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Gender differences in post-exercise peripheral blood flow and skin temperature

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Gender differences in post-exercise peripheral blood flow and skin temperature

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ABSTRACT

This study identified gender-related differences in post-exercise peripheral blood flow and body temperature in neutral environment (21 °C). The subjects were 11 male (22 ± 4 years) and 14 pre-ovulatory female (23 ± 3 years) recreational runners (VO_2max: 62 ± 5 mL / kg • min for men and 55 ± 5 mL / kg • min for women). Forearm blood flow, rectal (Trec) and forearm skin temperatures (Tsk), and forearm vascular resistance (mean arterial pressure / forearm blood flow) were measured pre-exercise (pre), immediately after (t=0), and every 15 minutes up to 105 minutes (t=105) post-exercise (45-minute run at 75 % of VO_2max). ANOVA revealed main gender effects for Trec, Tsk, and forearm blood flow (men > women) as well as for forearm vascular resistance (women > men). Compared to pre-exercise, Trec at t=0 showed a similar increase in men (1.3 °C) and women (1.2 °C). Trec decreased thereafter to reach pre-exercise level after 25 minutes in men. In women, Trec kept decreasing to reach a lower than pre-exercise level after 60 minutes ($p < 0.05$). Tsk was similar at pre and t=0 for both genders. In contrast, Tsk was lower in women than men (29.0 ± 1.3 versus 30.7 ± 1.5 °C) at t=105 ($p < 0.05$). Forearm vascular resistance was similar in men and women pre-exercise and decreased by about 50 % in both groups at t=0. Between t=30 and t=105, the women increased their forearm vascular resistance up to 35 % more than did the men. These observations suggest the existence of gender-related differences in thermoregulatory and cutaneous blood flow responses during recovery from submaximal exercise.

RÉSUMÉ

L'étude présentée visait à caractériser les températures du corps ainsi que le flux sanguin périphérique mesuré au niveau de l'avant-bras chez 11 hommes (22 ± 4 ans) et 14 femmes en phase menstruelle pré-ovulatoire (23 ± 3 ans), démontrant un même niveau d'entraînement (VO_2max: 62 ± 5 versus 55 ± 5 mL / kg • min respectivement), à la suite d'un exercice dynamique (course de 45 minutes à 75 % du VO_2max). Le flux sanguin de l'avant-bras, les températures rectale et cutanée, ainsi que la résistance vasculaire de l'avant-bras (pression artérielle moyenne / flux sanguin périphérique) ont été mesurés avant (pré), immédiatement après (t=0), at à toutes les 15 minutes jusqu'à la fin de la période de récupération (t=105). L'ANOVA témoigne d'un effet principal lié au sexe pour la température rectale, la température cutanée, et le flux sanguin périphérique (hommes > femmes), ainsi que pour la resistance vasculaire de l'avant-bras (femmes > hommes). L'exercice a eu pour effet d'augmenter la température rectale, par rapport à pré, d'une façon semblable chez les hommes et les femmes (1.3 versus 1.2 °C). Cependant, alors que la température rectale des hommes s'est stabilisée au niveau pré à partir de 25 minutes post-exercice, celle des femmes a continué de descendre pour atteidre un niveau inférieur au niveau pré-exercice ($p < 0.05$). La température cutanée était semblable entre les hommes et les femmes à pré et t=0. Cependant, une valeur post-exercice moindre a pu être observée chez les femmes comparé aux hommes (29.0 ± 1.3 versus 30.7 ± 1.5 °C) à t=105 ($p < 0.05$). La résistance vasculaire de l'avant-bras était semblable chez les hommes et les femmes pré-exercice et a diminué d'environ 50 % dans les deux groupes à t=0. Entre t=30 et t=105, les femmes ont augmenté leur résistance vasculaire de l'avant-bras jusquà 35 % de plus que l'on fait les hommes. Ces observations suggèrent qu'il existe des différences liées au sexe dans les réponses régulatrices de la température et du débit sanguin périphérique en récupération d'effort dynamique sous-maximal.

PREFACE

Exercise has often been used in the investigation of thermoregulatory control mechanisms as it presents a multitude of challenges to the interactive regulatory processes that maintain homeostasis. The competitive nature of various body functions, including requirement for oxygen delivery to active muscle, cutaneous vasodilation for heat elimination purposes, and blood pressure maintenance leads to the necessity for a tight interactive control of both the cardiac and peripheral circulatory processes.

Recent examination of the control of blood flow during exercise reveals that while the exercise-induced increase in body temperature is a major factor in the control of skin blood flow, an additional factor termed " non-thermoregulatory " may be involved. This is evidenced by an initial vasoconstriction accompanying the onset of dynamic exercise as well as an elevated core temperature threshold for vasodilation during exercise.

The current thesis presented in an article format may be divided into two major sections. First, a general review of the literature on the interaction of thermoregulation and exercise is presented, that aims at providing an update of the current understanding of the thermoregulatory functions and the ensuing control of peripheral blood flow . Traditionally, this information has been collected on healthy male subjects with little concern for potential gender-related differences in response. Such differences have however been reported for circulatory responses to orthostatic stressors as well as for skin blood flow response, which could be involved in the " non-thermoregulatory " component of the exercise blood flow regulation.

The second section of the thesis consists of the experimental work presented in an article format to be submitted for publication. Inasmuch, it consists of the traditional sections of a scientific article, namely : 1) an introduction, presenting a brief overview of the pertinent review of literature leading to the position of the problem; 2) methods; 3) results - consisting of most relevant findings; 4) brief discussion of results and their interpretation.

REVIEW OF LITERATURE

I. OVERVIEW OF HEAT TRANSFER MECHANISMS

All mammals, including humans, are homeotherms in that they maintain a constant internal temperature of 37 °C. In humans, the tolerated core temperature is relatively narrow and ranges from 36 to 40 °C. The body temperature therefore reflects a careful balance between heat production and dissipation. The present section will first concentrate on heat transfer mechanisms in general, applying not only to mammals but also to all living and non-living organisms and then, will focus specifically on the temperature control system in humans.

A thermal gradient refers to a temperature difference between two points that leads to the transfer of heat. Heat transfer always occurs in the same direction, from warm to cold. The four mechanisms for heat transfer are **conduction**, **convection**, **radiation**, and **evaporation**.

Conduction refers to the transfer of heat through direct molecular contact. At normal ambient room temperature and humidity, 3 % of heat loss occurs through conduction [16]. The thermal conduction of water is recognized to be 25 times greater than that of air [16].

Convection represents the transfer of heat through motion of a gas or liquid across a heated surface. At normal ambient room temperature and humidity, 12 % of total heat loss occurs through convection [16]. The greater the air movement, the greater the convection. Hence, convection becomes the most important avenue of heat loss under windy conditions [66]. The effect of wind on temperature can be described by the windchill factor:

$$K_0 = (100\ v + 10.45 - v)^{1/2} (33 - T_a)$$

where K_0 = windchill as kcal • m^2 / h

v = wind velocity in m / s

T_a = ambient air temperature in °C

Radiation is the transfer of heat in the form of electromagnetic waves. Any substance that is not at absolute zero (0 °Kelvin) emits radiant heat waves. On earth, the sun represents the greatest source of radiant energy. At rest, in normal ambient room temperature and humidity, 60 % of total heat loss occurs through radiation [16].

Evaporation occurs because water molecules absorb heat from their environment and become energetic enough (vibrate fast enough) to escape as gas (water vapor). Latent heat of vaporization is the amount of heat absorbed by sweat as it evaporates. The latent heat of vaporization for one gram of sweat to change from water to vapor is 2425 J or 0.58 kcal [43]. At rest, in normal room temperature and humidity, 20 % of total heat loss occurs through evaporation [16]. However, during exercise, up to 80 % of total heat loss will be the result of evaporation [16]. In a situation where the ambient temperature is greater than the skin temperature, evaporation becomes the only means of heat dissipation since the three other mechanisms serve to transfer heat from the environment to the body.

It is important to note that mammals of different species resort to different mechanisms of thermoregulation; therefore, the following section will focus on humans. The human central thermoregulatory centers are often compared to a thermostat in that a temperature set point exists around which all effector responses evolve [142]. When a thermal stress displaces body temperature away from the temperature set point and creates a load error, the load error is interpreted and an appropriate heating or cooling response is initiated. In some situations such as fever, the set point can be centrally affected and cause all effector responses to be regulated around a new temperature.

As with any regulatory system, the human thermoregulatory system relies on a set of three main components: **receptors**, **integrators**, and **effectors**. The receptors have the function to transmit afferent input to integrators via the spinal cord. There are both central and peripheral thermoreceptors. Central thermoreceptors are sensitive to blood temperature changes as small as 0.01 °C [16]. They are located in the body core including the spinal cord, the abdominal organs, and the anterior portion of the hypothalamus itself. On the other hand, peripheral thermoreceptors are sensitive to skin temperature changes. There are two types of thermoreceptors in the skin, each of which responds to a limited range of temperatures. Warmth receptors respond to

temperatures above 30 °C with increased discharge upon warming [153]. Receptors for cold are stimulated by temperatures below 35 °C and increase their discharge rate upon cooling [153]. There are ten times as many cold receptors as warmth receptors located in the skin [56]. These are free nerve endings, which are most dense in the skin of the face and hands.

The integrator system for the autonomic control of thermoregulation has been reported in many regions of the central nervous system. The most thermosensitive of these are the anterior portion of the hypothalamus, the preoptic area and the posterior hypothalamus [3]. The signals from peripheral and central receptors are received and integrated in the central areas to produce the appropriate responses of heat-promoting or heat-dissipating reflex mechanisms via the autonomic effector pathway.

1. Heat production and heat dissipation mechanisms

a) Heat production

The mechanisms of heat production are activated when the body temperature becomes lower than the temperature set point and therefore, a load error is created. A rapidly observed cutaneous vasoconstriction will have the effect of restricting the blood to the deep body area and consequently reducing heat loss through conduction, convection, and radiation. This reflex control of skin blood flow in humans is generally considered to be accomplished through sympathetic vasoconstrictor fibers and a sympathetic active vasodilator system [43, 74, 77, 88, 128]. The vasoconstrictor system is adrenergic and is found in all regions of skin [43, 72, 74, 88, 128].

A second mechanism used to produce heat is the nonshivering or facultative thermogenesis contributing to an increase in metabolic rate and therefore, heat production. This response is mediated by circulating catecholamines and triiodothyronine (T_3), which concentrations increase in response to cold exposure [3]. Catecholamines act on many enzyme systems to increase cellular metabolism, therefore increasing heat production. T_3 magnifies the metabolic response to catecholamines, and most importantly, stimulates oxidative phosphorylation in the

mitochondria favoring uncoupling in the electron transport system. In response to acute cold stress, maximal occupancy of the nuclear thyroid receptors (by T_3) determines the maximal response of uncoupling protein, an essential element in mitochondrial oxidative phosphorylation leading to heat production [3].

Shivering represents the main mechanism for increasing heat production. It is characterized by an involuntary contraction of muscle. It is very effective since no work is done by the contracting muscle and most of the expended energy appears as heat. The development of shivering follows a simple pattern involving more and more muscle groups [66]. More specifically, a progressive involvement of the muscles of the neck, abdominal, and pectoral muscles, and finally of the muscles of the extremities occurs [66]. An unexplained characteristic of shivering is its intermittent nature. Horvath et al. [68] demonstrated that it is only at extremely low temperature (-40 °C) that all nude subjects appeared to shiver almost continuously. The pattern and degree of shivering also vary considerably among subjects.

b) Heat dissipation

Humans employ two main mechanisms of heat dissipation. The first is cutaneous vasodilation. This causes deep body heat to be transferred superficially and facilitates heat exchange with the environment through conduction, convection, and radiation. Contrary to the sympathetic vasoconstrictor system, the active vasodilator system is less well understood. While known to be sympathetic nerve fibers, their neurotransmitter remains to be completely identified [74, 77]. However, in part based on the temporal association of their activities, it has been suggested that it may be linked to the sudomotor control of sweat glands [14, 74, 77]. Traditionally, the distribution of the cutaneous active vasodilator system has been confined to non-acral areas (e.g., torso, legs, arms) and specifically excluded of acral regions (e.g., hands, fingers, soles, ears, and nose) [43, 72, 74, 88, 128]. However, recent evidences by Johnson et al. [77] demonstrated that the dorsal hand and fingers, but not the palmar skin, have an active vasodilator system. More studies are required to confirm these new findings.

An enhanced sweating activity constitutes the second mechanism for elimination of heat. Activation of the sweat glands causes large amount of sweat to be produced.

Evaporation of the sweat then removes heat from the skin surface. The sweat rate is inversely related to water vapor pressure of ambient air and therefore, heat dissipation through evaporation becomes limited in a humid environment. The sweat glands primarily involved in thermoregulation are of the eccrine type. These are particularly abundant on the palm of the hands, soles of the feet, and forehead. The secretory part of the gland lies in the dermis; the duct extends upward to open in a funnel-shaped pore at the skin surface. The sweat secreted by the eccrine glands is a hypotonic solution derived from blood plasma by filtration. It is 99 % water, with some salts (mostly sodium chloride), antibodies, traces of metabolic wastes (urea, ammonia), lactic acid, and vitamin C. The exact composition depends on heredity and salt diet. Human thermoregulatory sweating is primarily controlled by sympathetic cholinergic fibers although sweat glands respond to both α and β adrenergic stimulation [136]. Since sweating and vasodilation operate in tandem in the heat, it follows that cutaneous blood flow determines to some extent the activity of sweat glands and / or sweat composition.

In summary, mammals are homeotherms and must maintain their internal body temperature within a relatively narrow range. Four mechanisms of heat exchange exist and these are conduction, convection, radiation, and evaporation. Humans regulate their body temperature around a temperature set point using a relatively complex system of receptors, integrators, and effectors. When humans are exposed to cold stresses, cutaneous vasoconstriction, nonshivering thermogenesis, and shivering are used as mechanisms of heat production. Conversely, exposure to heat stresses will cause a cutaneous vasodilation and an enhanced sweating activity in order to eliminate the excess of heat.

II. HUMAN THERMOREGULATORY RESPONSES AT REST

The present section will first discuss the general human thermoregulatory responses at rest during cold exposure and secondly during heat exposure. A brief discussion of the effect of the menstrual and circadian cycles as well as the effect of anthropometric measures and body fat on thermoregulation will then be addressed. Finally, a discussion of the gender-related differences in the thermoregulatory, cardiovascular and metabolic responses to cold and heat exposure will follow.

1. Cold exposure at rest

The human response to cold exposure has been extensively studied; however, virtually all studies have been performed on male subjects. Therefore, the following section will discuss the general and accepted hemodynamic and thermoregulatory responses to cold exposure.

Cold water and cold air are different environments which provide distinct stresses to the body. Primarily, water has 25 times the thermal conductivity of air [16]. In addition, water adds a hydrostatic pressure to the body, which influences cardiovascular responses independently of the thermal stress. Furthermore, water immersion causes the entire body skin temperature to be very similar to that of the water [46]. Contrary, in cold air, marked differences in skin temperature between subjects as well as between skin sites within the same subject are observed [46, 70].

Exposure to cold environment at rest is inevitably associated with a decrease in skin temperature [10, 28, 47, 48, 106, 107, 142, 146, 157, 160]. Similarly, a decrease in core temperature is seen when the exposure is of sufficient intensity and duration [26, 28, 66, 106, 142, 146, 157, 160]. The observed decrease in skin temperature is strongly linked to an increase in vascular resistance [124, 129], leading to a reduction in skin blood flow [74]. Under severe cold stresses, skin blood flow approaches zero [74]. In fact, finger blood flow measured by venous occlusion plethysmography was found to decrease by nearly 90 % in subjects aged between 20 and 30 years following a two-hour resting exposure to 10 °C. This general increase in total peripheral resistance is also responsible for an increase in arterial blood pressure [124, 129]. Raven et al. [124] studied the compensatory cardiovascular responses of 11 Caucasian men during a two-hour cold exposure to 5 °C, and found that not only the arterial blood pressure increased, but the cardiac output and arterial-mixed venous O_2 difference also increased. This increase in cardiac output was confirmed by Rowell [129]. In addition, a two-fold increase in oxygen uptake during resting cold exposure is a common finding in most studies [20, 124]. In fact, it has been shown that metabolism can be increased several fold, an increase to three times basal or resting heat production [66]. In some exceptional situations, heat production has been reported to be as high as five times the basal metabolic rate [67]; however, this appears to be the maximal heat production that can be caused by cold exposure [66]. It is worth mentioning

that most exposure to cold results in a metabolic increase considerably below these maximal values, depending on the thermal stress imposed [66].

2. Heat exposure at rest

As was the case for the response to cold exposure, the human response to heat exposure has been extensively studied; however once again, virtually all studies have been performed on male subjects. Therefore, the following section will discuss the general and accepted hemodynamic and thermoregulatory responses to heat exposure.

Needless to say that a general increase in core and skin temperatures is seen during exposure to heat stress. The extent of this increase is proportional to the degree and duration of the heat exposure. As the body temperature rises, several heat-dissipating responses are recruited at different stages.

The earliest observable response to be recruited is the release of constrictor tone in the superficial veins and resistance vessels of the skin [35, 43]. This is associated with an increase in skin blood flow that occurs mostly in the hands and feet but also in the limbs [11]. As the body temperature increases further, sweating and active vasodilation begin, and a large increase in limb skin blood flow occurs [11, 43].

Rowell [132] has extensively reviewed the overall cardiovascular responses to heat resting exposure in man. Generally, cardiac output tends to increase 50 to 75 % in the heat [32, 72, 99, 112, 132, 133, 151] depending on the severity and duration of the heat stress. This increase in cardiac output is achieved mainly by an increase in heart rate [132, 133]. Rowell et al. [133] exposed three men to heat using a water-perfused suit. After 40 to 53 minutes of heating to maximal tolerance, cardiac output increased by seven to ten liters per minute, primarily by increased heart rate from 60 to 100 beats / min; stroke volume rose only slightly (4 %). In the same study, the onset of heating caused an immediate drop in right atrial mean pressure, which reached values of 1-2 mmHg as heating continued. This drop in right atrial mean pressure was at least partly caused by a decrease in total peripheral resistance which followed a similar path, dropping upon initial heat exposure and continuing to do so until ten minutes after the removal from the heat environment.

These falls in right atrial mean pressure and in total peripheral resistance represent unanimous findings among the literature [11, 72, 132, 151]. Following the fall in total peripheral resistance, a marked increase in cutaneous blood flow is also observed [11, 72, 132, 151]. In the forearm, for example, blood flow rises from approximately 3-4 to around 24 mL / 100 mL • min during whole body heat stress [69, 132]; an increase confined to the skin [30]. In humans during whole body heat stress at rest, about two thirds of the demand for increased skin blood flow is met by an increase in cardiac output, the remaining one third resulting from redistribution [130] mostly from splanchnic and renal circulatory beds [132]. Interestingly, arterial blood pressure is well maintained during heat exposure, usually falling slightly immediately upon heat exposure and then gradually rising back to baseline values [132, 133].

To summarize, the thermoregulatory responses to heat exposure are characterized by an increase in core and skin temperatures, cardiac output, heart rate, and stroke volume, along with a decrease in total peripheral resistance, splanchnic and renal blood flow, and right atrial mean pressure. Next will be a brief discussion of the effect of menstrual and circadian cycles and anthropometric characteristics on thermoregulation followed by a presentation of evidence emphasizing the existence of gender-related differences in the thermoregulatory responses.

3. Effects of menstrual and circadian cycles

One striking limitation of many studies comparing thermoregulatory responses between genders has been the omission of controlling for the phase of the menstrual cycle. In an extensive review on thermoregulation in women, Stephenson and Kolka [142] have concluded that if thermoregulatory effector responses are to be compared between genders, or if both men and women are comprised in the study population, it is essential that women be studied in their early follicular phase. This conclusion is based on the recognized fact that the core temperature exhibits a rhythm during the menstrual cycle in which the body temperature is approximately 0.4 °C higher during the luteal phase than during the follicular phase [38, 51, 58, 64, 95, 122, 142, 143, 144]. Most of these studies have been performed on relatively young eumenorrheic women (20 to 40 years).

The existing data on the effects of the menstrual cycle on skin temperature is controversial as some studies found that it is not affected [38, 64, 122], others finding a higher skin temperature in the luteal phase [95, 144], and yet, others reporting lower skin temperature in the luteal phase [8, 51].

Similarly, of the four studies that evaluated the skin blood flow variation associated with the menstrual cycle phases, two found that it was not affected [27, 64] and the other two found that it was lower in the luteal phase [8, 38]. Bartelink et al. [8] measured the peripheral flow (fingers) using laser Doppler flowmetry in 31 healthy women (15-45 years) and found values of 43.9 ± 15.8 units in the pre-ovulatory phase and of 33.9 ± 12.8 in the luteal phase ($p < 0.05$). In the same study, baseline measurements of blood pressure and heart rate were similar among all phases of the cycle.

The menstrual cycle phases also affect the core temperature threshold for the initiation of sweating and vasodilation by increasing the core temperature at which sweating and forearm vasodilation begin [51, 64, 95, 142]. In addition to the effect of the menstrual cycle, a circadian rhythm in body temperature and threshold for forearm vasodilation and sweating initiation also exists in both men and women with the zenith occurring around 16:00 and the nadir occurring around 04:00 [142, 143, 145]. Stephenson et al. [145] studied five men during 20 minutes of cycling in 25 °C on six separate days (4:00, 8:00, 12:00, 16:00, 20:00, and 24:00). Their results show that the thresholds for sweating and cutaneous vasodilation were significantly higher at 16:00 and 20:00 than at 24:00 and 4:00, averaging 0.57 and 0.65 °C higher at 16:00 than 4:00 respectively. The resting core temperature showed a similar circadian rhythm averaging around 0.6 to 0.7 °C higher at 16:00 than 4:00. Similar results were also observed in women [143].

Collectively, these findings demonstrate that a resting body temperature ranging from 36.76 °C during early morning of the follicular phase to 37.48 °C during the afternoon of the luteal phase can be observed, a 0.72 °C difference in resting core temperature [142, 143]. As it will be demonstrated in the sections to come, controlling for both the menstrual cycle phases and the circadian rhythm are essential when studying gender-related differences in thermoregulation.

