33.6	33.6	33.55	33.61	33.7	33.79
	6	32.81	34.06	35.03	35.7	36.1	36.32	36.5	36.61
Average		32.95	34.09	34.87	35.46	35.83	36.07	36.21	36.30

Skin Temperature raw data con'd. 2 females (subject 1,2), 4 males (subject 3-6) in each group overtime.

Time (min)		40	45	50	55	60	65	70	75
UT_{High}									
	1	37.12	37.2	37.26	37.33	37.42	37.56	37.58	37.62
	2	36.94	37.11	37.26	37.41	37.54			
	3	37.52	37.61	37.68	37.79	37.98	38.11	38.23	38.4
	4	36.88	36.99	37.12	37.2	37.25	37.3		
	5	36.97	37.05	37.25	37.39	37.56	37.74	37.87	37.99
	6	36.5	36.62	36.77	36.89	37	37.16	37.3	
Average		36.99	37.10	37.22	37.34	37.46			
UT_{Low}									
	1	36.8	36.92	37.07	37.19	37.32			
	2	37.53	37.74	37.92	38.08	38.27	38.45		
	3	36.77	36.96	37.07	37.16	37.33			
	4	36.68	36.82	36.92	36.89	36.92	37.06	37.14	
	5	36.64	36.72	36.89	37.05	37.2	37.38	37.49	37.66
	6	36.73	36.76	36.82	36.97	37.08	37.2	37.31	
Average		36.86	36.99	37.12	37.22	37.35			
T_{High}									
	1	37.07	37.29	37.43	37.51	37.61	37.73	37.79	37.88
	2	37.21	37.43	37.57	37.67	37.79	37.94	38.08	38.18
	3	36.96	37.09	37.28	37.39	37.51	37.58	37.69	37.78
	4	36.92	37.09	37.23	37.42	37.52	37.54	37.68	37.86
	5	36.81	36.93	37.08	37.25	37.4	37.57	37.78	37.93
	6	37.03	37.15	37.26	37.41	37.57	37.74	37.91	
Average		37.00	37.16	37.31	37.44	37.57	37.68	37.82	37.93
T_{Low}									
	1	37.19	37.22	37.28	37.39	37.45	37.47	37.58	37.55
	2	36.58	36.75	36.8	36.8	36.95	37.09	37.19	37.37
	3	36.81	36.89	37.04	37.19	37.34	37.5	37.67	37.8
	4	37.07	37.11	37.12	37.32	37.43	37.48	37.59	37.69
	5	33.8	33.98	35.22	35.74	35.5	35.55	35.3	35.19
	6	36.75	36.76	36.86	36.96	37.05	37.18	37.3	37.35
Average		36.37	36.45	36.72	36.90	36.95	37.05	37.11	37.16

RPE raw data. 2 females (subject 1,2), 4 males (3-6) in each group overtime.

Time (min)		0	15	30	45	60	75
UT_{High}							
	1	2	2	3	3	4	5
	2	3	3	4	8	10	
	3	3	3	3	4	4	4
	4	3	3	5	7	9	
	5	2	2	2	2	3	3.5
	6	3	3	5	7	9	
Average		2.67	2.67	3.67	5.17	6.50	
UT_{Low}							
	1	4	4	5	6	9	
	2	2	2	2	3	3.5	
	3	3	3	4	5	6	
	4	3	3	4	4	5	
	5	3	3	3	4	4	5
	6	1	1	3	3	6	
Average		2.67	2.67	3.50	4.17	5.58	
T_{High}							
	1	1	1	1	1	2	1
	2	2.5	2.5	2.5	2.5	3	3
	3	0	0	0	0.5	2	4
	4	3	3	3	3	4	7
	5	2	2	3	4	5	7
	6	3.5	3.5	4	5	5	8.5
Average		2.00	2.00	2.25	2.67	3.50	5.08
T_{Low}							
	1	1	1	1	2	2	3
	2	0	0	0	0.5	0.5	2
	3	0.5	0.5	0.5	1	2	3
	4	2	2	2.5	3	3	3.5
	5	3	3	4	4.5	4.5	5.5
	6	2	2	3	4	5	5
Average		1.42	1.42	1.83	2.50	2.83	3.67

Thermal Comfort raw data. 2 females (subject 1,2), 4 males (subject 3-6) in each group overtime.

