

**VENTILATORY AND THERMOREGULATORY RESPONSES
DURING CONTINUOUS EXERCISE IN THE HEAT**


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Entitled


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The objectives of this study were to study the effects of heat and continuous exercise on cardiorespiratory function and thermoregulatory responses and to compare the relationship between body ventilation and thermoregulation at rest and during continuous exercise in the heat. Six sedentary volunteers with average age 23.33 ± 1.02 years participated in 2 experiments each: 25-min sitting comfortably and exercising by bicycle at 75 Watt continuous workload until 70% HRR was approached in the heat chamber at $44.19 \pm 0.13^\circ\text{C}$, $58.62 \pm 0.47\% \text{RH}$. The aforementioned parameters were measured and recorded at five-minute intervals until the end of the study. The level for statistical difference was set at $\alpha < 0.05$.

It was found that minute ventilation, oxygen consumption, respiratory rate, heart rate, skin temperatures, and body temperature increased significantly during exercise in the heat ($p < 0.05$) while there was no significant difference at rest ($p > 0.05$). Rectal temperature did not change at rest and changed in minimal range during exercise under heat stress ($p > 0.05$). Mean arterial pressure did not change throughout both of the studies. RER were kept constant in range of 0.9-1 in both trials. RPE, thermal sensation, and thermal discomfort did not change at rest but gradually increased during exercise in the heat. It was concluded that the body dissipates additional heat out of the body via skin and ventilation to keep homeostasis of thermoregulation during exercise in the heat which causes a non-significant difference of rectal temperature throughout the study of exercise under heat stress.

**KEY WORDS : VENTILATION / THERMOREGULATION / CONTINUOUS
EXERCISE / HEAT**

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การตอบสนองทางด้านการหายใจและสมดุลอุณหภูมิกาย ขณะออกกำลังกายภายใต้ความร้อน
(VENTILATORY AND THERMOREGULATORY RESPONSES DURING
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บทคัดย่อ

การศึกษานี้มีวัตถุประสงค์เพื่อศึกษาผลของความร้อนและการออกกำลังกายอย่างต่อเนื่องภายใต้ความร้อนต่อการทำงานของระบบไหลเวียนและการหายใจ และการตอบสนองทางด้านสมดุลอุณหภูมิกาย ในชายไทยที่มีสุขภาพแข็งแรง การทดลองกระทำโดยให้อาสาสมัครจำนวน 6 คน มีอายุเฉลี่ย 23.33 ± 1.02 ปี ร่วมทำการทดลอง 2 ครั้ง คือ นั่งเฉยๆในห้องชาน้ำที่มีอุณหภูมิเฉลี่ย 44.19 ± 0.13 องศาเซลเซียส ความชื้นสัมพัทธ์ $58.62 \pm 0.47\%$ เป็นเวลา 25 นาที และออกกำลังกายโดยการขี่จักรยานด้วยความหนักคงที่ 75 วัตต์จนกระทั่งอัตราการเต้นหัวใจเพิ่มขึ้นถึง 70% ของอัตราการเต้นหัวใจสูงสุดที่อุณหภูมิและความชื้นสัมพัทธ์เดียวกัน ผู้วิจัยวัดและบันทึกค่าตัวแปรต่างๆ ทุกๆ 5 นาที จนกระทั่งสิ้นสุดการทดลอง

ผลการทดลองปรากฏว่าระบบการไหลเวียนและการหายใจตอบสนองโดยการเพิ่มอัตราการเต้นของหัวใจต่อนาที ปริมาณอากาศที่หายใจต่อนาที ปริมาณการใช้ออกซิเจน อัตราการหายใจต่อนาที สมดุลอุณหภูมิกายตอบสนองโดยการเพิ่มอุณหภูมิที่ผิวหนังส่วนต่างๆ โดยเฉพาะบริเวณแผ่นหลัง แต่อุณหภูมิแกนกลางของร่างกายแทบจะไม่มีเปลี่ยนแปลง จากการทดลองสรุปได้ว่าปกติร่างกายระบายความร้อนออกทางผิวหนัง แต่เมื่อเมตาบอลิสมภายในร่างกายสูงขึ้น ร่างกายจำเป็นต้องกำจัดความร้อนส่วนที่เพิ่มขึ้นอีก โดยการระบายความร้อนออกทางการหายใจรวมกับการระบายออกทางผิวหนัง เพื่อที่จะพยายามรักษาอุณหภูมิแกนกลางของร่างกายให้คงที่