4. Influence of anthropometric measures and body fat

In addition to the effect of the menstrual cycle on thermoregulatory parameters, women have many morphological characteristics that are susceptible to affect their thermoregulatory effectiveness compared to men.

As a group, women have a higher body fat content and subcutaneous fat thickness than men, a smaller muscle mass, and because of their smaller body size, a larger surface area to mass ratio. One implication of the larger surface area to mass ratio is that for any given temperature gradient between the skin and the environment, women have a faster heat exchange with the environment, through conduction, convection, and radiation. Furthermore, since adipose tissue has a lower heat content than other body tissues [7], the higher percentage of body fat in women will require less energy in order to raise their temperature by a given amount. Body fatness, particularly subcutaneous fat, may also present advantages during exposure to the cold, due to the high insulative properties of fat. However, there exists evidence suggesting that poorly perfused muscle mass (at rest) could also contribute to body insulation and perhaps to a greater extent than body fat [155]. Veicsteinas et al. [155] estimated the superficial and overall maximal tissue insulation in nine men and found that the maximal superficial shell insulation (subcutaneous fat and skin) could account for only 10-15 % on overall maximal tissue insulation. They suggested that the poorly perfused muscle shell play a more important role as a defense against cooling than does the superficial shell. This in turn could cause the lower muscle mass of women to influence the peripheral insulation in the cold and place them in a disadvantageous position compared to men during cold exposure.

5. Gender-related differences in thermoregulatory responses

The following section will present evidence for gender-related differences in thermoregulatory, cardiovascular, and metabolic responses to cold and heat exposures.

5.1 Responses to cold exposure

Because of the fundamental differences between responses to cold air and cold water application and considering that the nature and duration of the cold stress are critical, the following section will present findings from exposure to cold air and cold water separately.

a) Core temperature

General agreement is found in the literature concerning the existence of gender-related differences in the core temperature response to cold water immersion. Female subjects cool more rapidly than male subjects at a given water temperature and immersion time [46, 97, 109, 115, 142]. Most of these studies attributed the greater cooling of women to their smaller muscle mass and / or larger surface area to mass ratio [97, 106]. McArdle et al. [106] studied the relationship between gender and body composition with thermoregulation in men and women during one hour of immersed sitting in water at 20, 24, and 28 °C. Within each gender, the subjects were classified in terms of their percentage of body fat (women low ≤ 22 %; women average = 24-27 %; men low ≤12 %; men average = 15-18 %; men high ≥ 22 %). When comparing groups with a similar level of body fat (average men = 16.8 % versus low women = 18.5 %), rectal temperature was found to drop significantly more in women than men. Furthermore, the authors found the women with twice the percentage of fat to have similar change in rectal temperature as men at all water temperatures. Increased body fat in the general women population does provide insulation during water immersion [46], however, the larger surface area to mass ratio and lower mass contributing to heat production (muscles) in women certainly contribute to faster cooling during water immersion compared with men [142].

In contrast to the cold water studies, cold air exposure studies are much more controversial. While some studies found that women show less of a decrease in core temperature than men in response to cold ambient air [28, 156, 157], others have found no gender-related differences in core temperature [46, 115, 160]. Wagner et al. [157] exposed men and women to a two-hour rest period in ambient air at 28, 20, 15, 10 °C. Results indicate that women maintained a nearly constant rectal temperature while their age-

matched group of men showed a decline as high as 0.4 °C. Conversely, Wyndham et al. [160] studied resting men and women exposed to 5 °C ambient air for one hour and found no gender-related differences in the final core temperature. These differences in findings may be due at least in part to differences in experimental design or methodological approach. For example, the studies which concluded that women show less of a decrease in core temperature than men in response to cold ambient air [28, 156, 157] exposed their subjects to temperature greater than 10 °C. In contrast, the study which found that there is no gender-related difference in core temperature response to cold involved a 5 °C exposure [160]. These observations suggest a role for the intensity of the thermal stress in the outcome of the comparison. On the other hand, gender-related differences in core temperature response might also be related to differences in thermogenic or vasoconstriction potential, which has also been observed in women when compared to men [39, 40, 45, 110].

b) Skin temperature

To date, there is no consensus as to what formula is the best indicator of "real" mean skin temperature. In general, mean skin temperature is measured as an average of four to ten individual sites of measures. There is much experimental evidence for the existence of gender-related differences in skin temperature response to cold exposure. When subjects are exposed to cold air (-10 to 15 °C), results generally show that despite a non-significant gender-related difference in core temperature, the women have lower mean skin temperature than men [5, 28, 46, 115, 146, 157, 160]. In general, women may be seen to have a mean skin temperature between 1 and 3 °C lower than men [5, 28, 115, 146, 160]. There is no agreement concerning the cause of this marked gender-related difference. Some authors have attributed the difference to the morphological differences in body fat [115, 157, 160], while others have not shown a relationship between body fatness and skin temperature [146]. Differences in regulation of peripheral blood flow through vasoconstrictive potential may contribute to this gender-related difference [39, 40, 45, 110]. Regardless of the cause, there is no doubt that women demonstrate lower skin temperature in response to exposure to cold air. However, there is no data on gender-related comparisons of skin temperature responses to whole body cold water responses.

c) Cardiovascular parameters

Comparative data on cardiovascular parameters for male and female subjects exposed to cold exposure are sparse. While descriptions of cardiovascular parameter responses to cold exposure are numerous in men [46, 54, 66, 124, 125, 146, 156], no studies reporting on such adaptations in women alone were found and only two studies were found where gender-related comparisons were made [146, 156]. Wagner and Horvath [156], reporting on cardiac output, showed a 10 % increase in response to a two-hour 10 °C exposure in both men and women, with no gender-related differences. Stevens et al. [146], who compared men and women in 21 and 5 °C environments during 20 minutes of rest, reported a 26 % significant increase in cardiac output from 21 to 5 °C in their male group and a non-significant 17 % increase in their female subjects. Results concerning stroke volume adaptations generally show a marked increase in men exposed for 20 to 120 minutes to ambient temperature of 5 to 15 °C [46, 54, 66, 124, 125, 146, 156] while no changes were reported in women under similar conditions [146, 156]. More disparity is observed in the heart rate response of men with some studies reporting bradycardia [54, 46, 146, 156] and one other reporting a slight tachycardia [124]. The women's heart rate response also lacks uniformity with no changes [156] or a very slight increase [146] being reported for 20 to 120 minute exposure to 5 to 15 °C.

Results from the two studies directly comparing gender-related differences in the cardiovascular responses to cold exposure indicate the presence of a modest increase in mean arterial blood pressure obtained by auscultation of the brachial artery in men but not in women [146, 156]. In both studies, there were no gender-related differences in the control values of mean blood pressure.

The results on peripheral blood flow (forearm and finger) measured through venous occlusion plethysmography show a similar decrease in both male and female subjects resulting from a similar increase in peripheral vascular resistance in response to all cold stresses (10, 15, 20 °C) [156]. On the other hand, Stevens et al. [146] reported a significant decline in total peripheral resistance in male subjects following a 20-minute exposure to 5 °C while the decrease was found not to be significant in women. Finally, peripheral oxygen extraction data were only reported by Wagner and Horvath [156] who

showed a similar increase in arterial-mixed venous oxygen difference with time during the 15 and 10 °C exposure, regardless of gender. A gender comparison of the control values for these parameters were not reported [146, 156].

d) Metabolism

The few studies using cold water immersion exposure to examine gender-related differences in metabolic responses generally report that, for the same degree of cooling, women show a lower metabolic response [46, 97, 106]. This may be substantiated by observations of a similar metabolic response in women and men exposed for one hour to 20 °C despite a greater decrease in core temperature in women (-1.6 °C) than men (-1.1 °C) [106].

The metabolic responses to cold air exposure however appear more controversial. Wyndham et al. [160] exposed resting men and women (18 to 24 years) to 5 °C for one hour resulting in no gender-related differences in the increase in metabolic heat production or core temperature response. On the other hand, Stevens et al. [146] tested young men and women in 21 and 5 °C environment during 20 minutes of rest and found men to increase significantly their metabolic rate by 62 % while the increase in women was not significant (24 %). In light of the small number of studies addressing gender-related differences in metabolic response to cold air exposure, it is difficult to conclude on the comparison in sensitivity or gain of the metabolic response.

Differences in threshold for metabolic responses have however also been reported. Results indeed suggest that the metabolic response to cold exposure in women may occur at higher core temperature and thus a lower cooling threshold than men (age range 21 to 41 years) implying a greater thermal sensitivity in women [28, 101, 157]. In fact, results from a recent study in which cooling was achieved by venous infusion of cold fluid and in which the skin temperature was maintained at 36.7 °C indicate that both the vasoconstriction and shivering thresholds are higher in women (37.1 and 36.1 °C respectively) than in men (36.7 and 35.6 °C respectively) [101]. Wagner and Horvath [156], examining the age- and gender-related differences, demonstrated no gender-related differences in younger men and women, but found older women to have a lower cooling

threshold (higher core temperature threshold) for increased metabolism than older men [156, 157]. In addition, older women were found to maintain a constant core temperature at a higher metabolic cost than men [156, 157]; again suggesting a greater gain in the metabolic response in women.

5.2. Responses to heat exposure

a) Core temperature

There exist relatively few studies examining differences in core temperature response of men and women during resting heat stress [10, 21, 28, 50, 57, 111, 159]. Most of these studies report no gender-related differences [21, 50, 57, 111, 159]. Morimoto et al. [111] studied women uniquely in the menstrual phase of their cycle during a two-hour exposure to 33 to 49 °C and found similar increases in rectal temperature in both men and women. Similarly, no significant gender-related differences in the rectal temperature were observed in acclimatized men and women exposed to 40 minutes of sitting rest at 39.1 °C [159]. Similar findings were reported in unacclimatized men and women exposed to 40 °C for 60 minutes [50]. However, the two previous studies did not control for the phase of the menstrual cycle.

Candas et al. [21] studied women in both pre- and post-ovulatory phases during exposure to 43 °C for 150 minutes and found that after 75 minutes of exposure, women had a 0.24 °C greater core temperature than men. However, by the end of the exposure (150 minutes), there were no more gender-related differences in core temperature. Haslag and Hertzman [57] exposed men and women to either rising ambient temperature (one hour at 25 °C , then 6.6 °C / h to 45 °C) or to steady ambient temperature (43.3 °C for three hours). Results demonstrated that under equal climatic conditions, women in their menstrual and pre-ovulatory phases exhibited core temperatures similar to that of male subjects but that the increase in core temperature was higher than that of men during their post-ovulatory phase. On the other hand, Bittel and Henane [10] examined men and women (21-41 years) exposed to an abrupt change from neutral to hot environment (6 °C increase per minute until thermal balance at 45 °C

was reached) for a total period that lasted for 90 to 120 minutes. Results indicate women in both pre- and post-ovulatory phase to have a greater increase in rectal and tympanic temperatures than men. A higher core temperature response in women was also seen in the study of Cunningham et al. [28] who exposed three men and three women to rising ambient temperature for one hour. However, these authors did not control for the menstrual cycle phases.

Discrepancies in findings could be related to the heat stress imposed since most studies which reported a greater rectal temperature response in women versus men exposed their subjects to a protocol involving a gradual rise in the ambient temperature [10, 28, 57] as opposed to a steady ambient temperature [21, 50, 111, 159]. These observations suggest that women may be less efficient at adapting to an increasing ambient temperature.

b) Skin temperature

As discussed in the previous section concerning exposure to cold stress, the skin temperature of women in cold environment is generally cooler than that of men. Three studies have examined the skin temperature response in a neutral environment of 23 to 24 °C [12, 154, 159]. Bollinger and Schlumpf [12] studied the finger tip temperature of young women (19-39 years), elder women (51-67 years), and young men (22-47 years), and found that there was no significant difference between the three groups at an ambient temperature of 24 °C. Van de Wal et al. [154], on the other hand, found a lower finger skin temperature in their healthy women (24-56 years) versus men (32-49 years) at 24 °C. A lower skin temperature response in women versus men in 23 °C environment was also found by Wells [159].

The data on gender-related differences in skin temperature responses to resting heat stresses are also controversial. Fox et al. [36] compared the thermoregulatory responses of men (27 years) and women (22 years) to 75 minutes of controlled ear temperature at 38 °C. The skin temperature at the end of the controlled hyperthermia was 37.38 °C for the men and 37.36 °C for women; a difference that was not statistically significant. Comparable values of 37.04 °C for both groups were found by Cunningham

et al. [28] following one-hour exposure to rising ambient temperature to 48 °C. Morimoto et al. [111] studied women in the menstrual phase of their cycle and found no gender-related differences in skin temperature at room temperature between 34 to 49 °C. On the other hand, Wells [159] found the skin temperature to be higher in her female group in 39 °C but the phase of the menstrual cycle was not mentioned. In the study of Haslag and Hertzman [57], where subjects were exposed to four hours of rising ambient temperature (6.6 °C / h until to 45 °C), skin temperature of men was higher than that of women in the first hour and half of exposure. However, the women's skin temperature increased more rapidly than that of the men after the first 1.5 hour, to reach equal values in men and women at an ambient temperature of 35 °C and to remain equal for the rest of the period of exposure; this pattern was common to all three phases of the menstrual cycle. During the two-hour exposure to 45 °C, a similar pattern of skin temperature increase was found in both men and women when the women were in the pre-ovulatory phase of their cycle but the increase was greater than that of men during the post-ovulatory phase [10]. Similar findings were reported under more thermoneutral condition of 30 °C [10].

In summary, the majority of studies find skin temperature responses to heat exposure (more than 35 °C) to be similar in both genders [10, 28, 36, 57, 111] although greater responses have also been reported in women [10, 159]. The discrepancy in findings may be at least in part related to differences in menstrual phase, which has not always been considered. It is interesting that for ambient temperatures below 15 °C, men generally exhibit a higher skin temperature than that of women. Similar findings are reported in neutral environment (23-24 °C) with the majority of studies reporting skin temperature significantly higher in men [57, 154, 159] and one other reporting no gender-differences [12].

c) Sudomotor functions

Racial differences in sudomotor function have long been described. Indeed, Kawahata [83] counted the number of active sweat glands on a unit area of 22 parts of the body and estimated the total number of active sweat glands over the body surface. Their results showed mean number of active sweat glands to be almost two times higher in residents of tropical climates compared to those from frigid zones. Gender-related

differences in sudomotor function have been extensively studies over the last 30 years. Results have been expressed either in terms of density and total number of heat activated sweat glands, in sweat rate estimated from net change in body mass or in sweat capsule content, as well as in sweat sensitivity, gain and threshold. It is important to note that the maximal sweat loss has been reported to be a linear function of VO_2max [29] and therefore, one must not overlook fitness status when comparing gender-related differences in sudomotor functions.

Few laboratories have studied the number and distribution of heat activated sweat glands [8, 36, 111]. Bar-Or et al. [7] were amongst the first to examine gender-related differences in sudomotor function. Results showed that following a 45-minute exposure to 47 °C, women have a higher sweat gland population density and estimated total number of heat activated sweat glands than men as measured by a starch-iodine technique. Similar findings were reported by Morimoto et al. [111], who showed women to exhibit a higher number of heat activated sweat glands than men in response to heat exposure to 33 to 49 °C under high humidity (80 % RH) but not in dry heat (30 % RH). In contrast, such a gender-related difference was not reported by Fox et al. [36] under 75 minutes of controlled hyperthermia in approximately 36 °C conditions; however, details concerning relative humidity or measurement units and technique were not provided.

Most studies on sweat rate report women to have a lower sweat rate than men in response to similar heat stresses [21, 36, 50, 111, 139]. In a study by Morimoto et al. [111] in which young men and women were exposed to heat (33 to 49 °C) for two hours with either low or high humidity, women were found to have sweat rates corresponding to 64-93 % of those of the men. However the difference was not marked in dry heat (29-31 % RH) but was predominant under high humidity (80-82 % RH). In addition, a definite depression of sweating was found in both genders in humid versus dry conditions but the difference was only significant in women suggesting an advantage for women in humid environment where evaporation is limited.

Considering that total sweat loss is possibly related to fitness state, it is possible that the generally observed gender-related differences may be due to differences in training-state between men and women. This observation is substantiated by the study of Wells [159] who found the evaporative weight losses to be similar in acclimatized men

and women of similar VO_2max in response to both temperate (23 °C) and desert (39 °C) environments. On the other hand, in another study by Haslag and Hertzman [57] controlling neither for VO_2max nor for acclimation state, gender-related differences in sweat rate were not observed. However, proper corrections for body size and metabolic rate may need to be considered in order to establish meaningful comparisons [80, 115].

The core temperature threshold for initiation of sweating is generally reported to be higher in women than in men [10, 26, 36, 50, 101]. Bittel and Henane [10] reported the sweating threshold to be 37.0 ± 0.2 °C in women in pre-ovulatory or follicular phase, 37.4 ± 0.1 °C in women in post-ovulatory or luteal phase, and 37.1 ± 0.1 °C in men. The differences were significant only between the men and the post-ovulatory women. Lopez et al. [101] found the core temperature threshold for sweating initiation, as measured in the tympanic membrane, to be 37.0 ± 0.2 °C in men and 37.3 ± 0.2 °C in women (follicular phase); a difference found to be significant. Fox et al. [36] reported the rectal temperature threshold for sweating initiation to be lower in the men (36.91 ± 0.06) than in the women (37.15 ± 0.09). The later study did not control for menstrual cycle phases. On the other hand, Haslag and Hertzman [57] found no gender-related difference in sweating onset at any phase of the menstrual cycle.

d) Cardiovascular parameters

Gender-related differences in central cardiovascular parameter responses to resting heat stress are extremely sparse; heart rate responses only being reported in two studies of passive heat exposure [36, 159]. Following a 75-minute resting exposure at 36 °C, Fox et al. [36] found the men's heart rate (95.10 ± 2.20) to be significantly lower than that of women (103.40 ±1.68); a 33 % and 40 % respective increase from neutral condition. In another study, a 40-minute exposure to 39 °C caused a similar final resting heart rate in both genders [159]. In the same study, Wells [159] also reported that the increase in heart rate due to heat was slightly higher for women (33 %) than for men (26 %); a difference very similar to the one found by Fox et al. [36].

e) Blood flow

There are very little data on resting peripheral blood flow in the heat. In neutral environment, Bollinger and Schlumpf [12] compared the finger blood flow values measured by venous occlusion plethysmography of 12 young women (19-39 years), 13 elder women (51-67 years), and 14 young men (22-47 years) while resting at 24 °C. Their results showed that the mean finger flow in the young men was more than twice as high as in the young women (10.2 ± 7.8 mL / 100 mL • min) but was very similar to that of older women (23.6 ± 9.7 mL / 100 mL • min). Similar results were also reported by Cooke et al. [27] with basal finger blood flow of men being twice that of women (16.9 ± 4.8 versus 7.7 ± 1.8 mL / 100 mL • min) in 23 °C. Similarly, Montgomery et al. [110] measured leg and pelvic blood flow by impedance plethysmography in young men and women in 22 °C and found both the leg and pelvic blood flows to be significantly higher in men (5.86 ± 0.26 and 6.54± 0.42 mL / 100 mL • min) than in women (3.99± 0.24 and 3.92 ± 0.14 mL / 100 mL • min).

Martin et al. [105] tried to delineate the effect of aging, gender, and physical training on peripheral vascular function. At rest in neutral environment, calf blood flow and conductance were greater in all exercised trained than untrained groups regardless of age and gender, thus suggesting an influence of fitness level on the vascular responses. The only gender-related difference found once age and physical fitness were controlled for was a higher resting calf blood flow in aged (60-71 years) trained women versus aged trained men.

There are very little data comparing peripheral blood flow between genders during passive heat stress [27]. In a study aiming to determine whether gender-related differences in local or central control of cutaneous blood flow exist, Cooke et al. [27] used a 40-minute total body warming period using an hypothermic blanket with fluid inflow of 45 °C. Similar to the finger blood flow results reported earlier, basal hand blood flow at 23 °C was higher in men (12.1 ± 2.0 mL / 100 mL • min) than in women (6.2 ± 1.5 mL / 100 mL • min). However, after body warming, hand blood flow of women (54.2 ± 4.2 mL / 100 mL • min) exceeded that of men (42.8 ± 3.2 mL / 100 mL • min). The authors suggested that the lower basal hand and finger blood flows in women could be due to a

greater sympathetic vasoconstrictor activity in women. On the other hand, Haslag and Hertzman [57] measuring cutaneous opacity pulses (amplitude of which has been recognized to be linearly related with blood flow) of men and women during exposure to a rising chamber temperature and found that although cutaneous vasodilatation progressed in a parallel manner in men and women, the cutaneous opacity was greater in the men presumably reflecting higher blood flow.

III. HUMAN THERMOREGULATORY RESPONSES TO EXERCISE AND RECOVERY FROM EXERCISE

The performance of dynamic exercise by humans represents a multitude of challenges for the active regulatory processes that maintain homeostasis. In order to fulfill the oxygen requirements of the active muscles, a local vascular vasodilation becomes necessary. Exercise therefore creates a primary drive for the redistribution of blood flow away from metabolically inactive tissues (including the skin) to active muscles. Such a peripheral vasodilation in turn creates a challenge to systemic blood flow delivery, which is met by alterations in both central (cardiac) and peripheral (in non-active tissues) circulatory actions.

As exercise proceeds and contracting muscles become a significant source of heat production, a direct competition arises between the hemodynamic reflexes subserving the demand of exercising muscles and the skin blood flow necessary to accommodate the dissipation of heat. Both of these requirements are met through increasing cardiac output and redistribution of blood flow. Since neither of these tactics is unlimited, the thermoregulatory drive to raise skin blood flow must be modified in the presence of exercise or circulatory failure will result. Hence the cardiovascular system faces the ultimate challenge of providing as much blood flow as possible to both working muscles and skin for thermoregulatory purposes, while maintaining an adequate blood pressure. The present section will therefore first focus on the thermoregulatory parameter responses of men and women during dynamic exercise and then progress to a similar discussion during the recovery period of dynamic exercise.