Time (min)		0	15	30	45	60	75
UT_{High}							
	1	0	8	8	9	10	12
	2	0	8	9	12	12	
	3	0	8	8	9	9	9.5
	4	0	9	10	11	12	
	5	0	7	8	8	8.5	8.5
	6	0	8	10	11	12	
Average		0	8.00	8.83	10.00	10.58	
UT_{Low}							
	1	0	9	11	12	12	
	2	0	7	8	8.5	9.5	
	3	0	7	8	10	12	
	4	0	8	9	9	11	
	5	0	8	9	10	10	11
	6	0	8	9	10	11.5	
Average		0	7.83	9.00	9.92	11.00	
T_{High}							
	1	0	8	9	9	10	11
	2	0	9	9	9	9.5	9.5
	3	0	8.5	8.5	9	9	12
	4	0	8	8	8	9	11
	5	0	7	8	8.5	9	11
	6	0	8	9	10.5	11	12.5
Average		0	8.08	8.58	9.00	9.58	11.17
T_{Low}							
	1	0	7	7	8	8	9
	2	0	7	7	8	8	10
	3	0	8	8	9	10	10
	4	0	7	7	7	8	9
	5	0	8	9	9.5	10	10
	6	0	9	9	11	11	12
Average		0	7.67	7.83	8.75	9.17	10.00

Appendix B
Sample Calculations

Sample calculation of the rate of core temperature increase between 30 and 60 minutes. (Table 7)

For UT_{High},

T_{re} at 30 minutes = 37.47°C
T_{re} at 60 minutes = 38.33°C

Therefore, ΔT_{re} between 30 and 60 minutes = 38.33°C - 37.47 °C = 0.86°C

And the rate of increase in T_{re} = ΔT_{re} / time
= 0.86°C / ½ h
= 1.73°C·h^{-1}

Sample calculation of theoretical tolerance times with different manipulations of trained, untrained; high and low fat and high and low $\dot{S}$. (Table 13)

Theoretical tolerance time = ΔT_{re} (from start to end) / rate of increase in T_{re}

Training	Fatnes s	$\dot{S}$	Calculation
+	+	+	2.46°C/0.97°C·hr^{-1}*60 (-0.3)= 152.16
+	+	-	2.46°C/1.27°C·hr^{-1}*60 = 116.22
+	-	+	2.1°C/1.25°C·hr^{-1}*60 (-0.3) = 100.8
+	-	-	2.1°C/1.55°C·hr^{-1}*60 = 81.3
-	+	+	1.4°C/0.887°C·hr^{-1}*60 (-0.3) = 94.7
-	-	+	1.5°C/1.233°C·hr^{-1}*60 = 72.99
-	+	-	1.4°C/1.187°C·hr^{-1}*60 = 70.77
-	-	-	1.5°C/1.533°C·hr^{-1}*60 (+0.3) = 58.7

Note: actual value for ΔT_{re} is used for each calculation.
+/- 0.3 represents the corresponding increase or decrease in the rate of heat storage.

Appendix C
Ethics Approval
(DCIEM/ UofT)

Defence and Civil Institute of Environmental Medicine
1133 Sheppard Avenue West - PO Box 2000 - North York - Ontario - Canada - M3M 3B9

Human Subject Ethics Review

Protocol Number:	L-224
Title:	The Role of Aerobic Fitness and Body Fatness in Determining Tolerance to Heat Stress while Wearing NBC Clothing
Investigator(s):	**Dr T. McLellan** and Mr G. Selkirk* *Graduate Student, University of Toronto
Sector:	Human Protection and Performance

<u>Ethical Review</u>

Committee Members	Dr J. Landolt (Chairman) Dr J. Baranski Mr P. Bergmans (external lay member) Dr M. Ducharme (absent, comments received) Dr W. Johnson, St Michael's Hospital (monitoring member) Dr A. Khan (medical member) Mr J. Ulrichsen (internal lay member; absent, comments received)
In Attendance	Dr T. McLellan, Mr G. Selkirk and LCdr R. Bordeleau
Date of Meeting(s)	16 December 1998

Review and Discussion

1. Dr McLellan spoke to the protocol indicating that the protocol is a continuation of studies on NBC protective clothing; this one will be a gender comparison of "fitness and fatness" for tolerating heat stress while wearing such clothing. Previous studies have shown that both components are important determinants of performance in hot environments.

2. The Committee had a number of concerns which were addressed by the investigators (memo McLellan/Landolt, 10 Dec 98) – attached).