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LIST OF ABBREVIATIONS

%BF	=	percent body fat
°C	=	degree Celcius
BMI	=	body mass index
BP	=	blood pressure
bpm	=	beat per minute
BSA	=	body surface area
BW _{pre}	=	pre exercise body mass
BW _{post}	=	post exercise body mass
cm	=	centrimeter
D _b	=	body density
DBP	=	diastolic blood pressure
g	=	gram
H	=	standing height
HR	=	heart rate
HR _{max}	=	maximum heart rate
HRR	=	heart rate reserved
HS	=	heat storage
kg	=	kilogram
kg/m ²	=	kilogram per square meter
L	=	liter
m	=	meter
MAP	=	mean arterial pressure
min	=	minute
PCO ₂	=	arterial pressure of carbon dioxide
PO ₂	=	arterial pressure of oxygen
RER	=	respiratory exchange ratio
RPE	=	rating of perceived exertion
RH	=	relative humidity

LIST OF ABBREVIATIONS (CONT.)

RHR	=	resting heart rate
rpm	=	revolution per minute
RR	=	respiratory rate
SBP	=	systolic blood pressure
SD	=	standard deviation
SEM	=	standard error of the means
Sp.gr.	=	specific gravity
T_{back}	=	skin temperature of back
T_{body}	=	mean body temperature
TC	=	thermal comfort
THR	=	target heart rate
T_{leg}	=	skin temperature of leg
T_{re}	=	rectal temperature
TS	=	thermal sensation
\bar{T}_{sk}	=	mean skin temperature
T_{thigh}	=	skin temperature of thigh
$T_{\text{upper arm}}$	=	skin temperature of upper arm
\dot{V}_{CO_2}	=	carbon dioxide production
\dot{V}_{E}	=	minute ventilation
$\dot{V}_{\text{E}}/\dot{V}_{\text{CO}_2}$	=	ventilatory equivalent for carbon dioxide
$\dot{V}_{\text{E}}/\dot{V}_{\text{O}_2}$	=	ventilatory equivalent for oxygen
\dot{V}_{O_2}	=	oxygen consumption
$\dot{V}_{\text{O}_2\text{max}}$	=	maximal oxygen consumption
$\dot{V}_{\text{O}_2\text{peak}}$	=	peak oxygen consumption
V_{T}	=	tidal volume
W	=	body mass

CHAPTER 1

INTRODUCTION

Numerous physiological changes occur within the body during exercise. The remarkable cardiovascular system changes to carry out its functions with maximal efficacy. Homeostasis of blood flow to the tissues is well regulated during exercise by increasing of the stroke volume and heart rate (69). Heart rate increases directly in proportion to the increase in exercise intensity (4,65,70,110). Changes in cardiac output, the product of heart rate and stroke volume, appear to be directly related with exercise intensity. Systolic blood pressure increases according to the increasing rates of work while diastolic blood pressure remains rather constant regardless of the intensity (109). In addition to these functions, cardiovascular function plays another role to control body heat by increasing blood flow to the skin (58,65,70,109). This characteristic becomes more important during exercise and even more critical whenever performing exercise in the heat where there is reciprocal alteration between blood flow to active muscles and skin which, in turn, enhances blood flow to the skin and *vice versa* (64). Thus, body has to appropriately regulate the two main contradictory streams of blood flow in order to sustain exercise in the heat. Up to the present knowledge, there is no evident or investigation on profiles of cardiovascular system and thermoregulatory responses under physical exercise in the heat. Moreover, appropriate contribution of ventilation is also needed as part of thermal regulation. Whenever the respond fails to match the body metabolic need, exercise may possibly be terminated.

Control of breathing is a critical determinant for gas exchange at rest as well as during exercise. It is well established that the respiratory tract of humans actively participates in thermal homeostasis. An elevated body temperature remarkably results in an increase in respiratory frequency and decrease in tidal volume with a net increase in ventilation (25,58,65,77,100,109). Wetter and colleagues (2001) found that tidal volume during exercise is approximately 4-5 times greater than the value at rest (107).