1. Dynamic exercise

Many authors have examined the effect of exercise intensity on the temperature responses [49, 98, 109, 114, 140]. The results are unanimous regarding core temperature; the thermoregulatory drive from increasing core temperature varies with heat production and consequently with both absolute and relative exercise intensities [29, 49, 59, 88, 98, 109, 114, 135, 140]. There is therefore no doubt about the fact that, within a subject, the higher the exercise intensity, the higher the core temperature. There is however some concern as to whether absolute or relative intensity plays a more important role.

In 1966, Saltin and Hermansen [135] observed that the level of core temperature was more closely related to the relative workload (% of VO_2max) than to the absolute exercise intensity. These findings were subsequently confirmed by many authors [29, 49, 114, 140]. On the other hand, the results concerning the effect of exercise intensity on skin temperature are less consistent. While some studies found that the cutaneous temperature values were greater during high intensity compared with low or moderate intensity exercise [98, 109], others found no relationship between mean skin temperature during the final minute of exercise and the relative or the absolute workloads [49]. Thus, an essential factor to be considered while comparing responses to dynamic exercise is the intensity of the exercise.

As a group, women have a lower maximal aerobic power (represented as VO_2max per kg of body mass) than men [118]. Because variations in core temperature and cardiovascular strain during exercise are dependent on the relative intensity of exercise (% of VO_2max), a lower VO_2max implies a higher relative exercise intensity for any given absolute exercise load and therefore higher core temperature and cardiovascular strain [6]. Thus, for comparative purposes, experimental protocols generally require men and women to perform the task at the same relative exercise intensity (% of VO_2max). The disadvantage associated with this approach is that of requiring men to exercise at a higher absolute intensity. In order to best control for that variable, men and women of similar aerobic capacity would have to exercise at the same absolute intensity. However, such a protocol would greatly affect the external validity of the results since one of the groups would not be representative of the general population. The following section will discuss the gender-related differences in

thermoregulatory parameter responses to dynamic exercise while performed in neutral, warm, and cold environments, respectively.

1.1 Neutral environment

a) Core temperature

Relatively few studies have looked at differences between genders for core temperature response to dynamic exercise in a neutral environment [29, 139, 146]. Davies [29] is the only one of these to have compared the core temperature responses between genders when both exercised at the same relative intensity. The other two investigations compared core temperature in both groups at a similar absolute exercise intensity [139, 146]. Davies [29] exposed men and women to one hour (at 21 °C) of treadmill running at 76 % of VO_2max and found a similar final rectal temperature of 39.1 °C in both groups. Stevens et al. [146] studied young men and women during three consecutive 20-minute exercise bouts of increasing intensity (50, 100, 150 W) in 21 °C. The VO_2max of women (41.2 ± 2.2 mL / kg • min) was significantly lower than the men's (48.8 ± 3.1 mL / kg • min) and therefore, the women exercised at a higher percentage of their VO_2max. As could be expected considering the close relationship between core temperature response and relative exercise intensity, their results showed that the rectal temperature of women increased to a greater extent than in men at 100 and 150 W. However, no gender-related differences in core temperature were found at 50 W. Similarly, walking at 1.43 m / s (an oxygen consumption corresponding to 14 mL / kg • min for both men and women) for two repetitive bouts of 50 minutes at 20 °C produced a similar final rectal temperature in men and women [139]. These few evidences suggest that the magnitude of gender-related differences in core temperature response to exercise at similar absolute intensity in neutral environment is not linear but rather curvilinear; the differences being emphasized for higher relative exercise intensities.

b) Skin temperature

Only four studies examined the skin temperature profile during exercise in neutral environment [29, 139, 146, 159]. Of these, Davies [29] and Wells [159] had their subjects exercise at 76 % of VO_2max for one hour and at 50 % of VO_2max for 40 minutes respectively. Both of their results demonstrated no gender-related differences in skin temperature.

On the other hand, when men and women both exercise at the same absolute exercise intensity, the skin temperature response appears to be dependent on the corresponding relative intensity of exercise. For example, in the study of Stevens et al. [146] on eight men and women cycling in 21 °C at 50, 100, and 150 W respectively, results showed skin temperature to be lower in women at a 50 W intensity which corresponded to 30 % of VO_2max for men and 41 % of VO_2max for women. However, at the higher exercise intensities corresponding to 46 and 64 % of VO_2max for men and 65 and 88 % of VO_2max for women, this gender-related difference was not observed.

In contradiction with this intensity dependent effect, Shapiro et al. [139] had their subjects exercise at an intensity corresponding to 27 % of VO_2max for men and 34 % of VO_2max for women and found no gender-related differences in skin temperature. Their distinct exercise types and protocols might explain the disparity between these results. For example, while Shapiro et al. [139] had their subjects exercise over 120 minutes, Stevens et al. [146] tested their subjects for only 20 minutes at each intensity. In addition, the type of exercise was considerably different in both studies with the subjects of the former walking while and the ones of the latter cycling. This could in turn influence the pattern of peripheral blood flow and consequently impact on the mean skin temperature.

c) Sudomotor functions

Once again few studies have examined the gender-related differences in sudomotor function in neutral environment [2, 29, 139, 159]. The only two studies which directly measured sweat rate ($g / m^2 \bullet h$) agree that there is no gender-related differences in a neutral ambient temperature (20-23 °C) [139, 159]. In the study by Wells [159], men and women exercised at a similar relative intensity which also corresponded to a

similar absolute intensity since both groups exhibited similar VO_2max. Shapiro et al. [139] on the other hand, who also found no gender-related differences in sweat rate, compared male and female subjects (US army soldiers) exercising at the same absolute intensity (1.34 m / s). Thus the women were exercising at a higher relative exercise intensity suggesting a relationship between sweat rate and absolute rather than relative exercise intensity.

Other findings on sweat loss obtained in the study by Davies [29] during a one hour run at the same absolute exercise intensity indicate higher sweat loss in the male group versus the female group. However, considering that the women had a lower VO_2max than the men (58.7 versus 72.1 mL / kg • min) and therefore exercised at a higher relative intensity, these few observations suggest that absolute intensity alone is not sufficient to explain gender-related differences in sweat loss. In the same study, the author also found the maximal sweat loss to be a linear function of VO_2max ($r = 0.90$) and the gender-related differences in sweat rate to disappear when plotted as a function of % of VO_2max.

Only one study investigated the sweating threshold and sensitivity during exercise in a neutral environment [2]. Anderson et al. [2] studied the thermoregulatory responses in nine men and women cycling at 60 % of VO_2max in 28 °C water. Similarly to what was found during passive heat exposure, results showed the core temperature threshold for initiation of sweating to be higher in women than men. Furthermore, the slope of sweat rates / core temperature (sweating sensitivity) was found to be lower in women versus men.

d) Blood flow

It is clear that dynamic exercise initiates vasomotor reflexes that have the effect of redistributing blood flow from inactive tissues (including skin) to working muscles in order to meet the increased demand for oxygen [132]. Numerous studies have examined the pattern of upper extremity blood flow in response to dynamic leg exercise in neutral environment using laser Doppler flowmetry or venous occlusion plethysmography. Exercise is known to be associated with a cutaneous vasoconstriction (in non-apical regions) in non-working areas immediately upon exercise initiation resulting in slight

changes in blood flow which is mediated strictly by an increase in active vasoconstrictor tone (as opposed to a decrease in active vasodilator activity) in both normothermic [73, 74, 84] and hyperthermic conditions [84]. The skin vasoconstriction associated with exercise initiation appears to be intensity-dependent and is especially pronounced when maximal workloads are approached [147, 148].

Skin blood flow rises in response to intermediate or long term exercise [72]. The vascular responses to upright cycling at constant work load (130 beats / min) for 60 minutes have been studied in five men (20-30 years) in a neutral environment (24 °C) [78]. Forearm skin blood flow rose throughout the exercise with modest changes at the onset (first 10 minutes), followed by progressive increments during the 10 to 40th minute and smaller rises thereafter. For the hour of exercise, the forearm skin blood flow increased by 8.26 mL / 100 mL • min. On the other hand, forearm muscle blood flow (inactive in cycling) showed an initial fall with exercise onset (3.84 to 2.13 mL / 100 mL • min) and remained depressed throughout the work period.

Many studies have evaluated the role of exercise intensity on the control of skin blood flow with an extensive review by Kenney and Johnson [88]. For example, six healthy men (35 ± 10 years) cycled in a random order on different days for 15 minutes at 50, 60, 70, 80, and 90 % of VO_2max in 25 °C [140]. Forearm blood flow averaged 2.9 mL / 100mL • min at rest and increased to 7.5, 10.7, 9.6, 11.3, and 5.4 mL / 100 mL • min following exercise at the respective intensities. The response was bi-phasic. Skin blood flow rose with increasing exercise intensities up to 80 % of VO_2max with a decrease near maximal exercise. In contrast to other inactive organs like the spleen and the kidneys in which the vasoconstriction is graded according to the relative work load [132], skin blood flow seems not to be markedly changed for exercise intensities between 50 and 80 % of VO_2max [140].

At lower exercise intensities, Hirata et al. [63] observed that at a given level of core temperature, finger blood flow was reduced when exercise intensity was increased from 20 to 45 % of VO_2max. During upright exercise, as opposed to passive heating, the linear rise in forearm blood flow per unit increase in core temperature appears to be attenuated when core temperature exceeds 38 °C suggesting an upper limit for

vasodilation [15, 90, 113]. These effects of exercise are entirely a function of the active vasodilator system (as opposed to a release of the active vasoconstrictor system) [85, 90] causing skin blood flow to be lower during exercise than during passive heat conditions for any given core temperature [72].

The role of exercise posture in control of skin blood flow has also been examined. Roberts and Wenger [126] studied four men who cycled at 40-51 % of VO_2max in the upright and supine positions at air temperatures of 15, 25, and 40 °C. Compared to supine exercise, a reduced skin blood flow of 2.9 ± 1.2 mL / 100 mL • min was observed in the upright position for any given core temperature; the reduction in blood flow being considerably more important at 40 °C than at 15 and 25 °C. Considering the role of cardiopulmonary baroreflexes in the control of peripheral blood flow, it may be suggested that the lower blood flows found in the upright position compared to supine could be related to a lower central blood volume and / or cardiac filling pressure leading to a enhanced stimulation of the vasoconstrictor reflex mechanisms [74, 104, 126].

Exercise has also been seen to cause an upward shift in the core temperature threshold for vasodilation measured using the laser Doppler flowmetry and venous occlusion plethysmography technique [75, 84, 140]. In the study of Smolander et al. [140] on six healthy men cycling for 15 minutes at 50, 60, 70, 80, and 90 % of VO_2max in 25 °C, the corresponding values for core temperature threshold for vasodilation were measured to be 37.42, 37.48, 37.59, 37.79, and 38.20 °C respectively. The authors thus suggested that cutaneous vascular response to dynamic exercise might be significantly attenuated at high relative workload [140]. The rise in core temperature threshold for vasodilation appears also to be affected by exercise intensity, but this effect is not measurable until at least moderate exercise is performed [140, 149]. On the other hand, the slope relating skin blood flow to core temperature does not seem to be significantly affected by exercise intensity [148]. No investigation of gender-related differences or of blood flow responses to exercise in female subjects in neutral environment has been found.

e) Blood pressure

As was the case for most of the variables discussed up to now, the mean arterial pressure has been found to be significantly correlated (negatively) with VO_2max [58, 80]. Mean arterial pressure is known to increase with increasing relative workload up to 100 % of VO_2max [3]. In addition, age is known to have a major effect on blood pressure; increased age being associated with higher levels of systolic and mean arterial blood pressure at the same exercise work load [59, 79, 105].

The few studies that have examined the blood pressure responses of men and women during exercise in neutral environment generally agree that women have a lower systolic blood pressure response than men in relatively young (20-35 years) subjects exercising at the same relative or absolute intensities [18, 44, 105]. However, this lower systolic blood pressure response during exercise in women may partly result from a lower resting systolic blood pressure [18, 44, 105].

On the other hand, when older (46-69 years) subjects are compared at the same absolute exercise intensity, no gender-related difference (if genders are matched for aerobic capacity) [62] or a higher systolic blood pressure in women (if men have a higher aerobic capacity) [105] is found. When present, those differences range anywhere from 10 to 50 mmHg. These findings are supported by the results of Martin et al. [105] who found that the age related increase in blood pressure during exercise is greater in women than in men. In fact, it was approximately twice as high in women as in men (35-42 % versus 18-21 % respectively; $p < 0.01$). Furthermore, these findings seem to be applicable to various exercise modalities including treadmill walking, running, biking, arm biking, and rowing [44].

1.2 Warm environment

a) Core temperature

The results of studies evaluating the core temperature responses to exercise in a warm environment are controversial [4, 31, 41, 42, 65, 108, 111, 139, 159, 161]. In warm environments

between 36 and 48 °C, the majority of studies agree that there is no gender-related differences in rectal temperature during exercise at similar relative intensities [4, 31, 41, 42, 76, 159]. Both relative humidity and acclimation status influence the gender-related differences in core temperature responses to exercise in the heat. This phenomenon was substantiated by a series of investigations performed between 1977 and 1995. Frye et al. [41, 42] tested their subjects in both acclimatized and unacclimatized states. Women had a greater and more rapid rise in rectal temperature than men before acclimation. In contrast, no gender-related differences were found post-acclimation to dry heat. On the other hand, Yousef et al. [161] found a higher rectal temperature in acclimatized women versus men following one hour at 40 % of VO_2max in dry heat.

In contrast, Horstman and Christensen [65] found that post-acclimation, men had a greater increment in rectal temperature in response to exercise at similar relative intensity in 45 °C dry heat. Moreover, in hot humid conditions (25-32 °C; 70-82 % RH), Millard-Stafford et al. [108] found a lower rectal temperature in acclimatized women versus men during the last 10 km of a 40 km run at similar relative exercise intensity. Avellini et al. [4] found a lower rectal temperature in women pre-acclimation and a similar response between genders post-acclimation at the same relative exercise intensity in humid heat. Two other studies comparing men and women at similar absolute exercise intensity support the importance of the relative humidity [111, 139]. Shapiro et al. [139] acclimatized men and women to heat and then evaluated the gender-related differences in thermoregulatory responses to two repetitive 50-minute walks (1.34 m / s) in hot-dry and hot-wet conditions. The rectal temperature responses were higher in men in humid hot conditions while higher in women in dry hot conditions. On the other hand, rectal temperature differences were not found between unacclimatized men and women in either humid (80 % RH) or dry (30 % RH) hot conditions in response to exercise at the same absolute exercise intensity (5.6 km / h) [111].

In summary, there appears to be no gender-related differences in the core temperature response to exercise in warm environments if exercise intensity and acclimation state are controlled. In addition, based on changes in core temperature, women appear to be advantaged in humid and men in dry heat conditions. This phenomenon is probably related to the differences in sudomotor function or vasodilatory capacity.

b) Skin temperature

Skin temperature responses during exercise in warm environment have been studied by many authors [4, 31, 41, 111, 139, 159, 161]. Similarly to what was reported in skin temperature responses to passive heating, a majority of studies reported no gender-related differences when subjects exercised at the same relative intensity in the heat [4, 31, 41] or a higher skin temperature in women [159, 161]. Most of the studies which found no gender-related differences were exercising at a relative intensity of approximately 30 % of VO_2max [4, 41]. On the other hand, the ones finding a higher skin temperature required women to exercise at intensities between 36 and 50 % of VO_2max [159, 161], suggesting a threshold exercise intensity for gender-related differences in skin temperature to appear.

The two studies that compared men and women at the same absolute exercise intensity seem to underline the importance of the relative humidity in the skin temperature response [111, 139]. Shapiro et al. [139] found the skin temperature response to 120 minutes of walking at 1.34 m / s to be higher in men in humid hot conditions and higher in women in dry hot conditions. This intensity corresponded to approximately 36 and 28 % of VO_2max for women and men respectively. On the other hand, Morimoto et al. [111] found no gender-related differences in skin temperature responses in both humid and dry heat during 30 minutes of walking at 5.6 km / h. Respective relative intensities of exercise were not calculated. Collectively, these findings suggest that a threshold in exercise intensity of above 30 % of VO_2max is necessary to induce a gender-related difference in skin temperature response during exercise in the heat. Moreover, relative humidity may influence the skin temperature responses, as was the case for the core temperature response.

c) Sudomotor functions

In a warm environment, the literature on gender-related differences in sweating responses is much more abundant [5, 31, 41, 42, 65, 96, 108, 111, 127, 139, 159, 161]. Similarly to the results at rest, the majority of studies involving a combination of heat exposure and exercise at the same relative intensity conclude that men sweat more than women [4, 31, 41, 42, 65, 161]. As it was suggested in the section of exercise in neutral environment, VO_2max, acclimation state, and relative humidity are important factors to consider when

comparing gender-related differences in sudomotor functions. Of all the above studies, only one matched the groups for maximal aerobic capacity [41]; the remainder consisted of a male group being relatively more fit (higher VO_2max) than the female group. This observation is important when considering the strong relationship between maximal sweat loss and VO_2max [29]. Also, only one study was performed in humid conditions [5]; the other being performed in dry heat conditions which apparently favor the men. In addition, these findings were observed on acclimatized subjects except in one study [42]. Finally, Yousef et al. [161], who determined whether or not there are significant differences in response to exercise in desert dry heat between black and white men and women, found that race had no significant effect on sweat rate.

On the other hand, three other studies were not able to find any gender-related differences at a similar relative exercise intensity [42, 108, 159]. Two of these compared the thermoregulatory functions of men and women matched for maximal aerobic capacities [42, 159]. Millard-Stafford et al. [108] omitted to match their subjects for VO_2max but performed their study in highly humid heat (70-82 % RH); a condition which appears to favor the women compared to the dry heat conditions which appear to favor the men (see core temperature section just described).

Even more consistent findings are seen in studies involving exercises at a given absolute intensity [31, 111, 139]. Although none controlled for the aerobic capacity, those studies are unanimous in that no gender-related differences are found in sweat rate in dry heat and that men sweat significantly more than women in humid heat. These findings are somewhat justified by the study of Frye and Kamon [41] which concluded that women tested in the humid heat sweat significantly less than when they were tested in the dry heat, while no difference was apparent between the two relative humidity conditions in men.

Very few studies have examined the gender-related differences in sweating sensitivity, defined as sweat rate per °C change in core temperature, and in core temperature threshold for the initiation of sweating [41, 65, 96, 127]. In a study performed on men, the core temperature threshold for sweating initiation was not found to be related to exercise intensity while sweating sensitivity increased from low to moderate and high exercise intensities [109]. In general, no gender-related differences are found in sweating

sensitivity [41, 65, 96, 127]. The only difference having been found in the study of Horstman and Christensen [65] in which women showed a higher sweat rate per °C change in core temperature than men following but not prior to acclimation. Similarly, no gender-related differences are found in the core temperature threshold for initiation of sweating when control for the phase of the menstrual cycle is achieved [41, 96]. On the other hand, Roberts et al. [127] did not control for the menstrual cycle phase and found that, similarly to what was found during passive heat exposure, women have a higher threshold than men.

To summarize, considering the close relation between sweat rate and absolute VO_2max, it appears that the gender-related differences traditionally observed in sudomotor functions disappear when the relative fitness level and acclimation state are similar. Furthermore, the relative humidity seems to be an important factor to control for when comparing gender-related differences in thermoregulation.

d) Cardiovascular parameters

Only one study was found that compared gender responses in stroke volume and cardiac output during exercise in a warm environment [65]. Horstman and Christensen [65] investigated similarly fit active men and women while cycling for 120 minutes at 40 % of VO_2max in 45 °C before and after acclimation to heat. Pre-acclimation, cardiac output (CO_2-rebreathing) was almost identical in the two groups as reflected by a higher heart rate but a lower stroke volume in the women than the men. Following acclimation, the women's heart rate and stroke volume were marginally (although not significantly) higher than that of men.

The heart rate responses to dynamic exercise in the heat have been investigated more frequently. The majority of studies report that there is no gender-related differences in heart rate responses when the subjects are acclimated and the exercise is performed at a similar relative intensity in the heat [41, 59, 65, 108, 159]. On the other hand, in a study performed in a desert environment with extreme dry heat of 39 °C, Yousef et al. [161] found that independent of race, women had a higher heart rate than men when both were exercising at 40 % of aerobic capacity. The importance of climate on the heart rate response to exercise has been demonstrated by Shapiro et al. [139] who found that in

humid heat (80-90 % RH), men and women exercising at a given absolute exercise intensity (1.34 m / s) showed similar heart rates but that women had a higher heart rate when exercising in dry heat (10-20 % RH). When men and women with similar aerobic capacity (64.2 and 65.7 mL / kg • min respectively) were compared at 30 % of VO_2max in humid heat; women were found to have a lower heart rate [5]. Results from a co-variate analysis of the relative influence of physical fitness, acclimation, gender and anthropometric factors on heart rate response during exercise in the heat indeed showed that 75 % of the variability in heart rate could be explained by climate and metabolic rate [60].

e) Vascular responses

As with previous sections, we are limited in our understanding of gender-related differences in cutaneous blood flow during exercise in warm environment. In a recent study of men and women cycling for one hour in 35 °C (80 % RH), no gender-related differences in forearm blood flow or conductance were observed [59]. Similarly, the vascular responses of equally fit men and women examined in the follicular phase of the menstrual cycle exercising in moderate heat were found not to be different [96]. In fact, the results showed that there were no gender-related differences in either the core temperature thresholds or the slopes of skin blood flow to core temperature during the same environmental and exercise stresses [96]. In contrast, Roberts and Wenger [127] reported that women had higher vasodilation thresholds than the men both before and after an exercise-training and / or heat-acclimation program.

f) Blood pressure

Only two studies measured the blood pressure responses during exercise in warm environment [59, 111]. Morimoto et al. [111] exposed young men and women to six episodes of heat in either high (80 % RH) or low (30 % RH) humidity. The subjects first sat for 30 minutes in the chamber; then walked at 5.6 km / h for 30 minutes; and finally sat for two other consecutive periods of 30 minutes. Results showed decreases in diastolic blood pressure in both groups in dry and humid environments but the extent of the decrease was more pronounced in men. In addition, while systolic blood pressure increased in women during exercise in both dry and humid heat, it remained unchanged

in men. In contrast, in a recent study by Havenith et al. [50], no gender-related differences in mean arterial blood pressure were observed in men and women cycling at 60 W for one hour in humid heat (35 °C at 80 % RH). However, because the study was not specifically designed to address gender-related differences, subjects were not matched for age and a 3:1 ratio was observed between male and female participants.