3. As Mr Glen Selkirk is a graduate student of the University of Toronto, approval must be obtained from that institute before experiments commence. A copy of that approval correspondence must be submitted to Chairman, DCIEM Human Subject Ethics Committee.

4. Subject to the concerns in paras 2 and 3, which were or are being addressed by the investigator, the revised protocol is APPROVED and assigned #L-224.

5. The investigator is reminded that any changes in the approved protocol or any untoward incidents arising or resulting from a subject's participation in the study are to be brought to the attention of the Committee and that all completed consent forms are to be submitted to the Chairman.

6. This approval is valid from the period of 18 months from the date of this meeting. Subject involvement must be complete by this date; otherwise, the protocol will require further review.

Jack P. Landolt, PhD
Chairman
DCIEM Human Subject Ethics Committee
(416) 635-2120

Attachments:

University of Toronto

OFFICE OF RESEARCH SERVICES

PROTOCOL REFERENCE #4458

May 17, 1999

Dr. T. M. McLellan
Defence and Civil Institute of Environmental Medicine
1133 Sheppard Avenue West
P. O. Box 2000
North York, Ontario
M3M 3B9

Dear Dr. McLellan:

Re: Your research protocol entitled, "The Role of Aerobic Fitness & Body Fatness in Determining Tolerance to Heat Stress While Wearing NBC Clothing"

We are writing to advise you that a Review Committee composed of Doctors B. Goode, M. Plyley and Professor H. Stewart has granted approval to the above-named research study.

One reviewer has forwarded the following recommendations:-

1. **On page three, under Sample – Recommend including a sample size calculation.**
2. **On page five – I would recommend that they give subjects some information regarding their hydration state before impendance body fat measurement, as body water affects this measurement.**

The approved consent forms are attached. Subjects should receive a copy of their consent form.

During the course of the research, any significant deviations from the approved protocol (that is, any deviation which would lead to an increase in risk or a decrease in benefit to human subjects) and/or any unanticipated developments within the research should be brought to the attention of the Office of Research Services.

Best wishes for the successful completion of your project.

Yours sincerely,

Susan Pilon
Executive Officer
Human Subjects Review Committee

SP/pp
Enclosure
cc: Prof. B. Kidd

Simcoe Hall 27 King's College Circle Toronto Ontario M5S 1A1 Telephone 416/ 978-2163 Fax 416/ 971-2010

Appendix D
Informed Consent

Volunteer Consent Form

Project Title: The role of aerobic fitness and body fatness in determining tolerance to heat stress while wearing NBC clothing. (Protocol L-224)

Principal Investigator: Dr. T.M. McLellan **Co-Investigator:** Glen Selkirk

1. I ____
(name, address, phone no.)

hereby volunteer to participate as a test subject in the DCIEM experiment to study the effects of aerobic fitness and body composition on the heat strain associated with wearing the Canadian Forces NBC protective clothing while exercising in a hot environment (i.e., 40°C and 30% relative humidity). I have had the opportunity to study and discuss the attached protocol with the investigator and a physician and I have been informed to my satisfaction about the possible discomforts associated with these tests. I agree not to engage in hard physical exercise or to consume alcohol or sleep medication for 24 hour before or caffeine or nicotine for 12 h before each test.

2. I am aware that my maximal aerobic power will be determined on a treadmill by progressively increasing the speed and elevation until I can no longer continue. During this test, my heart rate and expired air will be monitored.

3. I understand that my body composition will be assessed using underwater weighing, impedance and skinfold measurements.

4. I understand that there will be two weekly sessions (a familiarisation session and an experimental trial) that will involve wearing combat and NBC protective clothing and walking on a treadmill at 3.5 km/h at 40°C. These tests will continue for a maximum of 4 hours or until a) my core temperature (measured with a rectal thermistor) increases to 39.5°C, b) heart rate (measured with a telemetry unit) has increased to 95% of my maximal value and remained there for three minutes, c) adverse symptoms including dizziness or nausea preclude further exercise, d) I decide to voluntarily end the exposure, or e) the investigator or technician decides to end the trial. During these tests, my skin temperature will be measured with heat flow transducers, skin and clothing vapour pressures will be determined with humidity sensors, my ventilation will be collected at different time intervals to measure my metabolic rate, and cardiac blood flow will also be measured using impedance cardiography. I am aware that during each of these 2 sessions, up to 25 mL of blood will be taken. I understand that over the duration of the study, which will last at least 2 weeks, 50 mL of blood may be drawn. I have been made aware of and understand the discomfort involved with these procedures and the associated risks. I am aware that I must sign a separate invasive medical procedure consent form for this procedure. I understand that I will be asked to drink water prior to and throughout each trial. I also understand that my core temperature will continue being monitored for up to 45 minutes following the experiment and that I agree to drink water and Gatorade® during this recovery period.