It is documented that exercise-related anxiety also causes a sudden increase in ventilation, hyperventilation that exceeds the metabolic need for oxygen (109). Coast and colleagues (1993) found that work of breathing during exercise is lower than during hyperventilation at the same minute ventilation (18). As the body shifts from rest to exercise, metabolism increases in direct proportion to the increase in rate of work (109). Oxygen consumption ($\dot{V}O_2$) increases from its resting value to a steady state value within 1 to 2 minutes and there is a linear increase in the $\dot{V}O_2$ with increases in power output (72). Bergh and Ekblom (1979) found that peak $\dot{V}O_2$ was positively correlated to both esophageal and muscular temperatures ($r = 0.91$) (7). Comparing gender and respiratory responses, the differences between men and women respiratory responses to exercise are largely due to body size differences. Tidal volume and ventilatory volume are generally smaller in women at the same relative and absolute power outputs (109).

The body normally keeps thermal homeostasis by the dynamic regulation between heat gain and heat loss. Whenever it cannot be controlled, core temperature may markedly increase or decrease. The excessive internal body temperature (hyperthermia) and heat-related disorders such as heat exhaustion, heat strain, or heat stroke can be occurred (22). In the heat, the body transfers heat to the environment by of 4 mechanisms: conduction, convection, radiation, and evaporation. At normal ambient temperature (typical 21 to 25°C), the nude body loses about 60% of its excess heat by radiation (109). A high internal body temperature causes fatigue and is known as the main factor limiting endurance performance in hot environment (50). Subjects with high aerobic fitness perform longer physical activity in hot environment and tolerate higher level of hyperthermia than subjects with lower aerobic fitness levels (13,50). In contrast, Sawka and colleagues (1992) found that aerobic fitness level did not influence the core temperature when exhaustion from heat strain occurred (86). As body temperature rises, sweat production increases as well as sweat evaporation (107). During prolonged exercise where heat production increases, the body loses about 80% of its excess heat by evaporation of sweat from the skin surface (29,109). Under prolonged exercise, the environmental condition, for example, air humidity also plays a major role in heat loss, especially by evaporation. When the humidity is high, it generally limits sweat evaporation and heat

loss, and then the body's temperature rises (109). This evaporative heat loss is mainly the function of body surface area, and activation of sweat gland (64). As body surface area is limited in mature individuals, when a subject performs exercise at high workload under the heat it is possible that sweat glands function might be activated to some extent near the limit. It is evident that elevated body temperature is related to increase in minute ventilation (100,109). This investigation is aimed to determine the ventilatory and thermoregulatory profiles in humans who voluntarily involved in heat either at rest or during exercise. It is also aimed to find out the relationship of ventilatory and thermoregulatory responses during progressive exercise in the heat.

1.1 Hypothesis

It is hypothesized that respiratory ventilation and cardiac function during exercise might contribute, to some extent, to body heat regulation particularly at high intensity of exercise performed in the heat.

1.2 Objectives

1. To study the effects of heat and continuous exercise on cardiorespiratory function and thermoregulatory responses.
2. To compare the relationship between body ventilation and thermoregulation at rest and during continuous exercise in the heat.

1.3 Selected parameters

1. Rectal temperature
2. Skin temperatures
 - 2.1 Back temperature
 - 2.2 Upper arm temperature
 - 2.3 Thigh temperature
 - 2.4 Leg temperature
3. Minute ventilation
4. Oxygen consumption
5. Carbon dioxide production
6. Breathing frequency

7. Respiratory Exchange Ratio
8. Heart rate
9. Mean Arterial Pressure (MAP)
10. Total sweat loss
11. Rating of Perceived Exertion
12. Thermal sensation
13. Thermal comfort

1.4 Benefits of the study

This study may achieve the additional roles of the respiratory and cardiac system, which contributes to body heat regulation.

1. Results obtained from the present study may be used as guidelines on precaution or possible risks that can be taken place in those who have low performance and have to work or exercise in a hot environment.

2. Results of this study give rise in correlation between responses of cardio-respiratory systems at rest and exercise conditions in a hot environment.