In summary, from these studies comparing the thermoregulatory responses of men and women during exercise in the heat, it appears that there are no gender-related differences in core temperature when acclimation status and relative exercise intensity are controlled. While there appear to be no gender-related differences in skin temperature at low relative exercise intensities, higher skin temperature is found in women at high relative exercise intensities. Women appear to have a lower sweat rate than men when both groups exercise at the same % of VO_2max, but that difference may be related to differences in maximal aerobic power or acclimation status. The higher surface area to mass ratio of women may be responsible for the respective advantage and disadvantage of women in hot humid and in hot dry environment since heat production is mass dependent and heat dissipation is surface area dependent. The heart rate response is similar in men and women at the same relative exercise intensity. The data comparing the thermoregulatory responses of the genders are inconclusive for cardiac output, stroke volume, blood flow, and blood pressure.

1.3 Cold environment

a) Core temperature

The literature concerning gender-related differences in core temperature during exercise in cold environment is more restricted. Only two studies compared core temperature in men and women while exercising in cold water [97, 107]. Both of these studies found no gender-related differences in core temperature when both groups exercised at the same absolute exercise intensity. However, because of the lower maximal aerobic power of women, this corresponds to at a higher relative exercise intensity in women suggesting a lower heat production in women for relative exercise intensity increments.

The results of studies performed in cold air are not as consistent. While some of the studies which performed at the same absolute exercise intensity reported a higher rectal temperature (0.2 - 0.5 °C) in women [48, 146], one study found no gender-related difference [158]. Once again, gender-related differences in VO_2max were present in all these studies thus influencing the relative intensity of work. In the only study in which subjects exercised at similar relative exercise intensities, no gender-related difference in rectal temperature were observed for the first two hours of exposure; however, women showed a lower rectal temperature during the last hour of exposure [47].

b) Skin temperature

There appears to be consensus concerning the skin temperature response in men and women during exercise in a cold environment that women maintain a mean skin temperature 1-2 °C lower than men during exercise, just as may be seen at rest [47, 48, 146, 158]. No relationship or inconsistent relationship is generally found between mean skin temperature and body fatness during exercise in both men and women [47, 48, 107, 155, 158].

c) Cardiovascular parameters

Two studies have examined the cardiovascular parameter responses to exercise in a cool environment [48, 146]. Stevens et al. [146] measured cardiac output and stroke volume in eight men and eight women in both 21 and 5 °C environments during 20 minutes cycling at each of 50, 100, 150 W. In 5 °C, the cardiac output was not different between genders at 50 and 100 W, but was significantly higher in the men than the women at 150 W (17.3 versus 16.1 L / min). A significant increase in stroke volume from neutral temperature was also reported in the cold trial in men but not in women. Similarly, while the men's heart rate was significantly lower during exercise at 5 °C than at 21 °C, heart rate was not affected by ambient temperature in women. A higher heart rate in women versus men during exercise in the cold at a similar absolute exercise intensity was also found by Graham and Lougheed [48] and probably reflects the greater relative work load in women.

d) Metabolism

McArdle et al. [107] evaluated the effects of exercise on the metabolic responses to cold-water stresses in groups of young adult men and women classified in terms of body fat. When men and women of similar body fatness (16.8 versus 18.5 %) were compared while exercising at 36 W for one hour in water at 20, 24, and 28 °C, no gender-related differences in oxygen consumption were observed. On the other hand, others [48, 146] have found that when men and women are not matched for body fat, men have a slightly but significantly greater VO_2 (L / min) than women while exercising at the same absolute intensity in cold air suggesting a greater cold-related heat production in men. In a review article, Graham [46] suggested that a major gender-related difference in response to exercise in cold environment may be that men respond through a predominant increase in metabolism rather than allowing skin temperature to cool to the same extent as that seen in women.

In conclusion, the information available demonstrates that there are gender-related differences in the thermoregulatory responses to exercise in cold environments. Just as was the case at rest, the skin temperature of women in a cold environment is consistently lower compared to men during exercise. There is a gender-specific heart rate and stroke volume response. When exercising at the same absolute intensity, and the groups are not matched for aerobic capacity, no gender-related differences are found in core temperature. Finally, men seem to increase metabolism to a greater extent than women.

2. During recovery from dynamic exercise

The following section will discuss the thermoregulatory parameter responses during recovery from dynamic exercise. The time course of the thermoregulatory parameters following exercise has not been studied extensively. A description of the general temperature, vascular and blood pressure responses will be presented as well as gender-related differences.

a) Core temperature

As shown in Table 1, only two of the six studies which evaluated the core temperature responses following dynamic exercise compared responses between genders.

Table 1. *Studies on post-exercise temperature responses.*

Studies	Subjects		Exercise protocol	Recovery (minutes)	Recovery conditions	Core temperature response		Skin temperature response	
	F / M	Age (years)				Time for return to pre-exercise values (minutes)	Results at the end of recovery compared to pre-exercise	Time for return to pre-exercise values (minutes)	Results at the end of recovery compared to pre-exercise
Isea et al. (1994)	0 / 6	24-34	Maximal upright cycling	240 (supine)	22-24 °C	40	=	Not measured	
Brown et al. (1993)	0 / 12	23 ± 3	cycling for 45 min. at 50 % of VO_2max	60 (sitting)	24 °C 49 % RH	20	=	5	↓
Franklin et al. (1993)	0 / 11	21.6 ± 2.2	30 min. at 70 % of VO_2max on a bike at 3 different Tam	60 (supine)	-21 °C 52 % RH -31 °C 53 % RH -17 °C 58 % RH	-At 17°C : 20 -At 21°C : 20 -At 31°C : 20	-At 17 °C : = -At 21 °C : = -At 31 °C : ↑	-At 17 °C : >60 -At 21 °C : ~30 -At 31 °C : >60	-At 17 °C : ↓ -At 21 °C : = -At 31 °C : ↑
Thoden et al. (1993)	0 / 5	23.9 ± 2.04	2 hours rest followed by a treadmill run for 18 min. at 75 % of VO_2max	65	29 °C 50 % RH	> 65	↑	2-3	=
Millard-Stafford et al. (1995)	6 / 6	F = 29.2 ± 3.1 M = 30.1 ± 2.3	40 km run at 75 % of VO_2max but tended to be a bit higher in men after 35 km. in 25-32 °C 70-82 % RH	30	20 °C	> 30	↑	Not measured	
Walsh and Graham (1986)	8 / 8	F = 20.5 ± 1.0 M = 22.6 ± 0.3	Cycling (6 x 20 min.) at 60 W (F=43 % vs. M=34 % VO_2max) Recovery of 10 min. between repetitions (4 Δ Tam)	60	21 °C 59 % RH (10, 3.5, -3.5, -10 °C during exercise)	>60	↓	~ 10	F lower than M both ~ = to pre-exercise

Abbreviations used in the preceding table: F (women); M (men); ↑ (higher than pre-exercise); ↓ (lower than pre-exercise); = (equal to pre-exercise); ~ (approximately); Δ (different); Tam (ambient temperature).

As expected, results indicate that the core temperature remains significantly elevated for a period between 20 minutes to over one hour post-exercise in both men and women [17, 37, 71, 106, 151]. The response is greatly affected by the extent to which core temperature was increased during the exercise bout as well as the ambient temperature during recovery. As can be seen from table 1, results generally show core temperature to remain elevated after submaximal (34 to 75 % of VO_2max) and maximal exercise for

at least 20 minutes [17] although in some studies, values were found to remain elevated for as long as 40 [71] and 65 minutes post-exercise [151]. Time for return to baseline values was significantly increased when recovering in a warm ambient environment [37]. Moreover, while values generally return to pre-exercise levels, a further decrease to less than pre-exercise levels have also been reported under conditions of cooler (17-21 °C) ambient recovery temperature [37].

Two studies examined gender-related differences in the temperature responses following exercise [106, 158]. Walsh et al. [158] exposed men and women to six repeated bouts of intermittent cycling exercise for a total of three hours at four different ambient temperatures followed by recovery at neutral temperature (21 °C). Results showed no gender-related differences in the magnitude of changes in rectal temperature; however, the precise values were not reported. In both groups, rectal temperature gradually declined throughout the recovery period at the same rate and to the same extent for all exercising ambient temperature conditions. Millard-Stanfford et al. [106] found men to have higher rectal temperatures than women by 0.7 °C at the end of a marathon and by 1.1 °C at 30 minutes post-exercise. Unfortunately, there are no data on gender-related differences in the core temperature kinetics for longer recovery periods.

b) Skin temperature

The general skin temperature response following exercise has been investigated by very few studies [17, 37, 151]. As can be seen in Table 1, these studies suggest that the recovery skin temperature response of men is dependent upon the ambient temperature in which the subjects recover with skin temperature remaining above pre-exercise values for periods increasing as the recovery ambient temperature increases. In general, the skin temperature is greater than pre-exercise immediately following exercise termination and remains higher for periods ranging from 10 minutes at 17 °C to over 60 minutes at 31 °C. Skin temperature during the recovery period following dynamic exercise has also been found to be significantly higher under warm condition (31 °C) than under neutral (21 °C) and cool (17 °C) conditions [37].

Only one study compared gender-related differences in skin temperature post-exercise [158]. The results of Walsh et al. [158] show that at the end of exercise in all four

environmental temperatures (10, 3.5, -3.5, -10 °C), women had a significantly lower skin temperature than men by 1-3 °C. During the recovery period at 21 °C, cutaneous temperature increased rapidly in both genders with no significant differences in the rate of increase and a recovery of 90 % occurring within the first ten minutes post-exercise in both groups. However, women had significantly lower skin temperature than men through the entire recovery. These findings are consistent with results reported on skin temperature response to resting and exercising cold exposure.

From these findings on temperature responses during the recovery period following exercise, it is clear that the ambient temperature is a crucial factor to be considered. Protocols involving longer recovery periods would be required in order to allow enough time for the core and skin temperatures to stabilize.

c) Vascular responses

The general vascular responses during the recovery period following dynamic exercise has been studied by numerous investigators [17, 22, 23, 25, 52, 53, 55, 61, 71, 121]. Generally, results demonstrate that compared to pre-exercise values, peripheral blood flow is elevated and peripheral vascular resistance reduced immediately following dynamic exercise. Thereafter, values are seen to gradually decrease and increase respectively, but returns to pre-exercise values are not seen for periods extending from 10 [22] to over 120 minutes [71]. The magnitude of this response appears to be dependent on the intensity of the initial exercise [121]. Gender-related differences in those vascular responses have not been evaluated.

d) Blood pressure

Compared to most other cardiovascular parameters, the literature on the general blood pressure responses following dynamic exercise is much more extensive [17, 22, 23, 25, 34, 37, 52, 53, 55, 61, 71, 82, 89, 100, 119, 121, 123, 137, 141]. A post-exercise hypotension phenomenon has been described in healthy normotensive individuals in response to several types of large-muscle dynamic exercise (walking, running, and leg cycling), at submaximal intensities greater than 40 % of peak aerobic capacity, and exercise duration generally between 20 and 60 minutes [17, 25, 34, 37, 52, 61, 71, 82, 100, 121, 123, 137, 141]. This phenomenon is

defined by a sustained reduction in systolic and / or diastolic arterial blood pressure below control levels after a single bout of exercise [89]. Typically, the exercise-induced increase in systolic blood pressure reverts as exercise is terminated to reach a minimal value between five and 30 minutes post-exercise; values gradually reaching pre-exercise levels between 40 and 180 minutes post-exercise. The magnitude of decrease in systolic blood pressure may be affected by the duration and intensity of exercise but is usually between five and 20 mmHg [17, 25, 34, 37, 52, 61, 71, 82, 89, 100, 121, 123, 137, 141].

The mean arterial pressure responses generally observed are similar to those reported for systolic blood pressure [17, 25, 37, 52, 53, 55, 119, 121]. The diastolic blood pressure responses reported are not as consistent. While some studies have observed a post-exercise hypotension similar to that for systolic blood pressure [25, 34, 55, 71, 82, 100, 121, 123, 141], others have found no change from pre-exercise values [17, 22, 23, 37, 52, 61, 100, 119, 121].

Only two studies have examined gender-related differences in the blood pressure response during recovery from dynamic exercise [18, 98]. Interpretation of their findings is however limited since their recovery periods lasted only ten minutes and the authors only reported the values graphically. Both of these studies were performed on young subjects and indicate women to have lower systolic and diastolic blood pressures than men [18, 94]. In addition, Klassen et al. [94] concluded that the post-exercise hypotension phenomenon occurs both in men and women but that its magnitude is greater in women. Confirmation of these findings by studies involving longer recovery protocols is definitely required and could be of great clinical importance.

In conclusion, findings regarding gender-related differences in thermoregulatory responses to thermal stresses and exercise have been provided. However, these responses remain incompletely documented and precise underlying mechanisms remain to be clearly understood. Gender-related differences in the control of vasoconstrictor tone have however been reported which could potentially contribute to explain differences in sudomotor function or skin temperature responses.

IV. GENDER-RELATED DIFFERENCES IN THE CONTROL OF PERIPHERAL CIRCULATION

Many gender-related differences have been reported in the reflex control of heart rate and blood pressure in healthy men and women matched for age [1, 19, 39, 45, 69, 110, 134]. For example, a bolus administration of phenylephrine producing an abrupt rise in blood pressure causes significantly less of a bradycardia in women than in men for similar basal heart rates [1]. This response suggests a lower arterial baroreflex sensitivity in women and a lesser involvement of the cardiac vagal component in the baroreflex-mediated bradycardia [1].

In addition to arterial baroreflexes, cardiopulmonary baroreflexes are involved in blood pressure regulation through an effect on peripheral resistance [102]. Changes in central blood volume have been shown to result in reflex changes in peripheral blood flow such that a reduction in central blood volume causes a decrease in forearm blood flow through activation of constrictor reflexes. Investigation of the cardiopulmonary baroreflex sensitivity using lower body negative pressure usually shows an earlier and greater chronotropic response to orthostatic challenges in women than in men, concomitant with a lesser vasoconstrictor response [39, 40, 110]. These data support the hypothesis that vagal withdrawal may be the first line of defense for women during these mild stresses, whereas sympathetic stimulation to the vasculature is the primary response for men [39]. In addition, gender-related differences were also observed by Gotshall et al. [45] in response to a simple orthostatic test showing men to have a greater increase in total peripheral resistance (77 %) than women (43 %) during five minutes of standing. Similarly, using a cold pressor test on the hands and feet (30 seconds in 10 °C water and with ambient temperature of 24 °C), finger blood flow responses, although qualitatively similar in men and women, were prolonged to several minutes in women (five to eight minutes) compared to men (two to four minutes) [12]. Whether differences in the cardiopulmonary reflex control of blood flow can contribute to differences in the thermoregulatory adaptations of skin blood flow remains to be determined.

V. SUMMARY AND POSITION OF THE PROBLEM

The present review presents recent experimental evidence for gender-related differences in the physiological responses to thermal and orthostatic stressors and their interaction with prolonged dynamic exercise. The influence of covariates including body characteristics, aerobic fitness, acclimation state, climate, menstrual and circadian cycles may contribute to some extent to these differences. The interaction of gender-related differences in the control of peripheral blood flow in response to an exercise-induced thermoregulatory challenge has however not been investigated. The objective of the present study was thus to identify and compare peripheral the blood flow response of men and women and its relation to core and cutaneous temperatures during recovery from prolonged dynamic submaximal exercise in a neutral environment. This study is not designed to provide explanations for any potential gender-related differences that may be observed but remains a first descriptive approach to gender-related differences in the control of blood flow as a result of an exercise-induced thermal stress. In the event that gender-related differences in response are observed, results from this study may be used to infer as to the potential influences of the thermoregulatory and / or "non-thermoregulatory " components in the control of peripheral blood flow.

EXPERIMENTAL STUDY

INTRODUCTION

There exists sparse evidence comparing gender-related differences in cardiovascular and thermoregulatory functions. Gender-related differences in sudomotor function potentially related to cutaneous active vasodilator system function have been reported [72]. Generally, men are found to have a higher sweat rate than women both during passive and exercising heat exposure [4, 21, 31, 38, 41, 42, 50, 66, 111, 139, 161]. Compared to men, women are also generally reported to have less circulation to the extremities in a comfortable to cold environment [12] and lower skin temperature both during rest and exercise in cold environments [5, 28, 46, 47, 48, 115, 146, 150, 157, 158]. In a neutral environment, it is generally reported that young men have a resting cutaneous peripheral blood flow up to twice as high as that of young women [12, 27]. This situation, however, appears to be reversed in a warm environment where young women have a higher cutaneous peripheral blood flow versus young men [27].

Gender-related differences in vascular and sudomotor responses during the recovery from exercise have not been studied extensively. Examination of gender-related differences in temperature responses after exercise has been limited to the investigations by Millard-Stafford et al. [108] and Walsh et al. [158]. Immediately following a running marathon, rectal temperature was 0.7 °C higher in men than women [108]. After 30 minutes of recovery in neutral environment, the gap in rectal temperature had increased to 1.1 °C. Gender-related differences in skin temperature have also been examined during recovery following exercise in cold environments [158]. The results are consistent with evidence reported under resting and exercising conditions with women having significantly lower cutaneous temperature than men throughout the entire recovery period.

Moreover, gender-related differences have been reported in the control of peripheral circulation. Under neutral environments, peripheral circulation and / or peripheral resistance have been found to be regulated through the activation of cardiopulmonary baroreflexes. The investigation of cardiopulmonary baroreflex function sensitivity using lower body negative pressure application have shown an earlier and greater chronotropic response to orthostatic challenges in women than men,

concomitant with a lesser vasoconstrictor response [39, 40, 110]. Similar results have also been reported in response to a simple "sit-to-stand" orthostatic test where women responded with a lower increment in total peripheral resistance than men [45]. Considering the importance of the cardiopulmonary baroreflex in the control of cutaneous circulation, these observations may have implications for gender-related differences in the interaction of thermoregulatory function and vasomotor regulation and more specifically for the " non-thermoregulatory " component of blood flow response.

The purpose of the present thesis is therefore to identify and compare the peripheral blood flow response of men and women and its relation to core and cutaneous temperatures during recovery from prolonged dynamic submaximal exercise in a neutral environment.

METHODS

Subjects

Subjects were 11 men (22 ± 4 years) and 14 women (23 ± 3 years), who volunteered to participate in this study. Subjects were healthy and free of known cardiovascular diseases. They voluntarily engaged in regular endurance exercise by running at least 2-3 times per week and therefore, were very familiar with the exercise task involved in the present study. They did not however participate in competitive running. A precise description of the subjects' habitual level of activity prior to and during the study is provided in Tables 7 and 8 of Appendix B. A VO_2max exceeding 45 mL / kg • min and the capability to run for 45 minutes at 75 % of VO_2max were used as criteria for inclusion of subjects. In addition, all women not showing a regular menstrual cycle of 28-30 days were excluded. Subjects gave informed written consent prior to participation. The Ethics Committee of the Faculty of Education at McGill University approved all procedures for this study.

Procedures

The study was comprised of two testing sessions. During the first session, body characteristics were evaluated and a VO_2max test was performed on a treadmill. The second testing session consisted of 20-minute pre-exercise sitting baseline measurements, a 45-minute continuous submaximal run, and a 105-minute post-exercise measurement period with passive recovery. Due to the necessity to control for the recognized effect of menstrual [122, 142, 143, 144] and circadian [142, 143, 145] cycles on thermoregulatory parameters, a period of 2-6 weeks elapsed between the two testing sessions. Since it is possible for physical fitness to be altered over this period, subjects were instructed to maintain their activity pattern between the tests (Tables 7 and 8 of Appendix B).

Determination of maximal aerobic power

Upon arrival, subjects completed a questionnaire containing pertinent personal information. Measurements of body mass, height, and skinfolds (biceps, triceps, subscapular, suprailiac, and medial calf) were obtained, following the procedures outlined in the Canadian Standardized Test of Fitness [33]. The arithmetic sum of the five skinfolds was computed and body mass index (BMI), body surface area (BSA) and body surface area to mass (BSA / mass) ratio were calculated using the formulas:

$$BMI = \text{body mass (kg)} / \text{height}^2 \text{ (m)}$$

$$BSA = [\text{height (m)} \bullet \text{body mass (kg)} / 36]^{1/2}$$

$$BSA / \text{mass} = BSA (m^2) / \text{body mass (kg)}$$

The subjects performed a VO_2max test on a treadmill at constant (0 %) grade. The protocol started at 8.045 km / h (5 mph) and speed was increased by 1.609 km / h (1 mph) every two minutes until 12.872 km / h (8 mph), and then increased by 0.8045 km / h (0.5 mph) every two minutes until volitional exhaustion. Ventilation, respiratory rate, tidal volume, VO_2, CO_2 production, and respiratory exchange ratio were measured using a Sensormedic's 2900 Metabolic cart (MMC). The MMC was calibrated before each testing session. Correction for daily changes in temperature and barometric

pressure were performed by the computerized system. The reproducibility of VO_2max has been examined in many studies and has been summarized by Katch et al. [81]. According to this review of seven studies, the test-retest reliability ranged from r = 0.90 to r = 0.96.

Procedures for determination of thermal and vascular responses

The subjects were instructed to arrive at the laboratory at 11:00 a.m. and to refrain from consuming caffeine or from exercising on the same day of testing. They were also asked to refrain from alcohol consumption for 24 hours prior to their appointment time. In addition, the subjects were informed to eat a regular breakfast and to be finished eating at least two hours before the experiment. All experiments were conducted at the same time of day in order to control for circadian variation in thermoregulation [142, 143, 145]. In addition, all females were tested during the follicular phase of their menstrual cycle (estimated as day 0 to day 12 of their reported cycle) in order to control for the effects of menses on thermoregulatory parameters [122, 142, 143, 144]. The laboratory ambient temperature was constant at 21.0 ± 0.5 °C throughout all testing.