5. I have been told that the principal risks of this experiment involve hyperthermia, dizziness and/or dehydration and the complex of symptoms or conditions associated with these physiological states. I understand and accept these risks. I have also been given examples of minor (skin irritation) and remote (heart attack, bowel perforation) risks associated with this study and consider these risks acceptable. I am aware that there are inherent, unknown and currently unforeseen risks associated with any scientific research. All known risks have been explained to me to my satisfaction. I accept this possibility of currently unforeseen risks.

6. I hereby consent to the medical screening assessment outlined in the protocol and agree to provide responses to questions that are to the best of my knowledge truthful and complete. Furthermore, I agree to advise the investigators of any health status changes since my initial assessment (including but not limited to viral illnesses, new prescription or 'over-the-counter' medications). I have been advised that the medical information I reveal and the experimental data concerning me will be treated as confidential and not

THIS CONSENT FORM CONTINUES ON THE REVERSE SIDE OF THIS PAGE

revealed to anyone other than the investigators without my consent except as data unidentified as to source. I am aware that a physician will be on-call in DCIEM during any exposures in the environmental chamber.

7. For female subjects. I have been informed that this experiment may include unknown risks to a fetus. Therefore, I consent to the administration of a serum pregnancy test as part of the medical procedure prior to commencement of this experiment during the midluteal phase of my menstrual cycle. I understand that this result and all discussion pertaining to this matter will be treated as confidential between physician and subject. If I have any concern regarding a possible pregnancy, I will consult a DCIEM physician before undertaking or resuming any phase of the experiment. Furthermore, I will take appropriate precautions to prevent pregnancy for the duration of the entire experiment.

8. I am aware and agree that I must not donate blood within 30 days of any part of this experiment. I am also aware of the requirement to sign a separate consent form for invasive medical procedures. In the highly unlikely event that I become incapacitated during my participation, I hereby consent to whatever emergency medical intervention deemed necessary by the attending medical personnel. I also agree that I will go with the investigator to seek emergency medical attention if either I or the investigator considers that it is required.

9. I acknowledge that I read this form and I understand that my consent is voluntary and has been given under circumstances in which I can exercise free power of choice. I have been informed that I may, at any time, revoke my consent and withdraw from the experiment, and that the investigators or the physician may terminate my involvement in the experiment, regardless of my wishes.

Signature ____

Print Name ____

Witness ______________________________ Date ____________

Subject fit to participate as assessed by Physician ______________________

For military personnel on permanent strength at CFEME:

Approval in principle by Commanding Officer is given in Memorandum 7700-1 (CO CFEME), 18 Aug 94; however, members must still obtain their Sector Head's signature designating approval to participate in this particular experiment. CF personnel are considered to be on duty for disciplinary, administrative and Pension Act purposes during their participation in this experiment.

For other military personnel:

All other military personnel must obtain their Commanding Officer's signature designating approval to participate in this experiment.

For civilian personnel at DCIEM:

Signature of your Sector Head is required designating approval to participate in this experiment.

Sector Head's/Commanding Officer's Signature: ______________________

CO's Unit ______________

Principal Investigator ____________________________________

INVASIVE PROCEDURES CONSENT FORM

Project Title: The role of aerobic fitness and body fatness in determining tolerance to heat stress while wearing NBC clothing (Protocol L-224)

Principal Investigator: Dr. T.M. McLellan Co-Investigator: Glen Selkirk

1. *Rectal Probe:* A small plastic tube is inserted through the anus into the rectum and is left indwelling for the experiment. Insertion of the probe may result in mild discomfort, but since the Subject inserts the probe themselves, this is minimal. Although there is a possible risk of perforation of the bowel during insertion (perhaps causing severe abdominal inflammation necessitating emergency surgery), the investigator and his associates are unaware of this ever having occurred. Initially, the disinfected probe is given to the subject in a clean package and the subject will reuse their own probe, having sole responsibility for disinfecting the probe using standard techniques. Therefore, although there is a possible risk of transmission of infectious disease (such as HIV or hepatitis), this risk is extremely negligible.