1.5 Scope of the study

This research is designed and tested in sedentary healthy men who are either sitting quietly or exercise with constant workload in a sauna room. The temperature and the relative humidity in a sauna room are controlled constantly throughout the experiment. Subjects are requested to participate in two randomized trials and the selected physiological parameters will be recorded. Results will be analyzed thereafter.

CHAPTER 2

LITERATURE REVIEW

2.1 Human and hot environment

Human exposes to thermal fluctuations in both natural and artificial forms. While people near the north and south poles acclimatize with cold climate by keeping themselves warm using insulators, people in the tropical zone adjust body heat regulation by dissipating large amount of heat throughout the day. Man increases body heat via internal and external induction. Physical activity is known as main internal heat induction via complex metabolic processes (64). Sauna, hot and cold pack are external heat induction known worldwide. Sauna has a long history which closely related to cultures: the Russian banya, the native American sweat lodge or inipi, the Turkish hamam, even the Japanese onsen. Sauna has over 1500 years of history in Finland. It is a form of dry heat in a wooden room that used to open the tiny skin's pores in order to eliminate toxins through sweat. It can improve the body's immune defenses and favor recovery from stress (24). In the early of sauna, it was nothing more than a pile of rocks on the floor of the stream room. Hot embers from a fire were spread over this pile until the rocks were hot. Ashes were removed, and water was tossed upon them to produce steam.

As technology progressed the electric sauna heater came into use. It is easy to install, simple to use, and creates no pollution. Sauna rocks are as important to the sauna as the heater itself. They give off a continuous and gentle heat while the heater maintains a more constant temperature. Without any rocks, the sauna heater would produce a burning type of heat. In the present of sauna, it is divided into 2 types: wet and dry sauna.

Mechanical ventilation in sauna is adjusted when hot air is pushed upward, which draws cold air from an opening at the bottom portion behind the heater. On the wall opposite the heater is a vertical ventilatory unit that draws the air out of the sauna (Figure 1).

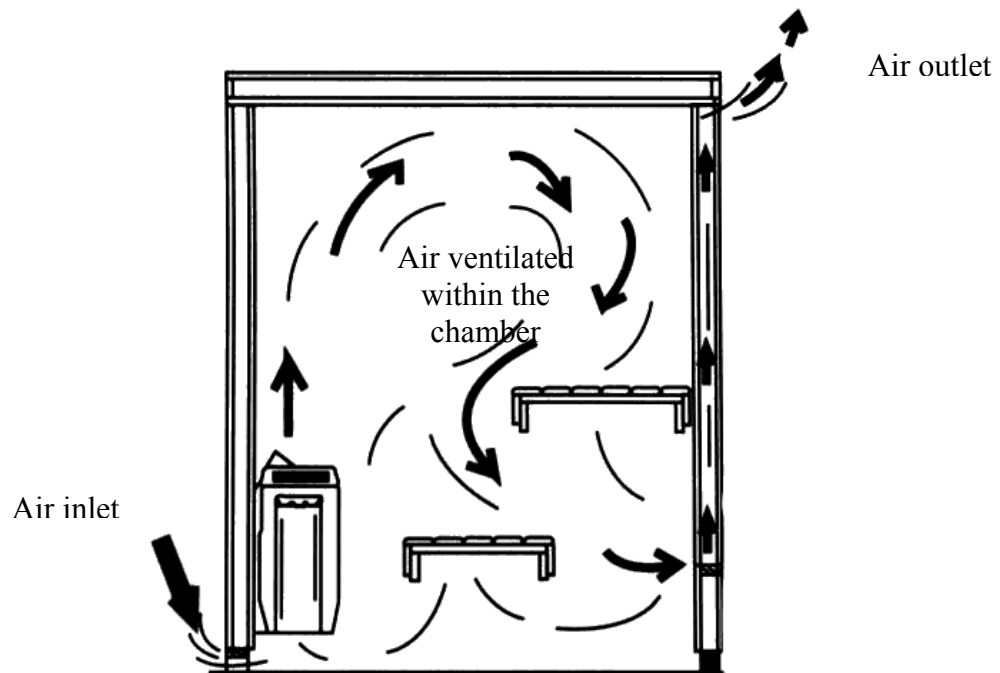


Figure 1 Diagram represents sauna and mechanical ventilation (37)