Upon arrival, subjects were asked to change into shorts and T-shirt and to insert a rectal probe. Subjects then sat for ten minutes with the left arm abducted and resting on a table elevated to heart level while the remaining equipment was positioned. Pre-exercise measurements were obtained every five minutes for a period of 20 minutes in the sitting position and baseline pre-exercise data were calculated as the average of these measurements.

Following collection of baseline pre-exercise data, the measurement equipment was removed (except for the heart rate monitor). Subjects then performed a 45-minute run at 75 % of their pre-determined VO_2max on a 200-m indoor track at a controlled ambient temperature of 22 °C. The subjects ran in the first lane in order to minimize the slope on the track. The purpose of having the subject run in a less controlled environment (versus treadmill) was to reproduce regular exercise routines as closely as possible. An example of factor limiting the appropriateness of the treadmill includes the

reduction of heat transfer through convection which is known to increase as wind speed increases [66]. The speed corresponding to 75 % of VO_2max was calculated from the maximal exercise test on the treadmill for each subject. This intensity for 45 minutes corresponds to "heavy" exercise for this population [13]. Subjects wore a heart rate monitor, which recorded and stored the heart rate every minute. A watch with a timer provided a regular auditory signal at the start of every lap in order to maintain the appropriate speed. This procedure was effective for controlling the speed for each subject. The investigator confirmed that the appropriate speed was maintained for the entire 45-minute run.

After the run, subjects jogged to the locker room (less than one minute) and were allowed a maximum of two minutes for showering. The purpose of the shower was to represent typical conditions associated with exercise routines. The exposure to the shower was limited to two minutes in order to minimize the influence of the water on thermoregulatory parameters. Although the water temperature was not precisely controlled, the subjects were instructed to set the temperature to their habitual level and to completely avoid exposition to cold water. Subjects changed into dry clothes, inserted a new rectal probe, and returned to the laboratory where monitoring equipment was re-attached. A new rectal probe (same thermistor) was inserted for sanitary reasons. Subjects sat back in the evaluation chair and post-exercise measurements were initiated. The time lapse between the end of the run and the beginning of the post-exercise measurement period was 8.8 ± 1.4 minutes, only one subject requiring more than 10 minutes.

Post-exercise measurements were obtained regularly for 105 minutes. During the post-exercise recovery, the subjects were passive. This consisted of sitting in the evaluation chair while reading, studying, or watching a movie (Walt Disney: Aladdin or Beauty and the Beast). The investigator was always present to ensure that subjects remained passive during the entire recovery period. The dependent variables measured were rectal (Trec) and forearm cutaneous (Tsk) temperatures, forearm blood flow (FBF), arterial blood pressures, and heart rate (HR).

Blood flow, blood pressure and temperature measurements

Trec was measured via a rectal thermistor probe inserted 8 to 12 cm past the anal sphincter [6, 98, 138, 144]. Similarly, a cutaneous probe was used to measure Tsk. The cutaneous probe was positioned on the anterior part of the left forearm and fixed with tape so that the outer surface of the thermocouple was not directly exposed to air. Both probes were connected to a portable telethermometer from which readings were obtained every 5 minutes. The thermistor probe and thermometer were calibrated against a standard mercury thermometer using a water-bath at different temperatures.

Forearm blood flow (FBF) was obtained by venous occlusion plethysmography using an electrically calibrated mercury-in-silastic strain gauge (Hokanson model EC-4 plethysmograph, D.E. Hokanson, Bellevue, WA). The gauge itself is a fine-bore silicone rubber tube completely filled with mercury, the ends of the tube being closed by copper plugs which are in electrical continuity with the mercury. The strain gauge was fitted around the left forearm just distal to the elbow at the level of the greatest forearm circumference. The size of the mercury gauge was selected for each subject according to his or her forearm circumference. Pressure in the venous occlusion cuff, located on the left middle arm, was set at 40-50 mmHg [8, 76, 103, 104, 152] and blood flow to the left hand was excluded with a wrist cuff inflated to 180-200 mmHg [152]. Immediately prior to each FBF measurement, the wrist cuff was manually inflated while the arm cuff was automatically inflated and deflated every 5 seconds using an Hokanson model E-20 Rapid Cuff Inflator. Forearm blood flow was measured during a two-minute period every 15 minutes. The signal output from the plethysmograph was connected to a personal computer via a A/D card converter for online data recording using the "LabView" (National Instruments) software program.

Forearm blood flow was derived from the rate of change in forearm circumference during acute venous occlusion. For calibration purposes, an electrical signal produced by the Hokanson EC-4 plethysmograph provided a voltage change equivalent to that observed for a 1 % change in the length of the strain gauge [152]. Each two-minute recording period comprised five to nine serial blood flow determinations from which an average blood flow was calculated. Forearm blood flow was obtained pre-

exercise as well as every 15 minutes starting immediately post-exercise with eight FBF measurements throughout the recovery period.

Systolic arterial blood pressure (SBP) and diastolic arterial blood pressure (DBP) were measured non-invasively on the right arm by standard brachial sphygmomanometry. Blood pressure was measured every 15 minutes during the last minute of each FBF measurement. Mean arterial blood pressure (MAP) was computed as (SBP + 2 x DBP) / 3. Forearm vascular resistance (FVR) was calculated as MAP divided by FBF [24, 71]. Heart rate (HR) was obtained every five minutes from a "Polar" heart rate monitor.

Resolution of the instrumentation

Table 1 summarizes the resolution of the instrumentation used for data collection. The coefficient of variation was calculated using resting data for the following variables: HR, VO_2, BP, Trec, Tsk, and FBF. For both men and women, the coefficient of variation was calculated as (standard deviation / mean) X 100.

Table 1: Resolution of the instrumentation

Variables	Resolution of the instrumentation (units)	Coefficient of variation (%) Men	Women
HR	1 beat / min	12.7	17.9
VO2max	1 mL / kg * min	8.0	8.5
BP	5 mmHg	10.0	7.5
Trec	0.1 °C	0.8	0.8
Tsk	0.1 °C	3.2	4.8
FBF	0.1 mL /100 mL * min	36.0	23.8

Statistical analysis

Descriptive statistics (mean and S.D.) were calculated using "Excel" in Microsoft Office 1997. The formula to calculate S.D. in Excel used "n-1" as the denominator in the equation. Student t-tests for gender comparison were performed for age, body characteristics, VO_2max, and 45-minute run characteristics. Mean comparison for

dependent variables were analyzed using a two-way (2 X 9) repeated measures ANOVA for main effects of gender and time. Bonferroni adjustment post-hoc analysis was used for identification of significant differences. Statistical analyses were performed using "Sigmastat" (Jandel Corporation) and "Systat" (© 1990, SYSTAT, Inc.) statistical software packages. Unless otherwise specified, statistical significance was set at the $p < 0.05$ level.

A calculation of measurement error was obtained for the critical variables that were recorded in this study. To determine whether changes in sequential value result from "variability in measurements" versus "response to exercise", the reproducibility of these variables was examined via test-retest reliability [9]. Error calculation was performed by comparison (t-test) of two pre-exercise measurements (pre 1 and pre 2) which were obtained during the 20-minute pre-exercise testing period. Since there were no statistical differences between the mean measurement error of men and women for any of these variables, the data were combined. For FBF, the pre 1 and pre 2 values for each subject represented the average of 5-9 measurements in a two-minute recording period as described in the procedure's section. Error calculation of FBF is summarized in Table 9 of Appendix C. Similarly, error calculation of Trec and Tsk appear in Tables 10 and 11 of Appendix C, respectively. The differences in variables from the two tests were not statistically significant, as represented by p values greater than 0.05, indicating that there were no systematic trend of changes from pre 1 to pre 2. For FBF, the measurement error (0.4 ± 0.3) expressed as a percent of the mean resting FBF was 17.7 %. Similarly, the measurement errors for Trec (0.1 ± 0.1) and Tsk (0.3 ± 0.3), expressed as a percent of the mean resting values, were 0.3 and 1.0 % respectively.

RESULTS

Subjects' characteristics and maximal exercise data

No significant difference in age was observed between male and female subjects. As seen in Table 2, height, body mass, BMI, BSA, and maximal oxygen uptake expressed both as (L / min) and (mL / kg • min) were significantly higher in the

male group. On the other hand, BSA / mass ratio and SOS were significantly higher in the female group. Maximal heart rate (Tables 3 and 4 of Appendix B) was not different between groups (men: 193 ± 11 versus women: 199 ± 7 beats / min).

Table 2: Subjects' characteristics

Gender		Age (Years)	Height (m)	Body mass (kg)	BMI (kg/m^2)	BSA (m^2)	BSA/mass (m^2/kg)	SOS (mm)	VO_2max (L/min)	VO_2max (mL/min•kg)
Women	Mean	23	1.67	59.7	21.33	1.66	0.028	65.7	3.303	55
	S.D.	3	0.06	5.6	1.65	0.10	0.001	13.6	0.390	5
Men	Mean	22	1.85	78.6	23.10	2.01	0.026	46.7	4.851	62
	S.D.	4	0.08	6.5	1.36	0.12	0.001	18.7	0.314	5
Gender differences		N.S.	p<0.0001	p<0.0001	p=0.0086	p<0.0001	p<0.0001	p=0.0072	p<0.0001	p=0.0028

Submaximal exercise bout characteristics

All subjects ran at the same relative exercise intensity (75 % of VO_2max) and for the same duration (45 minutes). Consequently to their higher VO_2max values, the men ran at a significantly faster speed (13.0 ± 0.7 km / h) and over a greater distance (9.78 ± 0.54 km) than did the women (11.6 ± 0.9 km / h and 8.72 ± 0.66 km) (Table 3). In addition, the time per 200 m lap was significantly greater in women (62 ± 5 seconds) than men (55 ± 3 seconds). Immediately prior to the start of the run (time 0 in Figure 1), the mean heart rate in beats / min was 105 ± 35 for women and 84 ± 14 for men. These values were higher than pre-exercise values since the subjects had warmed up, stretched, and were exposed to the stress of initiating the experimental run. Although this difference (25 %) between genders may seem relatively elevated, it was not statistically significant ($p = 0.07$) as the standard deviations were high. Some of the subjects may have been nervous prior to the run resulting in elevated values immediately prior to running. Heart rate changes over the 45-minute run are illustrated in Figure 1. Mean heart rates (beats / min) calculated over the entire run were significantly higher in women (172 ± 11) than men (164 ± 8) ($p < 0.01$).

Table 3: Submaximal (75 % of VO_2max) run characteristics

Gender		Distance (km)	Speed (km / h)	Time/lap (s)
Women	Mean	8.72	11.6	62
	S.D.	0.66	0.9	5
Men	Mean	9.78	13.0	55
	S.D.	0.54	0.7	3
Gender differences		p=0.0003	p=0.0003	p=0.0004

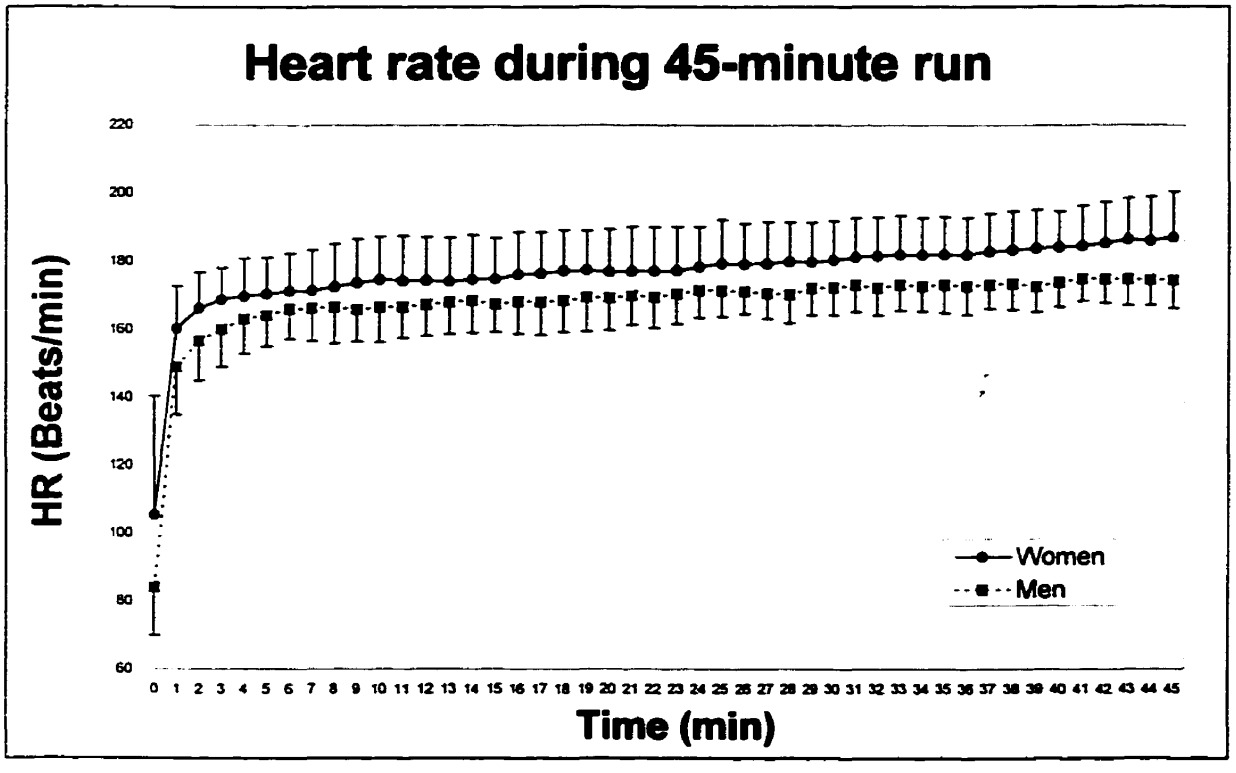

Figure 1: Heart rate (beats/min) during the 45-minute submaximal (75 % of VO_2max) run in men and women. Values are expressed as mean ± standard deviation.

Vascular and temperature responses

Baseline pre-exercise values

Baseline values for SBP, DBP, MAP, FBF, FVR, HR, Trec, Tsk measured at rest prior to the submaximal 45-minute exercise bout are shown in Table 4. Systolic and mean blood pressure were significantly higher in men than women. There were no significant gender-related differences in the pre-exercise values for DBP and Trec. Tsk and FBF were lower and FVR and HR higher in women than men. These differences, however, were not found to be statistically significant.

Table 4: Baseline pre-exercise values

Gender		SBP (mmHg)	DBP (mmHg)	MAP (mmHg)	FBF (mL/100mL·min)	FVR (units)	HR (beats/min)	Trec (°C)	Tsk (°C)
Women	Mean	107	73	85	2.1	42.26	67	37.0	31.0
	S.D.	8	6	6	0.5	12.11	12	0.3	1.5
Men	Mean	130	81	97	2.5	39.09	63	37.0	31.6
	S.D.	13	9	9	0.9	8.81	8	0.3	1.0
Gender differences		p<0.001	N.S.	p=0.018	N.S.	N.S.	N.S.	N.S.	N.S.

Immediate post-exercise and recovery values

Heart rate and blood pressure

Heart rate, systolic, diastolic and mean arterial blood pressure responses are shown in Figures 2, 3, 4, and 5, respectively. In each graph, the p values from the ANOVA, representing the main effects for gender and time, are shown in a citation box. The heart rate response was not significantly different between the two groups ($p = 0.074$). A main effect of time ($p < 0.001$) was however observed. The HR increased with exercise in both groups with the peak recovery value immediately post-exercise (men = 99 ± 8 beats / min; women = 106 ± 18 beats / min) with no gender-related differences. Post-exercise heart rate remained significantly elevated for 15 minutes

compared to pre-exercise in women, and 10 minutes in men, before returning to baseline pre-exercise levels (Figure 2).

A main gender effect ($p < 0.001$) was observed for systolic, diastolic and mean arterial blood pressure responses. Post-hoc analyses revealed SBP to be significantly higher in women at all times pre- and post-exercise (Figure 3). For DBP, there was a significant main effect for gender; however, post-exercise post hoc analysis did not identify any specific time period with a significant difference between groups (Figure 4). Mean arterial pressure was significantly higher in women during pre-exercise as well as post-exercise at 0, 45, 75, and 90 minutes (Figure 5). During recovery, the arterial blood pressure values were similar to pre-exercise values. Further analysis of the relative changes versus pre-exercise values demonstrated that the SBP decreased significantly more for the men than the women (Figure 6).

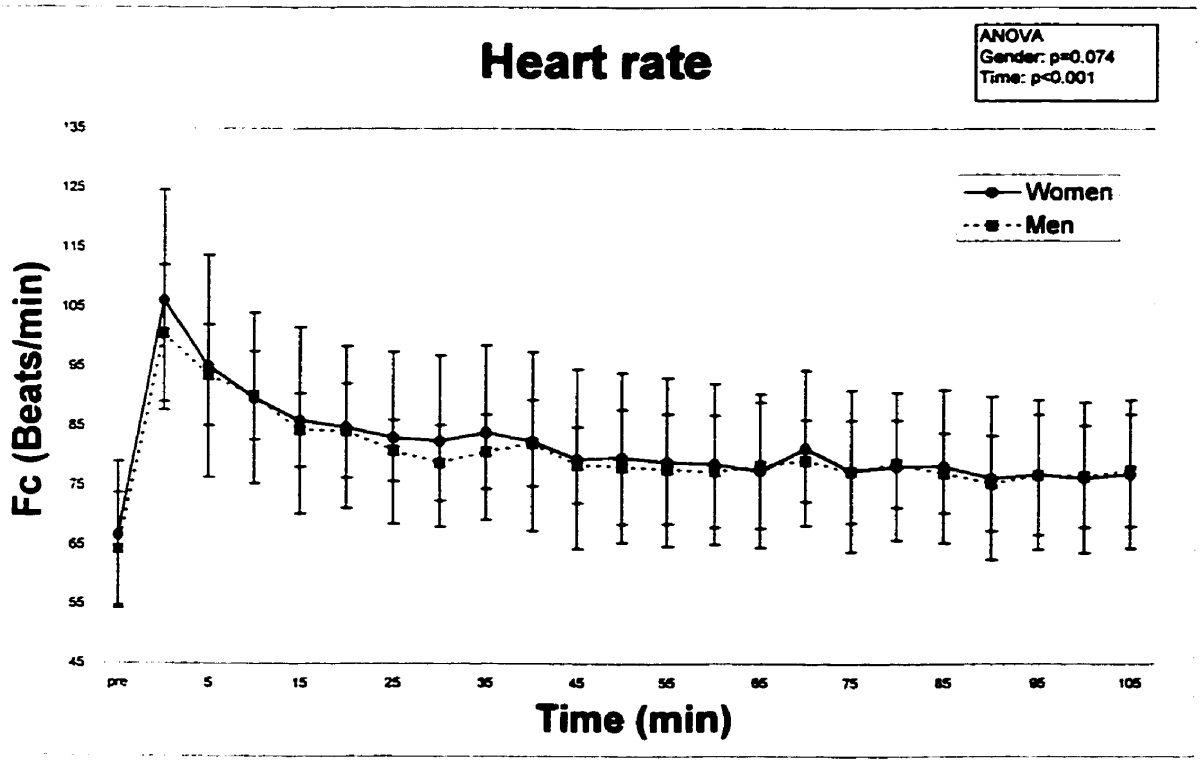

Figure 2: Heart rate (beats/min) pre- and post-exercise in men and women. Values are expressed as mean ± standard deviation. σ indicates $p < 0.05$ for post-hoc analysis revealing a specific difference between baseline (pre-exercise) and post-exercise values.

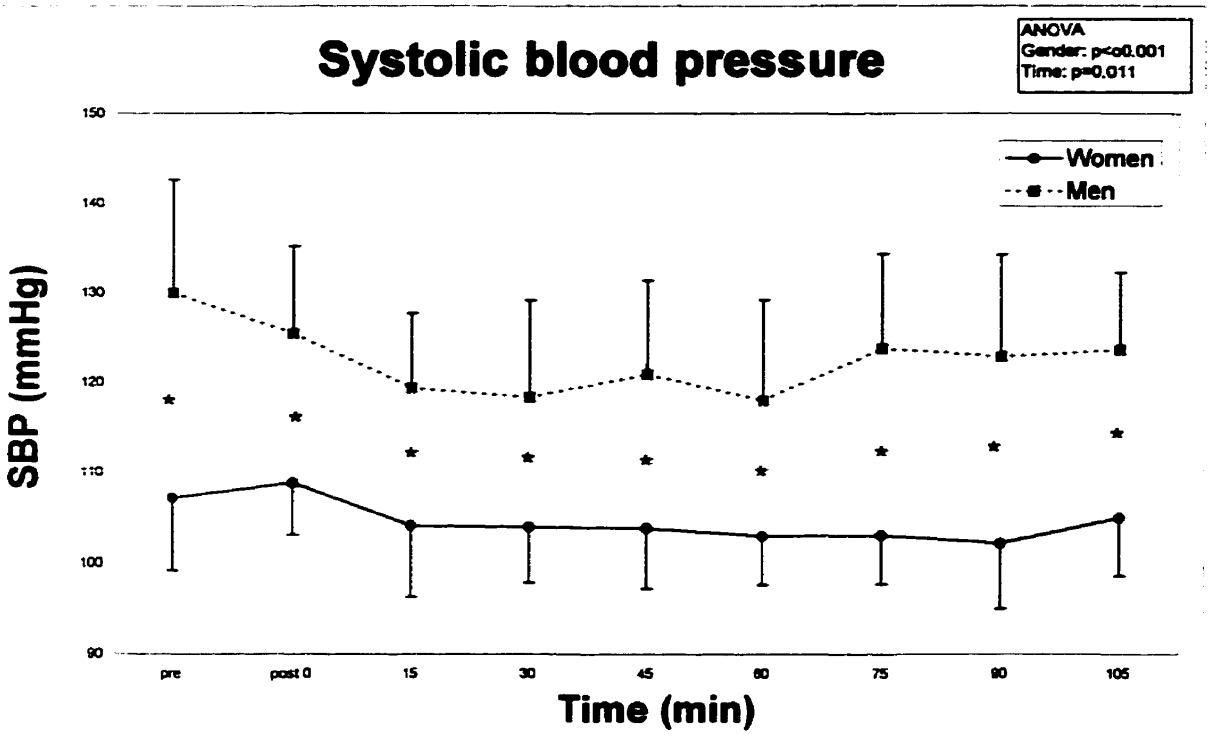

Figure 3: Systolic blood pressure (mmHg) pre- and post-exercise in men and women. Values are expressed as mean ± standard deviation. * indicates $p < 0.05$ for post-hoc analysis revealing a specific gender difference.