2. *Venipuncture:* A small needle is used to pierce the skin overlying a vein. This venipuncture is used to obtain a blood sample prior to exercise, as detailed in the subject information package. Either a physician or a properly qualified and physician-authorised technician performs the venipuncture. Complications may include infection of the wound site and leaking of blood into the surrounding tissue (bruising). Occasionally, fainting due to nervous reflexes may occur during the venipuncture.

I ______________________ hereby consent to the procedures above. These procedures and their complications have been explained to me to my satisfaction by the Investigator, and I have had the opportunity to ask questions both of the Investigator and of a physician.

Signature: ______________________ Date: __________

Print Name: ______________________ Date: __________

Witness: ______________________ Date: __________

Appendix E
Subject Recruitment Poster

National Defence / Défense nationale

Defence and Civil
INSTITUTE OF ENVIRONMENTAL MEDICINE
1133 Sheppard Ave. West
P.O. Box 2000, North York, Ont.
M3M 3B9
TEL (416) 635-

INSTITUT DE MEDECINE ENVIRONNEMENTALE
pour la défense
1133, ave Sheppard ouest
C.P. 2000, North York (Ont.)
M3M 3B9

VOLUNTEERS NEEDED TO EVALUATE THE INFLUENCE OF AEROBIC FITNESS AND BODY COMPOSITION ON HEAT TOLERANCE WHILE WEARING NBC PROTECTIVE CLOTHING DURING EXERCISE IN A HOT ENVIRONMENT

__Purpose__ To examine the effects aerobic fitness and body fatness have on the heat tolerance associated with wearing NBC protective clothing during exercise in a hot environment.

__Subjects__ Healthy males and females between 18-30 years of age

Volunteers will be reimbursed for their participation according to guidelines for stress allowance established by the Department of National Defence and the Defence and Civil Institute of Environmental Medicine

__Procedures__ Incremental exercise test to maximum for assessment of fitness and body composition measurements using impedance, skinfolds and underwater weighing.

2 sessions involving treadmill exercise in the environmental chamber at 40°C and 30% relative humidity for a maximum of 4 hours wearing full NBC protective clothing.

Measurement of rectal and skin temperatures, skin and water garment vapour pressures, cardiac output by impedance cardiography and heart rate will be taken during each session as well as a blood sample via venipuncture before and after the trials.

__Where__ Subjects will be evaluated in the exercise laboratory and the environmental chamber at DCIEM

__When__ January to May, 1999 Monday through Fridays

__Contact__ Interested volunteers should contact Glen Selkirk ((416) 336-0480 or (416) 635-2000 ext. 3098) or Dr. Tom McLellan ((416) 635-2151)

Or email glen.selkirk@utoronto.ca

Canada

AUTOVON 827-4101 FAX (416) 635-2104

Appendix F
Subject Information

December 16, 1998

Subject Information

Title: The role of aerobic fitness and body fatness in determining tolerance to heat stress while wearing NBC clothing. (Protocol L-224)

Principal Investigator: Dr. T.M. McLellan
Co-Investigator: G. Selkirk

Background:

Canadian Forces personnel may be required to operate in environments of high ambient temperature and/or humidity. In addition, the operating environment may be contaminated with nuclear, biological, and/or chemical (NBC) agents. Protection in such environments is provided by a semi-permeable NBC overgarment along with impermeable rubber gloves, boots, and respirator. Present NBC clothing designs typically feature very low water vapour permeability, due to clothing thickness and its multi-layered construction. This layering effect results in the trapping of insulative air layers around the body, impairing heat transfer from the body to the environment. The wearing of such clothing limits the evaporation of sweat from the body to the point where the rate of metabolic heat production is far greater than the rate of heat loss, producing a state of uncompensable heat stress. In such situations, the high rate of heat storage may result in a rapid onset of heat exhaustion. The rate of sweat evaporation and physical work capacity in young males has been shown to be severely reduced while wearing the protective clothing in a hot environment compared with normal combat clothing which allows a more effective heat exchange with the environment (McLellan et al., 1993 (Ethics Protocol No. 207), McLellan 1993 (Ethics Protocol No. 265)).