Sauna bathing is a popular leisure activity that involves exposure to supraphysiologic temperatures, often exceeding 80 degrees Celsius (30). Previous studies reported the sauna-induced physiological changes as increasing in heart rate (30,47,53,54,94,97), small increasing in systolic blood pressure (30), and decreasing in stress hormones (57). Although sauna bathing is generally considered to be safe, there have been reports of syncope (91), myocardial infarctions (93), and sudden death associated with its use (93,102). Giannetti and colleagues studied the effects of sauna in sixteen patients with proven coronary artery disease. They found that sauna used was clinically well tolerated by the patients with stable coronary artery disease but it was associated with asymptomatic myocardial ischemia (30). Sugahara and colleagues (2003) studied the efficacy and safety of thermal vasodilation therapy by sauna in infants with severe congestive heart failure secondary to ventricular septal defect (VSD). They found that heart rate and systemic blood flow increased significantly, pulmonary blood flow and systemic vascular resistance decreased significantly after sauna bathing. They concluded that sauna therapy improved hemodynamics and the clinical status in infants with chronic heart failure (CHF)

secondary to VSD (103). On the contrary, Kihara and colleagues reported that after 2 weeks of sauna exposure on cardiac function in patients with CHF was clinically improved which related to the improvement of vascular endothelial function (54). Effects of sauna therapy also reduced cardiac arrhythmia in patients with CHF (53). Similarly, Ikeda and colleagues reported that repeated sauna therapy improved survival rate in cardio-myopathic hamsters (47).

However, sauna-related burns may occur after prolonged bathing. Anthony Papp observed burn patients in Kuopio University Hospital Burn Center during 1994-2002 and found that every fourth burn in this unit was due to sauna-related. Even though most of these burns were minor but 54% required operative treatment. A total of 71% of patients were male and 40% of all patients were under the influence of alcohol. The reason for the higher incidence of men among the sauna-related burns was due to the fact that men bathe more often than women and alcohol may aggravate damages during bathing in men than women (2).

2.2 Body temperature regulation

Normal body temperature fluctuates during the day according to physical activity, emotion, and ambient temperature variation (65). The body attempts to maintain thermal neutrality between heat gain and heat loss which is critical sustaining life (65,109). The highest and the lowest temperatures in the body are core temperature (T_{core}) and skin temperature (T_{skin}) respectively (65,109). T_{core} can be defined from various sites: in rectum, eardrum, or esophagus. Skin temperatures can be measured on the body's surface such as arm, leg, trunk, back, etc. Mean body temperature (T_{body}) represents an average of skin and core temperature, which is related to environmental condition.

At neutral ambient temperatures T_{body} is computed as follows:

$$T_{body} = (0.6 \times T_{core}) + (0.4 \times \bar{T}_{skin}) \quad (65)$$

Under hot environment, T_{body} is computed as follows:

$$T_{body} = (0.79 \times T_{core}) + (0.21 \times \bar{T}_{skin}) \quad (19)$$

This means that T_{core} mainly contributes to T_{body} in a greater extent than \bar{T}_{skin} . Human, as homeotherms, operates body temperature within a narrow range of

internal body temperatures (T_{core}). Despite regular exposure to environmental extremes, the body regulates temperature within a range of $37 \pm 1^\circ\text{C}$ ($98.6 \pm 1.8^\circ\text{F}$) (15,65).

There is central coordination center for temperature regulation in the hypothalamus, which is a part of the diencephalons. The information about the external temperature is provided by thermoreceptors in the skin and muscular vessels whereas the internal temperature is monitored by central thermoreceptive neurons in the anterior hypothalamus (Figure 2). Central thermoreceptors monitor the temperature via the blood in order to cope with either high or low environmental temperatures (65). It is well documented that mechanisms of body temperature regulation are conducted via vasoconstriction/vasodilation, hormonal and neural controls (Table 1).