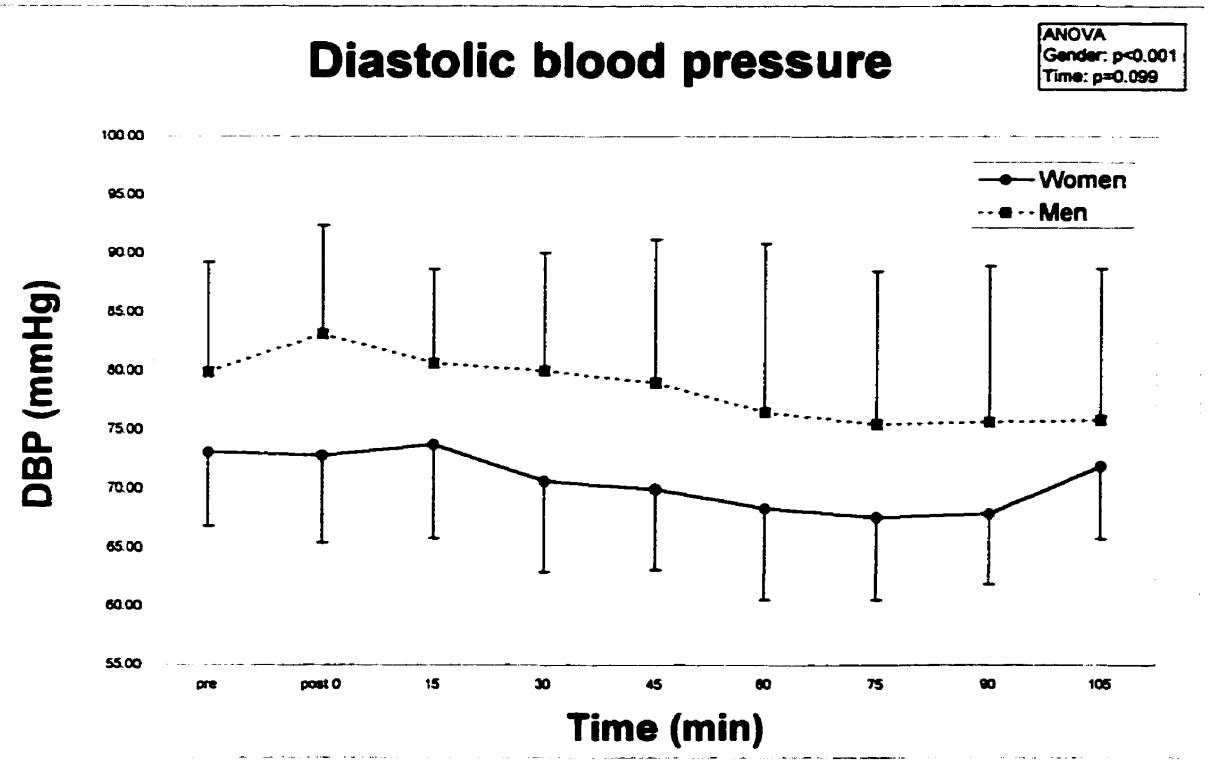

Figure 4: Diastolic blood pressure (mmHg) pre- and post-exercise in men and women. Values are expressed as mean ± standard deviation.

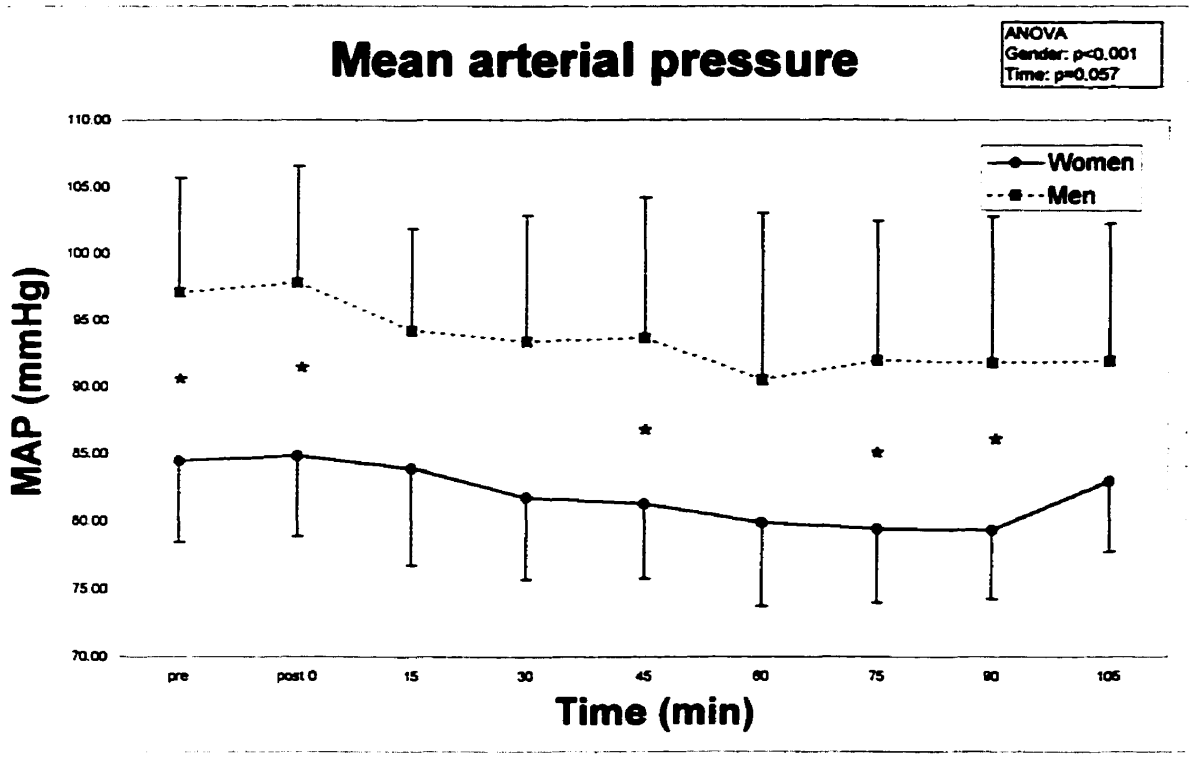

Figure 5: Mean blood pressure (mmHg) pre- and post-exercise in men and women. Values are expressed as mean ± standard deviation. * indicates $p < 0.05$ for post-hoc analysis revealing a specific gender difference.

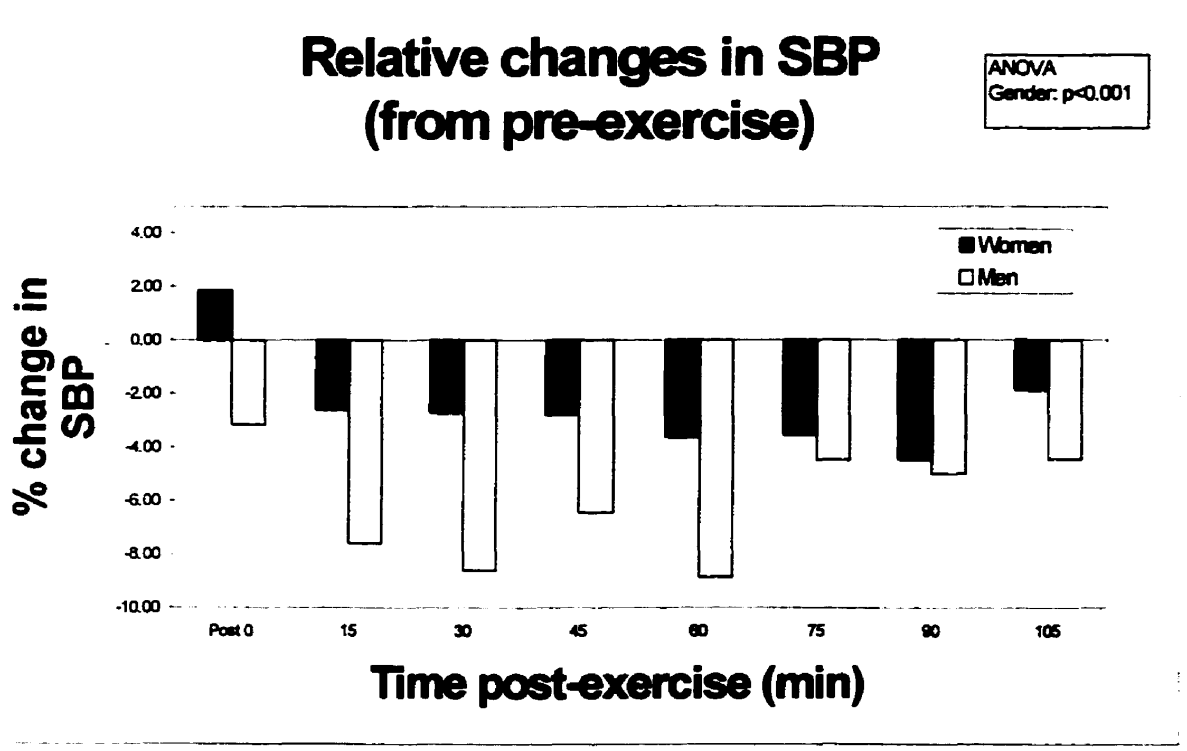

Figure 6: Relative changes in systolic blood pressure (%) versus pre-exercise values in men and women.

Temperature responses

Rectal and skin temperature variations immediately after exercise and recovery are shown in Figures 7 and 8, respectively. As expected, main effects of time were observed for both rectal and forearm temperatures. Responses in Trec were similar in both groups during the recovery period. Results from ANOVA revealed main gender effects for both rectal ($p = 0.011$) and skin ($p < 0.001$) temperatures. Post-hoc analysis for rectal temperature, however, did not identify significant differences at any specific time during recovery. Trec was highest at the first post-exercise measurement for both men and women (38.3 versus 38.2 °C); values decreasing thereafter to reach a value similar to pre-exercise in men but significantly lower than pre-exercise in women, as observed from 60 minutes post-exercise until the end of recovery. Further analyses of the relative changes in rectal temperature measurement from pre-exercise revealed a main gender effect ($p < 0.001$) (Figure 9).

Forearm temperatures were also qualitatively similar between genders, both groups showing highest values between 5 and 15 minutes into passive recovery with a gradual decrease thereafter (Figure 8). In men, Tsk decreased and stabilized at the pre-exercise value while in women, Tsk was significantly higher than pre-exercise between 0 and 25 minutes of recovery, and was significantly lower level than pre-exercise from 60 minutes post-exercise to the end of recovery. Post-hoc analyses revealed significant gender differences in Tsk for the last ten minutes (95 to 105) of the recovery period, women showing lower values than men. Further analysis of the relative changes in Tsk versus pre-exercise confirmed that women exhibit relative increases immediately post-exercise and 15 minutes into recovery respectively (4.0 % and 5.0 %) compared to men (1.6 % and 3.4 %). Similarly, after 60 minutes of recovery, relative changes from pre-exercise were higher in women (more than two-fold higher) compared to men (Figure 10).

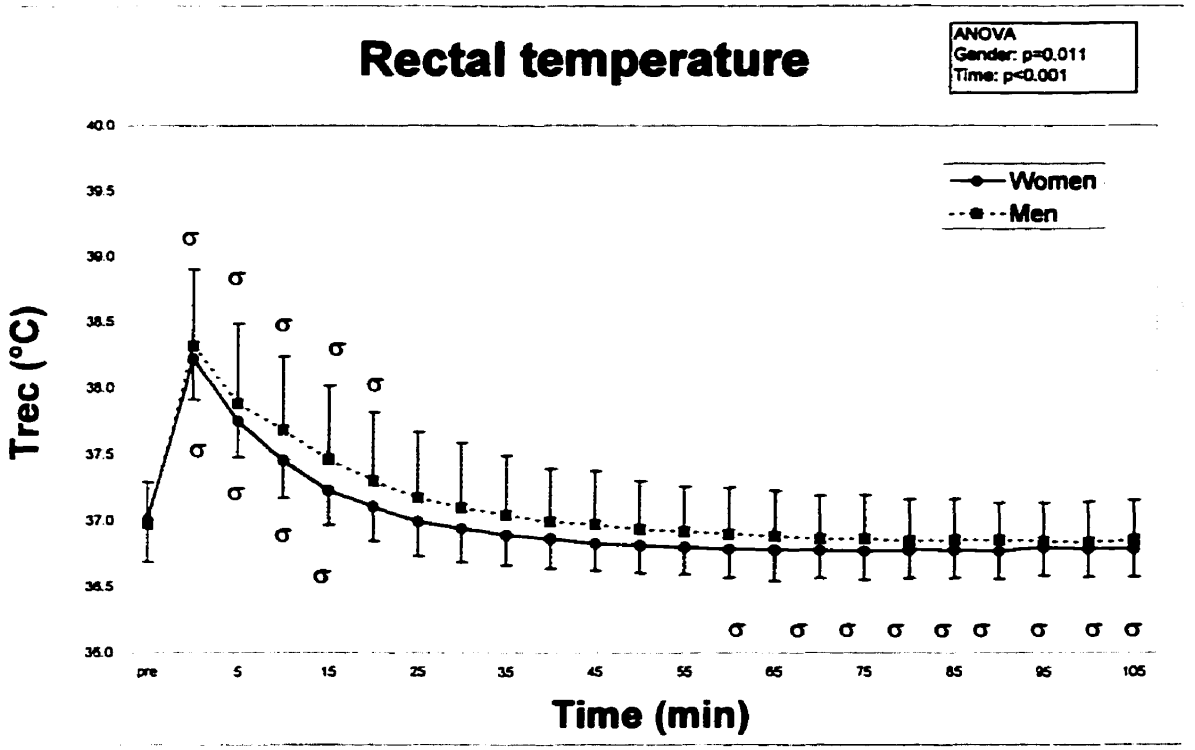

Figure 7: Rectal temperature (°C) pre- and post-exercise in men and women. Values are expressed as mean ± standard deviation. σ indicates $p < 0.05$ for post-hoc analysis revealing a specific difference between baseline (pre-exercise) and post-exercise values.

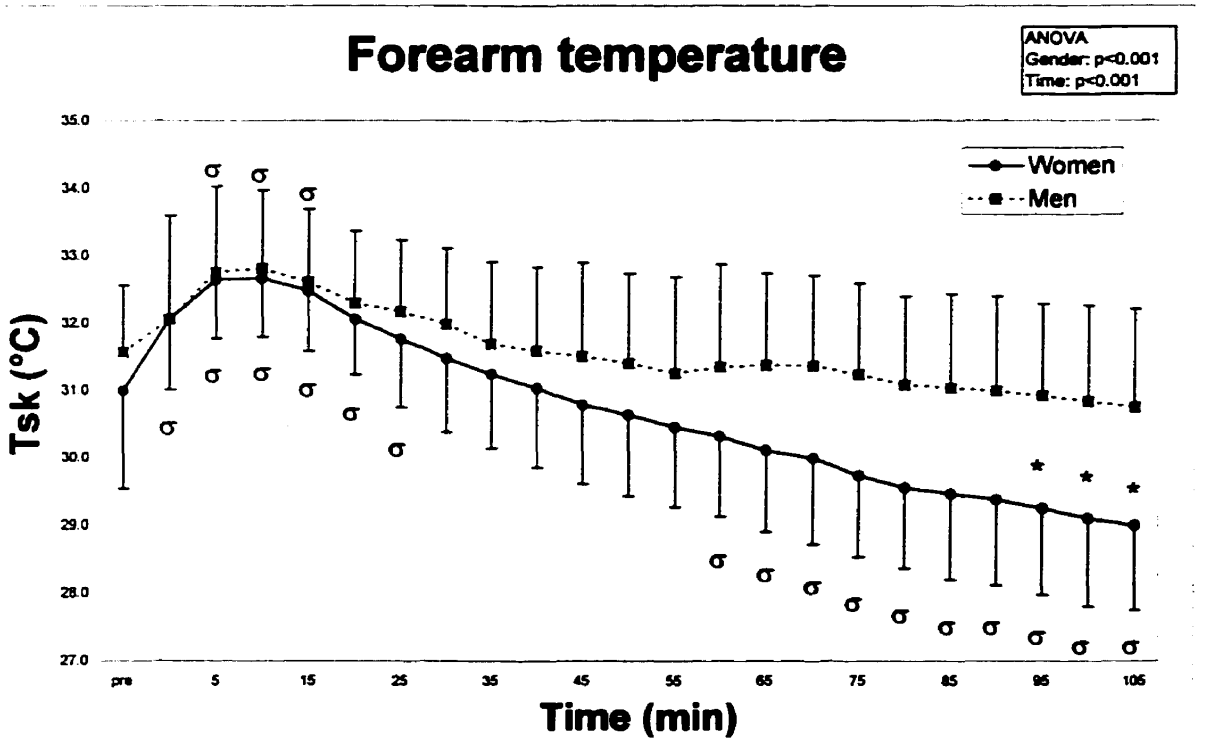

Figure 8: Forearm cutaneous temperature (°C) pre- and post-exercise in men and women. Values are expressed as mean ± standard deviation. * indicates $p<0.05$ for post-hoc analysis revealing a specific gender difference. σ indicates $p < 0.05$ for post-hoc analysis revealing a specific difference between baseline (pre-exercise) and post-exercise values.

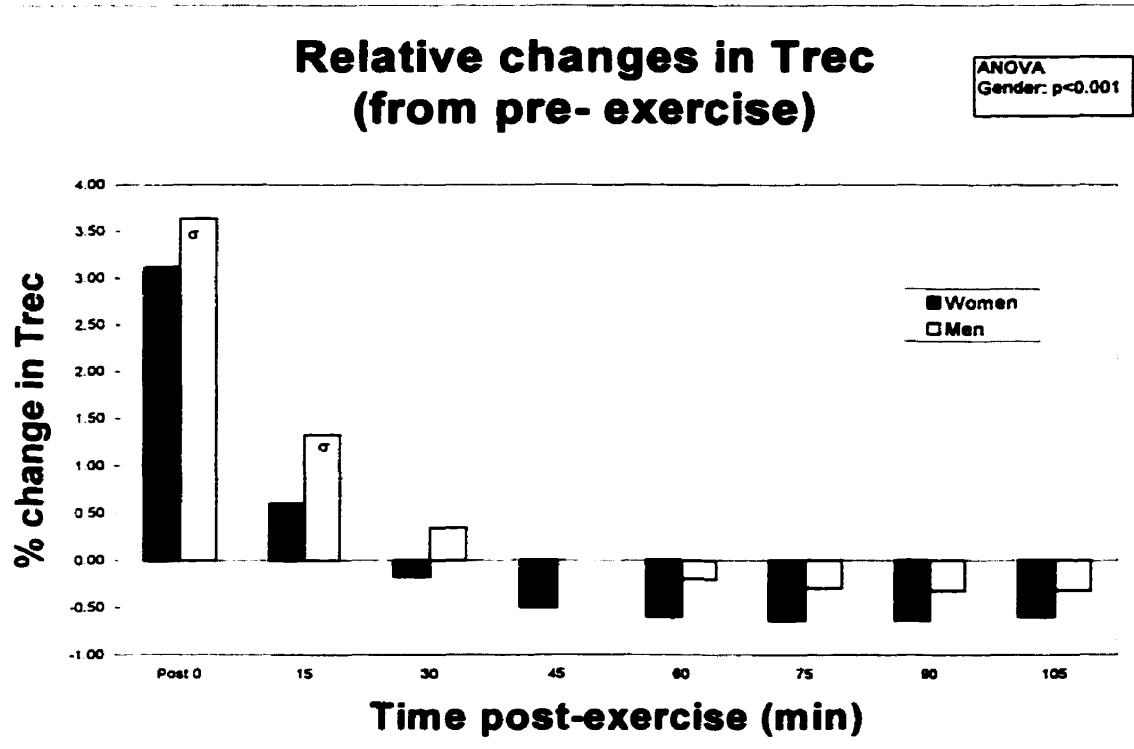

Figure 9: Relative changes in rectal temperature (%) versus pre-exercise values in men and women . σ indicates $p<0.05$ for post-hoc analysis revealing specific differences between baseline (pre-exercise) and post-exercise values.

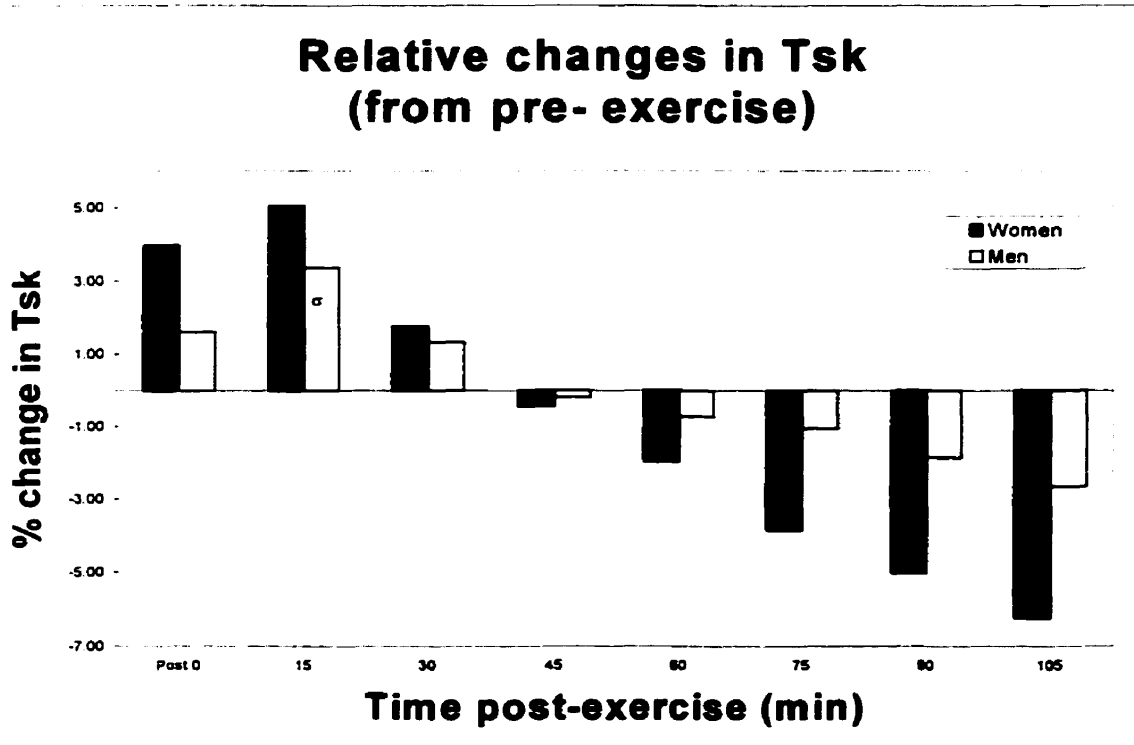

Figure 10: Relative changes in forearm cutaneous temperature (%) versus pre-exercise values in men and women. σ indicates $p < 0.05$ for post-hoc analysis revealing specific differences between baseline (pre-exercise) and post-exercise values.