It has been reported that during compensable heat stress an increase in aerobic fitness results in a decrease in cardiovascular and thermoregulatory strain (Cadarette, Sawka, Toner, & Pandolf, 1984). This reduction in strain is due to the increase in evaporative heat-loss through an increased sweat rate at a given core temperature and the decrease in resting core temperature associated with aerobic fitness (Cadarette et al., 1984). It has been postulated that these benefits of aerobic fitness may also play a role in an uncompensable heat stress situation, such as while wearing NBC protective clothing (Aoyagi, McLellan & Shephard, 1994; Cheung & McLellan, 1998). However, an 8-

week endurance training program which increased aerobic fitness ($\dot{V}O_{2max}$) by 16% failed to increase work tolerance to heavy exercise lasting less than 1 hour with previously low-fit subjects (Aoyagi et al., 1994). Similarly, daily aerobic training for two weeks, which increased $\dot{V}O_{2max}$ by 6.5% failed to improve tolerance during light exercise lasting approximately 80-90 minutes (Cheung & McLellan, 1998a). In contrast, cross-sectional comparisons have revealed that high fit subjects with a $\dot{V}O_{2max}$ close to $60\,mL \cdot kg^{-1} \cdot min^{-1}$ had extended work tolerance times during light exercise compared with subjects of lower fitness with a $\dot{V}O_{2max}$ close to $45\,mL \cdot kg^{-1} \cdot min^{-1}$ (Cheung & McLellan, 1998b). These latter data imply that high levels of aerobic fitness acquired through a long-term commitment to regular aerobic training is an important determinant of tolerance during uncompensable heat stress.

Recent sex-related comparisons of tolerance to uncompensable heat stress have revealed that body fatness is also an important determinant of performance (McLellan, 1998). Because of the lower heat capacity of adipose tissue compared with lean tissue, such as blood, muscle, and bone, for the same total mass a higher percentage of body fatness will lower the heat capacity of the body and reduce total body heat storage. McLellan (1998) observed nonsignificant differences in tolerance time and heat storage between the sexes only when men and women were matched for body fatness alone or in combination with aerobic fitness. Interestingly, the high fit subjects compared by Cheung and McLellan (1998b), also had a significantly lower body fatness compared with the subjects of lower aerobic fitness.

The explanations for variation in tolerance time between and within the sexes indicates the role which body fatness plays as a factor in tolerance to uncompensable heat stress. As well, it further suggests aerobic fitness to be a factor. In light of these findings, the question arises which factor (aerobic fitness/ body composition) is more important in terms of increasing tolerance times, or is it a combination of the both which maximizes performance. Therefore, this study will attempt to answer these questions.

Methods:

Subjects

60 healthy male and female volunteers between the age of 18-30, selected from the surrounding university and military communities will be recruited. The subjects will be grouped for fitness and fatness levels. The groups will consist of: High fit- low fat(HL); high fit- high fat(HH); low fit – low fat(LL); low fit – high fat(LH).

Definition of groups:

High fit - $\dot{V}O_{2max}$ 55-65 $mL \cdot kg^{-1} \cdot min^{-1}$

Low fit - $\dot{V}O_{2max}$ 35-45 $mL \cdot kg^{-1} \cdot min^{-1}$

High fat – 20-30% body mass

Low fat - <12% body mass

Groups HL and LL, and groups HH and LH will be matched for fatness but differ in fitness. Similarly, groups HL and HH and groups LL and LH will be matched for fitness but differ for fatness. Ten subjects will be recruited for each group. An additional 20 subjects will be recruited whose fitness and fatness levels do not meet the criteria defined above. Testing will occur between January and March to limit heat acclimation through casual exposure. No subjects will be heat acclimatized prior to participation in the study. Medical approval and a full explanation of procedures, discomforts and risks will be given prior to written consent (see attacned copy). Subjects will be asked to refrain from hard exercise (i.e. Running, swimming, cycling and weight lifting), alcohol, non-steroidal antinflammatories (NSAIDs) such as ibuprofen (advil/motrin) and aspirin, and sleep medication 24 hours before and caffeine or nicotine for 12 hours before each session.