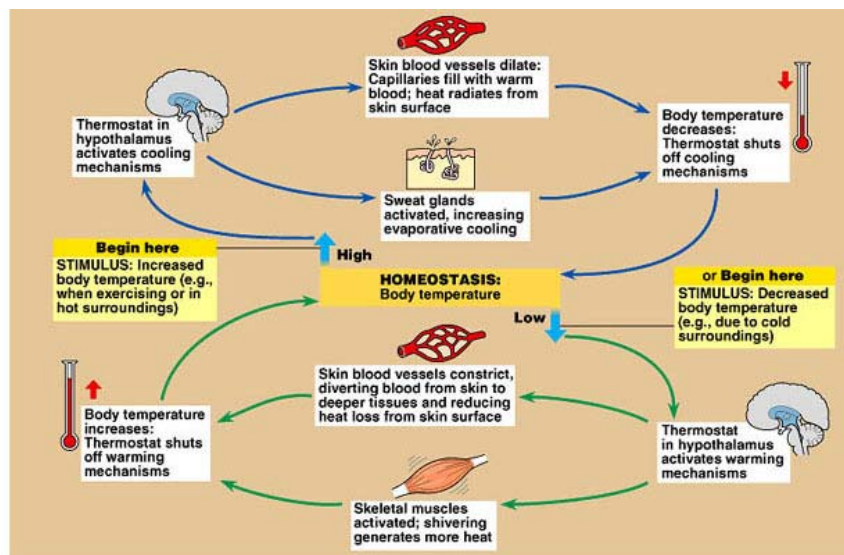


Figure 2 Homeostasis of human body temperature (80)

Table 1 Summary of body temperature regulation mechanisms (64)

Mechanisms for temperature regulation	
- Stimulated by cold	
• Decreases heat loss reduction of surface area (curling up)	- Vasoconstriction of skin vessels; postural
• Increases heat production increased thyroxine and epinephrine secretion	- Shivering and increased voluntary activity;
- Stimulated by heat	
• Increases heat loss	- Vasodilation of subcutaneous skin vessels; sweating
• Decreases heat production decreased secretion of thyroxine and epinephrine	- Decreased muscle tone and voluntary activity;

2.2.1 Body's heat production

Factors that contribute to heat production consist of:

1. Basal metabolic rate (BMR) -Basal metabolic rate is the absolute minimal energy requirement for sustaining the body's function in the awaking state. Many factors influence basal metabolic rate such as body size (the bigger body surface area provides higher BMR), age (BMR declines with aging), and gender (BMR is lower in female).

2. Muscular activities - Shivering generates significant metabolic heat (maximum of 3 to 5 times resting metabolism), which shows the greater contribution of muscle in defending against cold. The metabolic rate during exercise rises as much as fifteen times above the resting level. In trained athletes it can be as much as twenty times (64). Under low ambient temperatures (-30°C), exercise energy metabolism can sustain a constant core temperature without the need for heavy clothing (58).

3. Hormones – Various hormones play regulating roles in body's heat regulation via cellular metabolism. Thyroid hormones (thyroxine and tri-iodothyronine) are the main regulators of BMR. In addition, the action of two adrenal medulla hormones, epinephrine and nor-epinephrine, partially accounts for increased basal heat

production during cold exposure as well as thyroxine. Testosterone and human growth hormone also raise BMR for some extent (57). Hormonal responses to exercise are present in Table 2. Kenny and colleagues (1995) studied sympathetic responses to hyperthermia in the anesthetized rats. They found that renal, lumbar, and splanchnic sympathetic nerve discharge increased significantly during hyperthermia (55). Williams and colleagues (2002) studied effects of cool and hot humid environmental conditions of neuro-endocrine responses of horses subjected to treadmill exercise. They found that plasma adrenaline, noradrenaline, and cortisol increased significantly in hot humid environmental condition. These increases also closely related to the exercise intensity (107).

Table 2 Modifying factors on hormonal responses to exercise (57)

Hormonal responses to exercise: modifying factors	
1. Characteristics of the exercise activity <ul style="list-style-type: none"> a. Intensity of the exercise activity b. Duration of the activity c. Type of exercise – e.g. running, cycling, swimming, etc. d. Special effects – e.g. immersion 	4. Methods of sampling the hormones <ul style="list-style-type: none"> a. Blood versus urine b. Indwelling cannula versus repeated stabs c. Length of presampling d. Sampling frequency e. Fluids maintaining IV patency
2. Fitness of the individual <ul style="list-style-type: none"> a. Cardio-pulmonary fitness b. Strength and flexibility c. Familiarity of subject with specific activity Training over previous 24 hours 	5. Biochemistry of the hormones <ul style="list-style-type: none"> a. Blood production rates – direct and indirect b. Protein binding – specific and non-specific c. Clearance rates and systems – target tissues / metabolism and excretion in liver and kidney
3. Baseline endocrine function <ul style="list-style-type: none"> a. Age related differences b. Sex related differences c. Effects of biological rhythms: circadian, menstrual, lifetime, menstruational, circhoral d. Stress – physical and psychological e. Metabolic – glucose, salt, and fluid loads f. Endocrine disorders 	6. Ambient conditions. <ul style="list-style-type: none"> a. Temperature, Humidity, Altitude, pO₂ b. Laboratory versus free range c. Competitive versus non-competitive