Vascular responses

Forearm blood flow and vascular resistance responses are shown in Figures 11 and 12, respectively. The ANOVA revealed significant main effects for gender and time ($p < 0.001$) with the FBF being higher and FVR lower in men. Forearm blood flow (mL / 100 mL • min) increased significantly immediately post-exercise in both men (6.3 ± 2.1) and women (5.0 ± 1.9) and gradually returned to pre-exercise values thereafter (Figure 11). Post-hoc analysis did not identify specific gender-related differences at any specific time. Further analysis of the relative changes in post-exercise versus pre-exercise FBF (Figure 13) values revealed that women's FBF decreased relatively more than men's from 45 minutes post-exercise until the end of the recovery. Compared to pre-exercise values, FBF at 105 minutes post-exercise was 20.7 % lower in women and 6.8 % higher in men.

As expected, FVR exhibited an inverse response compared to FBF, decreasing significantly immediately post-exercise in both men (16.83 ± 7.59 units) and women (19.61 ± 7.51 units) and increasing back to pre-exercise values thereafter (Figure 12). Post-hoc analysis did not show specific gender differences either pre- or post-exercise. Further analysis of the relative changes (post- versus pre-exercise) indicate similar decreases in FVR in men (54.5 %) and women (51.8 %) immediately post-exercise (Figure 14). From 30 to 105 minutes of recovery however, women increased their FVR up to 35 % more than the men.

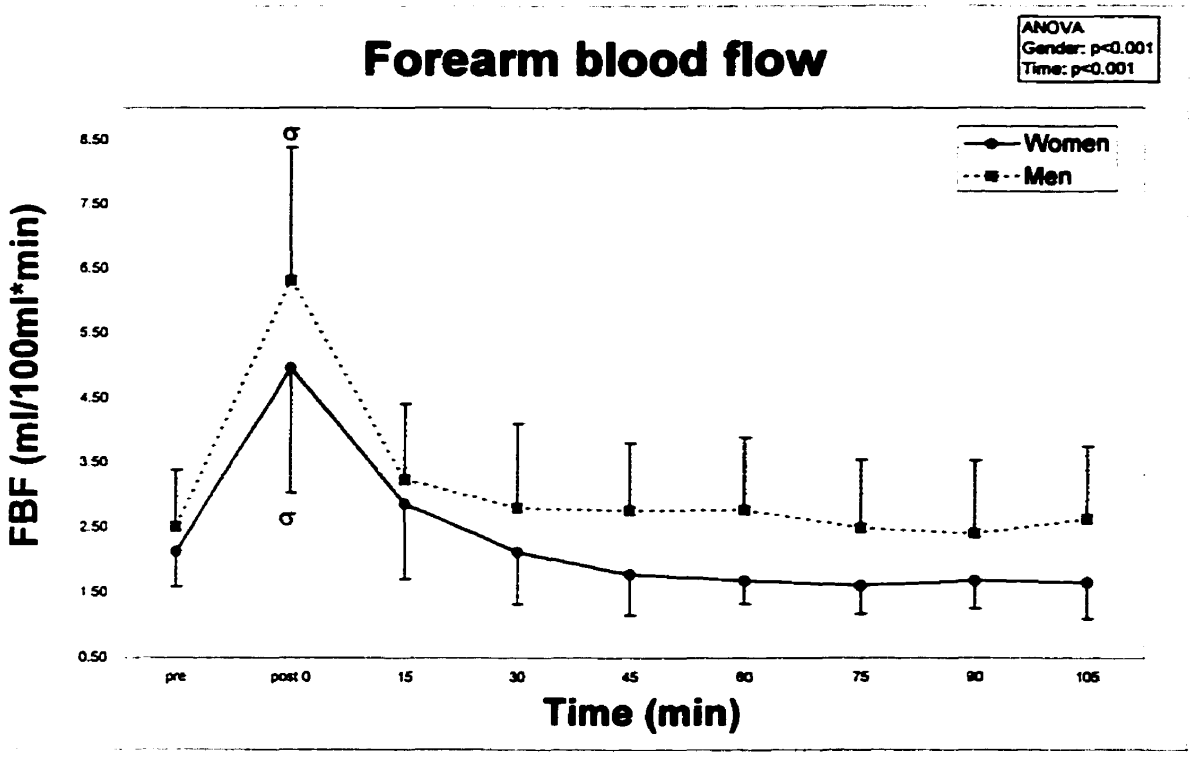

Figure 11: Forearm blood flow (mL / 100mL • min) pre- and post-exercise in men and women. Values are expressed as mean ± standard deviation. σ indicates $p < 0.05$ for post-hoc analysis revealing specific differences between baseline (pre-exercise) and post-exercise values.

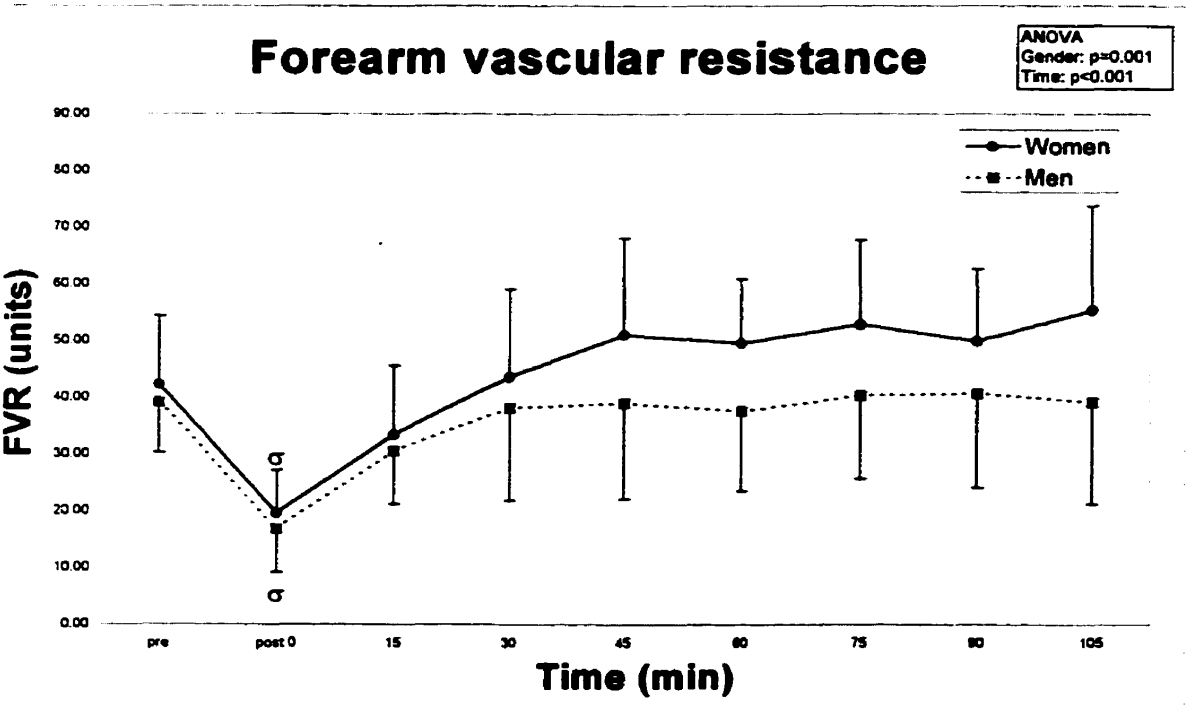

Figure 12: Forearm vascular resistance (units) pre- and post-exercise in men and women. Values are expressed as mean ± standard deviation. σ indicates $p < 0.05$ for post-hoc analysis revealing specific differences between baseline (pre-exercise) and post-exercise values.

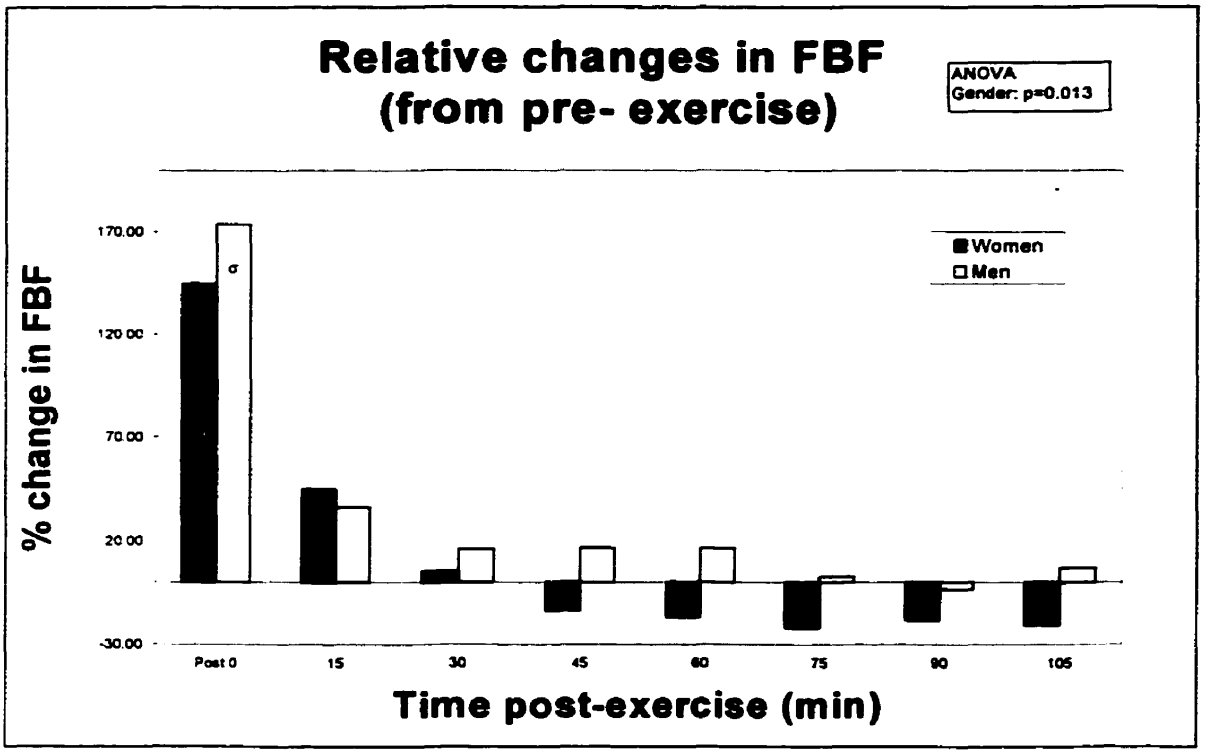

Figure 13: Relative changes in forearm blood flow (%) versus pre-exercise values in men and women. σ indicates $p < 0.05$ for post-hoc analysis revealing specific differences between baseline (pre-exercise) and post-exercise values.

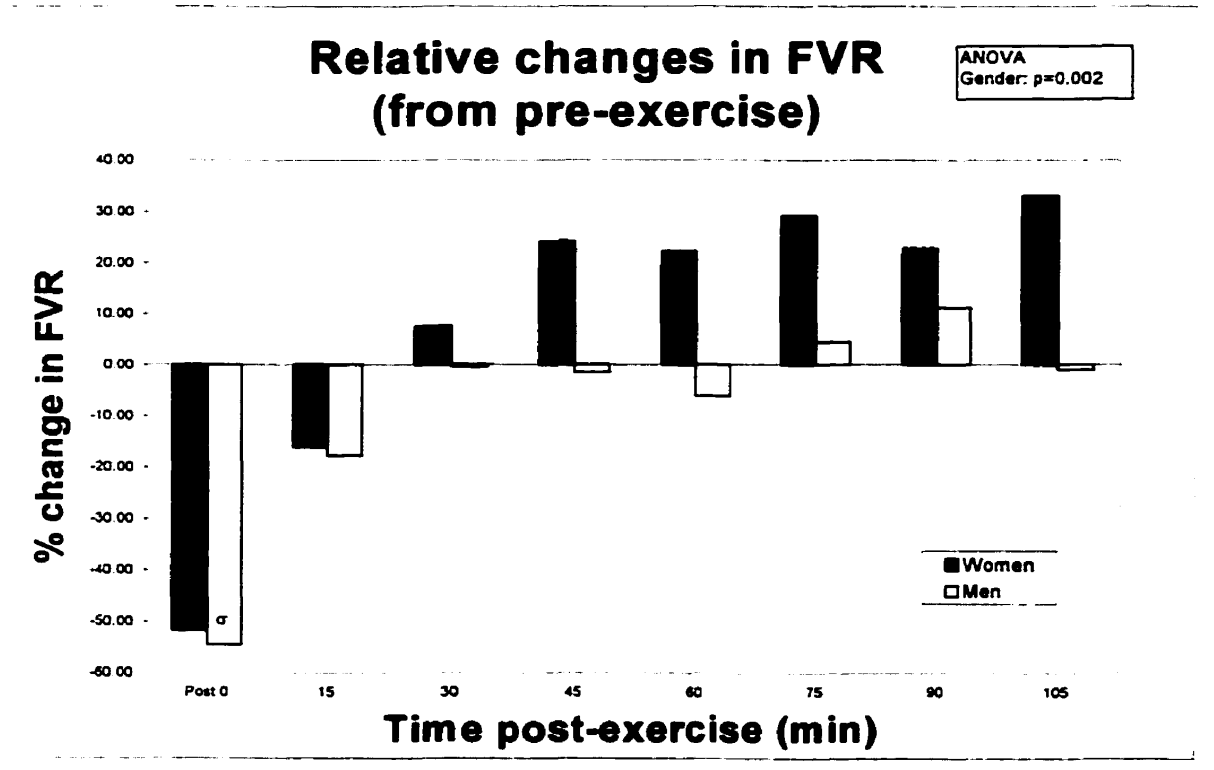

Figure 14: Relative changes in forearm vascular resistance (%) versus pre-exercise values in men and women. σ indicates $p < 0.05$ for post-hoc analysis revealing specific differences between baseline (pre-exercise) and post-exercise values.

DISCUSSION

Gender effect during exercise recovery

The major finding from this study is a significant main gender effect for forearm blood flow as well as for rectal and skin temperatures, during recovery from dynamic submaximal exercise. Indeed, results from the present study indicate women to consistently show a lower blood flow than men. This is in general agreement with the few investigations of gender-related differences in cutaneous blood flow in a neutral environment [12, 27, 110]. Results from finger blood flow measurements obtained at rest in neutral conditions showed women to have values more than twice as low as that of men [12, 27]. Similarly, Montgomery et al. [110] found leg blood flow index to be 22 % lower in female than male subjects. The present results are thus in agreement with these findings showing a 16 % lower resting forearm blood flow in women.

Few investigations have examined gender-related differences in peripheral blood flow in response to exercise. The FBF response of men and women (20 to 73 years) to exercise in a warm environment have revealed no gender-related difference [59]. In the present study, similar increases in FBF immediate post-exercise were found in both men and women (173 and 144 %). However, FBF measured at 105 minutes post-exercise indicated values 7 % higher than pre-exercise in men but 21 % lower than pre-exercise in women.

Thermogenic reflex components

The control of cutaneous blood flow is dependent on both thermogenic and non-thermogenic reflexes [72]. Thermogenic reflexes are those in which responses are induced by changes in internal as well as peripheral temperatures [72]. Indeed, changes in internal temperature have been found to influence the relationship between skin temperature and skin blood flow [72, 76, 116, 117].

In the present study, a main effect of gender was found for rectal or internal temperature, which could thus contribute to differences in thermogenic reflexes. A significant increase in rectal temperature from pre-exercise values was observed immediately post-exercise with maximal values of 38.3 ± 0.6 °C in men and 38.2 ± 0.3 °C in women. Increases in rectal temperature ranging between 0.5 and 1.4 °C are generally found following prolonged dynamic exercise in neutral ambient temperature [17, 37, 71, 151]. The increases found in the present study are thus typical responses to exercise. Rectal temperature decreased gradually during recovery reaching pre-exercise levels after approximately 30 minutes, which is in agreement with general rectal temperature behavior during recovery in neutral ambient temperature [17, 37, 71]. The present results hence support the involvement of a thermogenic reflex control of peripheral blood flow since the time period during which the major decrease in blood flow was observed (between 0 and 15 minutes post-exercise) also coincided with the time period during which the greatest decrease in core temperature occurred. However, while rectal temperature had returned to baseline in both genders after 55 minutes of recovery, a further fall in rectal temperature was found thereafter in women.

In contrast, peak forearm skin temperature of men and women (32.8 ± 1.3 and 32.7 ± 0.9 °C respectively) was not recorded immediately post-exercise but five to ten minutes later, remaining elevated for the first 15 to 25 minutes of recovery. Following an initial rise in FBF and skin temperature, values decreased gradually with time, skin temperature values returning to baseline in male subjects after approximately 35 minutes but decreasing further in female subjects to reach values significantly lower than baseline from 60 to 105 minutes post-exercise. The magnitude of change in skin temperature from the dynamic leg exercise is in agreement with reports showing peak recovery skin temperature ranging between 32.0 and 33.6 °C for exercises of 30 to 45 minute duration in neutral environment [17, 37]. Such a pattern in the peak response of skin temperature following exercise has not been consistently reported; recovery studies in neutral environment generally showing peak skin temperature to occur immediately post-exercise [17, 37]. Results from both of these studies where however observed using cycling exercise. Differences could also be attributed to measurement error since duplicate measurements of skin temperature were not obtained in the present study. Although single-spot measurements of skin temperature may be criticized on grounds of potential differences between cutaneous sites [70], in the present study, the same

investigator placed all cutaneous probes and care was taken to minimize inter-subject variation.

In the present study, it was viewed desirable for the subjects to shower and change into dry clothes prior to the initiation of post-exercise data collection to best reproduce usual exercise routines and to avoid additional heat dissipation through evaporation of garments wet from perspiration. This mechanism is known to proceed for some time after exercise completion and thus, would have contributed to heat dissipation even if subjects had been invited to change into dry clothes immediately after exercise. Subjects were instructed to set the water temperature to warm but not hot temperatures and to return to the laboratory as quickly as possible. Although the time elapsed between cessation of exercise and collection of recovery data was less than 10 minutes, it is possible that these conditions influenced the pattern of skin temperature response. However, the present results are comparable to forearm skin temperatures reported in men under comparable exercise and environmental conditions in research designs where a shower was not included [91, 93, 151]. In addition, both male and female subjects received an identical treatment, the standard deviations in rectal temperature measurements were similar for measurements made both prior to and following the shower, and gender-related differences in skin temperature were not observed in the immediate but rather in the late post-exercise response. It thus appears unlikely that this factor acted as a confounder in the observed gender-related differences even though the significant differences in BSA / mass ratio and skinfolds observed between the genders could potentially have altered the responses to the shower.

It is interesting that the pattern of response in forearm blood flow was not in time with skin temperature observations. Indeed, maximal forearm blood flow values were found at the first post-exercise measurement period (post 0), values decreasing markedly between 0 and 15 minutes of sitting recovery, a period during which skin temperature remained elevated. The magnitude of increase in forearm blood flow observed in the present study following running exercise is in agreement with the literature generally showing a 0.4 to 3 fold increase in forearm blood flow following cycling exercise [22, 25, 78, 121]. Running involves not only legs but also some arm action, which could have increased arm blood flow compared to cycling exercises. Since blood flow was not measured at times exactly coincident with skin temperature

measurement, it is difficult to establish a definite time relationship between these parameters. A clear explanation for the delayed response in peak skin temperature compared to forearm blood flow remains to be provided. One possibility is that there exists a lag-time for heat transfer through biological tissues. That is, the increase in FBF results in the initiation of heat transfer from the blood vessels to the skin surface, culminating in an increase in skin temperature. The duration of this heat transfer process could be responsible for the lag-time in peak skin temperature observed in the present study.

Differences in heat transfer could also be related to differences in body surface area to mass (BSA / mass) ratio. The present results are consistent with the general observation of a greater BSA / mass ratio in women compared to men [5]. One implication of the larger BSA / mass ratio is that, for any given temperature gradient between the skin and the environment, women have a faster heat exchange with the environment, through conduction, convection, and radiation. It is therefore possible that the greater BSA / mass ratio in women caused them to loose their body heat earlier than men, hence resulting in a greater fall in core temperature (below baseline) and consequently a greater vasoconstrictive response explaining the lower skin temperature.

Non-thermogenic reflexes

Non-thermogenic reflexes such as cardiopulmonary baroreflexes, sensitive to changes in central blood volume, contribute to the regulation of cutaneous blood flow. Under neutral and cold environments, skin temperature has consistently been found to be lower in women [5, 6, 28, 46, 47, 48, 115, 146, 150, 157, 158]. This phenomenon has traditionally been attributed to a higher sympathetic afferent vasoconstrictor activity in women, although a specific explanation for this higher resting tone has not been provided. More recently, Kellogg et al. [84, 86] have used bretylium, a selective noradrenergic vasoconstrictor blockade, to examine the role of active noradrenergic vasoconstrictor reflexes in the control of blood flow during exercise. Results demonstrated that the vasoconstriction found upon exercise initiation could be largely and entirely accounted for by enhanced active vasoconstrictor tone. The use of bretylium blockade, during lower body negative pressure application to stimulate cardiopulmonary baroreflexes,

similarly indicated that the induced vasoconstrictor response could be attributed to active vasoconstriction in normothermia. In addition, the cardiopulmonary baroreflex also appears to control the active vasodilator system in hyperthermic conditions.