Menstrual cycle phase is known to influence temperature regulation during uncompensable heat stress (Tenaglia, McLellan, & Klentrou, 1997). Therefore, women, matched for either fitness or fatness, must be tested during the same phase. Not withstanding increased logistical concerns (for scheduling in the correct phase, assuring that female technical support is available for dressing and undressing of female subjects) and costs (such as increased screening and assessment for women who will not meet the fitness criteria and radioimmunoassays to verify the phase of the cycle), women will be accepted as potential volunteers. Any women who do meet the selection criteria, described above, will be tested during the early follicular phase (day 2-5) of the menstrual cycle for non-users of oral contraceptives and during days 3-6 of the week when no exogenous steroidal supplement are provided for women using oral contraceptives. The familiarisation trial, described below, will be performed during the late luteal phase for non-users and during days 24-27 of the 28-day cycle for users of oral contraceptive. Non-users must provide a history of a normal menstrual cycle and users must have been using the contraceptives for at least 6 months prior to the study. Females using DepoProvera (sustained release of progesterone), as a contraceptive will be excluded.

Experimental Protocol

All subjects will undergo the following test protocol:

i) session 1- prospective subjects will be given a medical approval, then provide written informed consent. Following this, maximal aerobic power ($\dot{V}O_{2max}$) will be determined with a treadmill protocol that involves increases in speed and elevation. Verbal encouragement will be given during the final stages of the treadmill test. The subjects will then be placed in groups using the criteria listed above for the different groups. Maximal heart rate will be measured during the treadmill protocol using a transmitter/telemetry unit. Max heart rate will be defined as the heart rate at the end of the max test. Body density will be determined using underwater weighing and skinfold thickness measurements using skinfold calipers.

ii) session 2- a familiarisation exposure to the hot-dry environment (40°C, 30% relative humidity) while wearing the NBC ensemble and walking on a treadmill at 3.5 km/hr. 200mL of warm water will be ingested prior to entering the chamber and every 15 mins during the exercise. This session will continue for 4 hours or until core temperature reaches 39.5°C (a new end-point criteria for NBC studies which is less than the value of 40°C used in other exercise studies at DCIEM (Bell & McLellan, 1998, Ethics Protocol No. L-203)), heart rate reaches or exceeds 95% of maximum for three minutes, dizziness or nausea preclude further exercise, the subject asks to be removed from the chamber or the investigators decide to remove the subject from the chamber. Impedance cardiography will be used to measure cardiac output every 15 minutes during the exposure. To obtain this measurement, subjects will be asked to straddle the treadmill belt for 1 minute during every 15 minute period and to hold their breath for approximately 10 seconds.

iii) session 3- This experimental session will be a repeat of session 2 performed 1 week later.

A 10 mL venous blood sample will be taken prior to and following the heat exposures, for determining hematocrit, hemoglobin and osmolality. For the blood sample the subject will lie down for 10 minutes prior to giving the sample. An impedance measurement for body composition will also be taken at these times to test the effect of heavy exercise on the validity of this measurement technique. For females an additional 5 mL blood sample will be taken prior to heat exposure to verify phase of menstrual cycle. The total volume of blood withdrawal during the familiarisation and experimental sessions will be 40mL for males and 50mL for females.

During the familiarisation and experimental sessions, core temperature, mean skin temperature, heat flow, and skin and garment water vapour pressures will be determined every minute, heart rate every 5 minutes and metabolic rate will be measured every 15 minutes. Changes in nude weight before and after the trial will be used to calculate fluid loss. Dressed weight will also be recorded at the beginning and end of the trials.

Data Analyses:

A 3-factor ANOVA (2 grouping factors and 1 repeated factor) will be performed on the dependent measures sampled over time (i.e. Rectal and skin temperature, heat flow, heart rate and metabolic rate). In addition, a 2-factor ANOVA (2 grouping factors) will be calculated for the dependent measures recorded at discrete time intervals (i.e.

tolerance time, sweat rate and heat storage). When a treatment effect is found ($p<0.05$), a Neuman-Keuls post-hoc analyses will be performed to isolate differences among treatment means. Multiple regression analyses will be performed to examine the relationships between subject characteristics, such as body fatness, aerobic fitness and surface area to mass ratio, and dependent measures such as tolerance time, heat storage, and the time for a given increase in rectal temperature during the trial.

Approximate Time Involvement:

The two exercise sessions (familiarisation (session 2) and heat stress test (sessions 3)) will each involve a maximum 5.5-h commitment (4-h exercise, with 1-h pre-experiment used for subject preparation and 0.5-h post-experiment for showering and dressing). Session 1 which involves medical screening, determination of $\dot{V}O_{2max}$ and assessment of body density will require approximately 3-h. The total time involvement in the testing protocol should be 14 hours.