Differences in the effects of exercise on cardiopulmonary reflex loading conditions, such as central blood volume, could thus contribute to the non-thermogenic component in the control of blood flow. Gender-related differences in cardiopulmonary baroreflex gain and / or sensitivity have previously been reported [39, 40, 45, 110]. Gender-related differences in forearm blood flow during recovery from exercise could thus be related to differences in post-exercise central blood volume resulting in differences in non-thermogenic reflex activation. Prolonged exercise, such as used in the present study, is known to decrease intravascular volume and thus central blood volume due to both plasma volume shifts between intravascular and extravascular compartments as well as water losses through sweating [26]. Thus, the occurrence of a greater fall in central blood volume in women compared to men could result in greater unloading of cardiopulmonary baroreceptors and greater active vasoconstrictor reflexes.

Central blood volume was not directly measured in the present study. The differences in mean arterial pressure could however be used as an index of the efficiency of baroreflexes to maintain blood pressure. Results indicate mean arterial pressure to be significantly lower in women before exercise as well as at 0, 45, 75 and 90 minutes post-exercise. However, calculated changes in mean arterial pressure as a result of the prolonged exercise bout were not significantly different between groups. Sweat loss could also contribute to lowering central blood volume. A greater relative water loss in female compared to male subjects could thus also contribute to a greater stimulation of vasoconstrictor reflexes. Unfortunately, the influence of subjects' hydration state and / or water losses was not measured in the present study.

Similarly, changes in central blood volume and intravascular water losses in response to exercise may be related to fitness level. In the present study, an attempt was made to control for fitness level by having all subjects exercise at the same relative intensity. Although changes in core temperature is directly related to the absolute exercise intensity, comparison of steady-state core temperatures in different individuals have been found to be better correlated with relative than with absolute exercise

intensity [88]. Nonetheless, an ideal scenario would have been to compare men and women with similar aerobic capacity while exercising at the same absolute (and therefore relative) exercise intensity.

Conclusion

Results from the present study demonstrate the existence of gender-related differences in cutaneous blood flow as well as in rectal and skin temperatures during recovery from dynamic submaximal exercise. Unfortunately, the design of the present study does not allow to provide a precise explanation for this observation. These findings can however be used to provide insights into possible mechanisms and represent a basis from which further study may be inspired.

APPENDICES

APPENDIX A

REFERENCES

REFERENCES

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APPENDIX B

INDIVIDUAL SUBJECTS' CHARACTERISTICS

Table 1: Individual body characteristics for the men

Subjects	Age (yrs)	Height (m)	Body mass (kg)	BMI (kg/m^2)	BSA (m^2)	BSA/mass (m^2/kg)	SOS (mm)
1	21	1.88	76.9	21.8	2.00	0.026	48.4
2	21	1.75	75.7	24.7	1.92	0.025	52.4
3	20	1.96	85.1	22.2	2.15	0.025	36.5
4	33	1.75	67.2	24.0	1.81	0.027	38.5
5	24	1.88	85.0	24.0	2.11	0.025	93.1
6	19	1.88	84.5	23.9	2.10	0.025	48.4
7	21	1.84	73.4	21.8	1.94	0.026	34.9
8	24	1.87	86.1	24.6	2.11	0.025	63.2
9	19	1.94	77.2	20.5	2.04	0.026	39.9
10	21	1.90	83.0	23.0	2.09	0.025	34.4
11	22	1.73	71.0	23.7	1.85	0.026	24.1
Mean	22	1.85	78.6	23.1	2.01	0.026	46.7
S.D.	4	0.08	6.5	1.4	0.12	0.001	18.7

Table 2: Individual body characteristics for the women

Subjects	Age (yrs)	Height (m)	Body mass (kg)	BMI (kg/m^2)	BSA ($m^{2)}$	BSA/mass (m^2/kg)	SOS (mm)
1	22	1.63	57.8	21.8	1.62	0.028	56.0
2	27	1.68	64.3	22.8	1.73	0.027	90.0
3	19	1.78	64.7	20.4	1.79	0.028	62.0
4	22	1.68	54.0	19.1	1.59	0.029	63.0
5	24	1.65	53.4	19.6	1.56	0.029	39.9
6	26	1.65	53.0	19.5	1.56	0.029	52.5
7	22	1.57	51.1	20.7	1.49	0.029	72.4
8	29	1.62	67.4	25.7	1.74	0.026	69.0
9	22	1.73	66.2	22.1	1.78	0.027	75.0
10	25	1.59	54.3	21.5	1.55	0.029	66.0
11	21	1.71	60.2	20.6	1.69	0.028	67.3
12	20	1.68	61.6	21.8	1.70	0.028	76.1
13	22	1.71	63.0	21.8	1.73	0.027	72.7
14	26	1.74	64.5	21.3	1.77	0.027	66.3
Mean	23	1.67	59.7	21.3	1.66	0.028	66.3
S.D.	3	0.06	5.6	1.7	0.10	0.001	11.9

Table 3: Treadmill results for the men

Subjects	VO_2max (L/min)	VO_2max (mL/min•kg)	HRmax (Beats/min)
1	5.051	65.6	195
2	4.876	64.2	191
3	5.356	63.0	179
4	4.298	64.1	180
5	4.446	52.3	198
6	5.241	62.0	190
7	5.035	68.6	204
8	4.783	55.6	212
9	4.718	61.1	178
10	4.778	57.6	197
11	4.785	67.4	196
Mean	4.852	62.0	193
S.D.	0.314	5.0	11

Table 4: Treadmill results for the women

Subjects	VO_2max (L/min)	VO_2max (mL/min*kg)	HRmax (Beats/min)
1	3.251	56.0	188
2	3.330	51.8	200
3	3.892	59.9	200
4	3.110	57.6	188
5	3.354	63.3	195
6	3.362	63.4	194
7	2.513	49.3	204
8	3.894	58.1	203
9	3.748	56.8	197
10	2.711	49.9	198
11	3.091	51.4	211
12	3.418	55.5	204
13	3.235	51.3	195
14	3.329	51.6	206
Mean	3.303	55.4	199
S.D.	0.390	4.7	7

Table 5: Individual skinfold results (mm) for the men

Subjects	Triceps	Biceps	Subscapula	Suprailiac	Medial calf	Sum
1	9.1	4.1	11.3	16.8	7.1	48.4
2	9.3	4.3	12.3	18.4	8.1	52.4
3	6.1	3.2	7.9	9.9	9.4	36.5
4	4.8	4.1	9.6	15.1	4.9	38.5
5	14.8	8.1	13.6	27.9	28.7	93.1
6	8.1	4.7	15.0	11.4	9.2	48.4
7	7.3	3.9	8.5	8.8	6.4	34.9
8	6.9	4.0	17.7	27.5	7.1	63.2
9	6.1	4.0	11.4	12.2	6.2	39.9
10	5.1	3.3	11.8	9.6	4.6	34.4
11	4.3	2.5	8.1	4.4	4.8	24.1
Mean	7.4	4.2	11.6	14.7	8.8	46.7
S.D.	3.0	1.4	3.0	7.5	6.8	18.7

Table 6: Individual skinfold results (mm) for the women

Subjects	Triceps	Biceps	Subscapula	Suprailiac	Medial calf	Sum
1	11.8	3.9	9.5	18.2	12.6	56.0
2	14.9	9.0	25.4	31.8	8.8	89.9
3	14.4	8.5	11.9	16.6	10.6	62.0
4	14.0	6.1	12.0	14.6	16.5	63.2
5	8.9	4.7	6.9	10.3	9.1	39.9
6	14.2	6.9	10.0	10.7	10.7	52.5
7	16.6	10.9	14.6	19.0	11.3	72.4
8	17.0	9.7	14.9	14.0	13.4	69.0
9	14.9	8.6	19.6	19.5	12.4	75.0
10	12.5	6.8	13.9	18.5	14.3	66.0
11	16.4	6.6	12.7	16.9	14.7	67.3
12	16.1	4.8	13.2	22.6	19.4	76.1
13	15.5	9.5	15.4	9.9	22.4	72.7
14	16.9	4.5	15.3	15.0	14.6	66.3
Mean	14.6	7.2	14.0	17.0	13.6	66.3
S.D.	2.3	2.2	4.5	5.7	3.8	11.9

Table 7: Individual training profile for the men

Subjects	Running frequency per week	Weight training frequency per week	Others
1	2	3	Varsity basketball
2	2	3	Intramural basketball
3	2	3	Varsity basketball
4	3	3	Varsity soccer
5	4	0	Intramural basketball
6	2	3	Varsity basketball
7	2	3	Varsity basketball
8	3	1	Biking 2 X / wk
9	3	4	Varsity downhill ski
10	4	4	Swimming 2 X / wk
11	2	3	Swimming 2 X / wk

Table 8: Individual training profile for the women

Subjects	Running frequency per week	Weight training frequency per week	Others
1	4	4	None
2	2	4	None
3	2	2	Varsity basketball
4	3	2	Biking 2 X / wk
5	3	2	Swimming 3 X / wk
6	6	3	None
7	2	2	Aerobic 1-2 X / wk
8	3	0	Stair master 3 X / wk
9	2	2	Biking 4 X / wk
10	3	3	None
11	3	2	None
12	3	2	None
13	2	2	Swimming 3 X / wk
14	2	1	Rowing 2 X / wk

APPENDIX C

TEST-RETEST ANALYSIS

Table 9: Test-retest analysis of resting FBF

		FBF (mL / 100 mL • min)		
Subjects	Gender	Pre 1	Pre 2	Measurement error (Pre 1 - Pre 2)
1	Women	2.5	2.2	0.3
2	Women	2.2	2.0	0.2
3	Women	1.9	1.8	0.1
4	Women	2.9	2.3	0.6
5	Women	2.8	2.1	0.7
6	Women	2.0	1.9	0.1
7	Women	1.9	1.8	0.1
8	Women	2.4	1.9	0.5
9	Women	2.9	2.5	0.4
10	Women	2.0	1.9	0.1
11	Women	1.8	1.5	0.3
12	Women	1.1	1.0	0.1
13	Women	1.6	1.3	0.3
14	Women	4.0	2.4	1.6
15	Men	2.5	1.8	0.7
16	Men	4.0	3.5	0.5
17	Men	2.8	2.6	0.2
18	Men	1.9	1.7	0.2
19	Men	1.3	1.6	0.3
20	Men	2.6	2.8	0.2
21	Men	2.6	2.2	0.4
22	Men	2.7	3.0	0.3
23	Men	2.3	2.6	0.3
24	Men	2.0	1.8	0.2
25	Men	2.3	2.0	0.3
Mean		2.4	2.1	0.4
S.D.		0.7	0.5	0.3
p value			p = 0.13	

Table 10: Test-retest analysis of resting Trec

		Trec (°C)		
Subjects	Gender	Pre 1	Pre 2	Measurement error (Pre 1 - Pre 2)
1	Women	37.4	37.2	0.2
2	Women	36.8	36.8	0.0
3	Women	37.2	37.1	0.1
4	Women	36.7	36.7	0.0
5	Women	37.5	37.4	0.1
6	Women	36.9	36.9	0.0
7	Women	37.6	37.6	0.0
8	Women	36.9	36.8	0.1
9	Women	36.8	36.7	0.1
10	Women	36.8	36.7	0.1
11	Women	36.9	36.8	0.1
12	Women	36.6	36.6	0.0
13	Women	37.2	37.1	0.1
14	Women	37.3	37.1	0.2
15	Men	37.0	37.0	0.0
16	Men	37.0	37.0	0.0
17	Men	37.1	37.0	0.1
18	Men	36.6	36.5	0.1
19	Men	36.9	36.7	0.2
20	Men	36.6	36.5	0.1
21	Men	37.1	37.0	0.1
22	Men	37.7	37.6	0.1
23	Men	37.4	37.4	0.0
24	Men	36.8	36.9	0.1
25	Men	37.0	37.0	0.0
Mean		37.0	37.0	0.1
S.D.		0.3	0.3	0.1
p value			p = 0.44	

Table 11: Test-retest analysis of resting Tsk

		Tsk (°C)		
Subjects	Gender	Pre 1	Pre 2	Measurement error (Pre 1 - Pre 2)
1	Women	31.8	31.6	0.2
2	Women	31.8	31.8	0.0
3	Women	31.3	30.7	0.6
4	Women	31.4	31.4	0.0
5	Women	32.4	31.7	0.7
6	Women	30.6	29.6	1.0
7	Women	32.6	32.6	0.0
8	Women	31.0	30.9	0.1
9	Women	32.2	31.8	0.4
10	Women	30.8	30.6	0.2
11	Women	30.4	30.8	0.4
12	Women	29.7	29.3	0.4
13	Women	31.7	31.4	0.3
14	Women	31.4	30.5	0.9
15	Men	31.6	31.0	0.6
16	Men	32.5	32.0	0.5
17	Men	31.0	30.6	0.4
18	Men	32.5	32.2	0.3
19	Men	29.6	29.9	0.3
20	Men	33.1	33.1	0.0
21	Men	32.5	32.8	0.3
22	Men	31.5	31.3	0.2
23	Men	31.7	31.4	0.3
24	Men	31.5	31.2	0.3
25	Men	31.4	31.7	0.3
Mean		31.5	31.3	0.3
S.D.		0.9	0.9	0.3
p value		$p = 0.34$		

APPENDIX D

SUMMARY OF DESCRIPTIVE AND INFERENTIAL STATISTICS

Table 12: Two-way repeated measures ANOVA (gender x time) for SBP

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
GENDER	17762.958	1	17762.958	246.268	0.000
TIME	1469.905	8	183.738	2.547	0.011
GENDER*TIME	436.358	8	54.545	0.756	0.642
ERROR	14930.604	207	72.129		

Table 13: Two-way repeated measures ANOVA (gender x time) for DBP

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
GENDER	3933.110	1	3933.110	44.317	0.000
TIME	1209.652	8	151.207	1.704	0.099
GENDER*TIME	206.026	8	25.753	0.290	0.969
ERROR	18371.104	207	88.749		

Table 14: Two-way repeated measures ANOVA (gender x time) for MAP

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
GENDER	7436.577	1	7436.577	117.657	0.000
TIME	976.384	8	122.048	1.931	0.057
GENDER*TIME	90.445	8	11.306	0.179	0.994
ERROR	13083.574	207	63.206		

Table 15: Two-way repeated measures ANOVA (gender x time) for FBF

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
GENDER	37.922	1	37.922	33.587	0.000
TIME	259.623	8	32.453	28.743	0.000
GENDER*TIME	5.148	8	0.643	0.570	0.802
ERROR	233.720	207	1.129		

Table 16: Two-way repeated measures ANOVA (gender x time) for FVR

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
GENDER	2502.506	1	2502.506	11.513	0.001
TIME	18077.985	8	2259.748	10.396	0.000
GENDER*TIME	1661.382	8	207.673	0.955	0.472
ERROR	44993.937	207	217.362		

Table 17: Two-way repeated measures ANOVA (gender x time) for HR

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
GENDER	453.257	1	453.257	3.226	0.074
TIME	19057.548	8	2382.193	16.956	0.000
GENDER*TIME	109.779	8	13.722	0.098	0.999
ERROR	29081.604	207	140.491		

Table 18: Two-way repeated measures ANOVA (gender x time) for Trec

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
GENDER	0.724	1	0.724	6.578	0.011
TIME	42.368	8	5.296	48.110	0.000
GENDER*TIME	0.281	8	0.035	0.319	0.958
ERROR	22.787	207	0.110		

Table 19: Two-way repeated measures ANOVA (gender x time) for Tsk

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
GENDER	40.615	1	40.615	25.784	0.000
TIME	156.631	8	19.579	12.429	0.000
GENDER*TIME	21.431	8	2.679	1.701	0.100
ERROR	326.069	207	1.575		

Table 20: Pre- and post-exercise values for male and female subjects

			SBP (mmgh)	DBP (mmgh)	MAP (mmgh)	FBF (ml/100 ml*min)	FVR (units)	HR (beats/min)	Trec (°C)	Tsk (°C)
Pre-exercise	Women	Mean	107	73	85	2.1	42.26	67	37.0	31.0
		S.D.	8	6	6	0.5	12.11	12	0.3	1.5
	Gender differences		p<0.001	N.S.	p=0.018	N.S.	N.S.	N.S.	N.S.	N.S.
	Men	Mean	130	81	97	2.5	39.09	63	37.0	31.6
		S.D.	13	9	9	0.9	8.81	8	0.3	1.0
Post-exercise 0 minute	Women	Mean	109	73	85	5.0*	19.61*	104*	38.2*	32.2*
		S.D.	6	7	6	1.9	7.51	18	0.3	1.1
	Gender differences		p<0.001	N.S.	p=0.011	p=0.275	N.S.	N.S.	N.S.	N.S.
	Men	Mean	125	84	98	6.3*	16.83*	99*	38.3*	32.1
		S.D.	10	9	9	2.1	7.59	11	0.6	1.5
Post-exercise 15 minutes	Women	Mean	104	74	84	2.9	33.47	86*	37.2*	32.5*
		S.D.	8	8	7	1.2	12.05	16	0.3	0.9
	Gender differences		p=0.002	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	Men	Mean	119	82	94	3.2	30.58	83	37.5*	32.6*
		S.D.	8	8	8	1.2	9.40	5	0.6	1.1
Post-exercise 30 minutes	Women	Mean	104	71	82	2.1	43.54	83	36.9	31.5
		S.D.	6	8	6	0.8	15.48	14	0.3	1.1
	Gender differences		p=0.006	N.S.	p=0.054	N.S.	N.S.	N.S.	N.S.	N.S.
	Men	Mean	118	81	93	2.8	38.09	78	37.1	32.0
		S.D.	11	10	9	1.3	16.26	6	0.5	1.1
Post-exercise 45 minutes	Women	Mean	104	70	81	1.8	50.97	80	36.8	30.8
		S.D.	7	7	6	0.6	17.00	15	0.2	1.2
	Gender differences		p<0.001	N.S.	p=0.024	N.S.	N.S.	N.S.	N.S.	N.S.
	Men	Mean	121	80	94	2.8	38.93	78	37.0	31.5
		S.D.	10	12	11	1.0	16.85	7	0.4	1.4
Post-exercise 60 minutes	Women	Mean	103	68	80	1.7	49.52	79	36.8*	30.3*
		S.D.	5	6	6	0.4	11.28	13	0.2	1.2
	Gender differences		p=0.003	N.S.	p=0.172	N.S.	N.S.	N.S.	N.S.	N.S.
	Men	Mean	118	77	90	2.8	37.55	76	36.9	31.3
		S.D.	11	15	13	1.1	14.07	8	0.4	1.5
Post-exercise 75 minutes	Women	Mean	103	68	79	1.6	52.82	78	36.8*	29.7*
		S.D.	5	7	5	0.4	14.79	13	0.2	1.2
	Gender differences		p<0.001	N.S.	p=0.02	N.S.	N.S.	N.S.	N.S.	N.S.
	Men	Mean	124	76	92	2.5	40.28	76	36.9	31.2
		S.D.	11	13	11	1.1	14.53	7	0.3	1.4
Post-exercise 90 minutes	Women	Mean	102	68	79	1.7	49.87	76	36.8*	29.4*
		S.D.	7	6	5	0.4	12.71	14	0.2	1.3
	Gender differences		p<0.001	N.S.	p=0.022	N.S.	N.S.	N.S.	N.S.	N.S.
	Men	Mean	123	76	92	2.4	40.62	74	36.9	31.0
		S.D.	11	14	11	1.1	16.53	6	0.3	1.4
Post-exercise 105 minutes	Women	Mean	105	72	83	1.7	55.35	77	36.8*	29.0*
		S.D.	6	6	5	0.6	18.38	12	0.2	1.3
	Gender differences		p<0.001	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	p<0.05
	Men	Mean	124	76	92	2.6	39.18	76	36.9	30.7
		S.D.	9	13	10	1.1	17.92	8	0.3	1.5

Baseline (pre-exercise) and post-exercise values for systolic blood pressure (SBP), diastolic blood pressure (DBP), mean blood pressure (MAP), forearm blood flow (FBF), forearm vascular resistance (FVR), heart rate (HR), rectal temperature (Trec), and forearm skin temperature (Tsk) for men and women. Values are mean and standard deviation. P values for significance of the gender differences. * $p<0.05$ for post-hoc revealing specific difference between baseline (pre-exercise) and post-exercise values (within gender).

APPENDIX E

MCGILL UNIVERSITY ETHICS APPROVAL

APPENDIX F

CONSENT FORM

Consent for exercise testing

I,_____(print name)
authorize Dr. David Montgomery, Dr. Hélène Perrault, and Ingrid Marchand to administer the exercise tests outlined below. I understand that I may discontinue the testing if at any time I experience unusual discomfort. I understand that the staff conducting the tests will ask me to discontinue the tests if any indication of abnormal response to the tests become apparent. I understand that I will perform the tests as listed below and I have the opportunity to question and discuss the exact procedure that will be followed.

Tests to be performed:

1) Aerobic capacity (one test) - You will warm-up on the treadmill for approximately 5 minutes at the speed you desire. Then, you will run on the treadmill for approximately 11-15 minutes during which the treadmill speed will commence at 8.045 km / h and 5 % grade. Every 2 minutes, the speed will increase 0.8045 km / h (keeping 5 % grade). You should run as long as possible so that a true maximum value can be obtain.

2) Moderate intensity run (one test) - You will run on the McGill indoor track at the speed at which you usually train for a total of 45 minutes. A heart rate monitor will be worn during the test.

3) Blood flow and temperature - For 2 hours following your run, you will sit in a testing room. During this time, your temperature and your forearm blood flow will be measured every 10 minutes. You may watch television, read or study.

I acknowledge that I have read this form and I understand the test procedure to be performed and the inherent risk and I consent to participate. I understand that the data will be released only to the principal investigators.

SIGNATURE OF SUBJECT:_____ **DATE:**_____