Safety Recommendations and Risks:

1. All subjects will be screened by a Physician prior to the exercise trials. Also, blood pressure will be monitored by an investigator before all exercise trials in the heat and if it is greater than 140/90 then the subject will be referred to the covering Physician. The experiment will not proceed if rectal temperature prior to heat exposure exceeds 37.6°C for males, and for females tested during the follicular phase of the menstrual cycle, and 37.9°C for females tested during the luteal phase.

2. The incidence of myocardial infarction in the general population has been estimated at about 1 in 10000 with maximal exercise tests (Gibbons et al. 1989). This risk is even more remote considering that the subjects will have been medically screened by a physician prior to any exercise testing. Emergency resuscitation equipment will be on hand at the test locale and the investigators and technicians are trained and certified in cardiopulmonary resuscitation. Subjects may experience some stiffness in their legs for one or 2 days after the experiment due to the prolonged nature of the exercise.

3. Adverse effects of heat exposure can involve headache, vertigo, fatigue, weakness, dizziness, nausea and dehydration, and may progress to hyperthermia, heat stroke, heat exhaustion or heat cramps. Risks to the fetus due to heat exposure are unknown, thus women who are pregnant will be excluded as volunteers. Exercise in the heat is accompanied by profuse sweating. Average values for NBC experiments approximate 1 L/hour but some very fit individuals have reached 2 L/hour. Unless this fluid loss is replenished, such sweating will lead to a state of dehydration which can be dangerous to one's health once more than 5% of body weight is lost through sweating. Although rectal temperatures in excess of 40°C are often recorded in athletes who have just completed a marathon run, temperatures greater than this level can be dangerous. Particularly during combined exercise and heat stress, dehydration will impair one's ability to sweat and therefore impair one's ability to avoid a dangerous increase in the body's core temperature. Rectal temperature will be monitored throughout the experiment and testing will halt according to criteria previously described. Rectal temperature will continue being monitored after the experiment and undressing procedures are completed. Following the familiarisation and experimental sessions, Gatorade® will be provided to replenish fluid loss, and subjects will not be allowed to leave the laboratory until rectal temperature begins to decrease. Once rectal temperature begins to decrease this means that the conditions for heat loss exceed those for heat gain and there is no further risk of continued heat storage. There is also some risk of skin irritation and rash with the repeated taping of the skin thermistors used to monitor skin temperature and the tape used for impedance cardiography. A mild steroid topical cream (Betnovate® 0.05%) will be applied if a skin rash develops.

4. The disinfected rectal probe is given to the subject in a clean package with their name clearly written on the outside of the package. The subject alone is responsible for handling their probe, cleaning and disinfecting it after each session and placing it back in its package after the session has ended. Specific instructions regarding these procedures are provided on a one-on-one basis to the subject by the investigator or technician. Briefly, the subject is told to first wipe the probe clean with a tissue and then a swab

treated with alcohol. The subject is also provided with an open-ended cylinder containing fresh disinfectant (2% glutaraldehyde) and instructed to place the probe in the solution for approximately 15 minutes. Following disinfection, the probe is washed with water, wiped and placed in its package. The package is taped shut and the subject's name is clearly written on the package. The insertion of the probe may result in mild discomfort and there is a theoretical but very remote risk of perforation of the bowel with the insertion.

5. Bruising, feeling of stiffness, possible infection of the puncture site, or fainting are the only side-effects of venipuncture that have been reported with similar experiments at DCIEM involving thousands of venous blood samples. The venipuncture and blood sampling will be performed by personnel trained in phlebotomy.

Physician Requirements:

A physician will be required to perform the medical screenings before the experimental sessions begin. The presence of a physician in the environmental climatic facility will not be required during the actual experiment. All experiments will be conducted during regular working hours. Glen Selkirk will inform the "covering" physician in advance of the experimental schedule, and will ensure that a physician is in the building before commencing these tests.

Reimbursement of Subjects:

Subjects are entitled to stress allowance for DND experiments as outlined in Memorandum 7200-2 (HPSD) December, 1992.

Benefits of Study:

There is a demonstrated need to reduce heat strain associated with wearing the current Canadian Forces NBC protective clothing. Current studies have indicated aerobic

fitness and body composition to be factors in determining tolerance times in an
uncompensable heat stress environment. This study will attempt to provide guidelines of the preferential levels of aerobic fitness and body composition necessary to maximize heat tolerance in an uncompensable environment.