4. Dietary-induced thermogenesis - Thermal effect of food occurs immediately during the processes of digesting, absorbing, and assimilating nutrients. It typically reaches maximum within one hour after eating depending on food quantity and type. This heat production ranges between 10 and 35% of ingested food energy (65).

5. Environment - In cold environment, heat will be preserved within the body by increasing metabolic heat production and constriction of skin vessels (64). In the hot environment, the environmental heat is gained into the body through the skin due to heat gradient. The body copes with heat stress by lower the metabolic rate and dilation of skin vessels (59). It is controversial that as man exercises in the heat up to certain intensity, his metabolic rate and skin vessels may response differently from resting condition.

2.2.2 Body's heat loss

Body's heat loss occurs in four routes:

1. Radiation - Human, a homeotherm, is usually warmer than the environment. Thus heat will be theoretically loss from the body in the pulsatile waves via radiation without contact to cooler objects in the environment. This form of heat-transferring process is not sufficient enough to lower body heat (64).

2. Conduction - Heat loss by conduction is the direct transfer of heat through a liquid, solid, or gas from one molecule to another. Even though warm blood is moving from deep body parts toward the skin, there is less remarkable direct contact between skin and external objects. Thus this type of heat loss contributes to only about 3% of heat loss (64).

3. Convection – Heat loss by convection through the skin by moving of the air and carrying the heat away. Thus the effectiveness of convective heat loss depends mainly on the wind speed. Under normal conditions, at rest, approximately 15% of body heat is lost to the air by convection (64).

4. Evaporation - This process involves changing a liquid from the body into a gas. It requires large amount of heat energy and effectively provides the major physiologic defense against overheating. There are routes of this mode of heat transfers continuously to the environment: vaporization via skin surface and respiratory passages. Under normal rest condition, about 22% of heat loss occurs

through evaporation. The effective sweat evaporation from the skin depends on three factors: 1.) skin surface area exposed to the environment, 2.) temperature and relative humidity of ambient air and 3.) convective air currents around the body (64).

Humidity of air plays a major role in heat loss, especially by evaporation. When humidity is high, it limits sweat evaporation and heat loss. As a result, body's temperature increased. Body temperature may remarkably and rapidly increase during high-intensity than during moderate-intensity exercise in a tropic climate (14,69).

Berglund and Gonzalez (1977) observed the physiological and sensory responses from sedentary man resting in humid environment at different ambient water vapor pressure (10 to 40 Torr) and found that the rate of evaporation from the skin, mean skin temperature and heart rate were relatively constant until a critical vapor pressure was reached, below which level they both began to increase substantially. They concluded that sweating, discomfort and temperature sensations increased gradually with increasing ambient water vapor pressure. Above critical ambient water vapor pressure, sweating and discomfort sensations accelerated markedly (8).

2.3 Thermal stress and Exercise

Variations in body temperature have considerable effect on many physiologic functions. During exhaustive exercise, peak aerobic power and heart rate reduce at low body temperature as well as physical performance (7). The observed rates of reduction were time to exhaustion $20\% \cdot ^\circ\text{C}^{-1}$, VO_2 $5\text{-}6\% \cdot ^\circ\text{C}^{-1}$, and heart rate $8 \text{ beat}\cdot\text{min}^{-1} \cdot ^\circ\text{C}^{-1}$ (7). Heart rate at the end of exercise was linearly correlated to core temperature (7,49). Elevated body temperature induced by continuous exercise did not affect physical performance but increased VO_2 and heart rate (7).

At normal room temperature (typical 21 to 25°C), the nude body losses about 60% of its excess heat via radiation (108). A high internal body temperature causes fatigue and to be the main factor limiting endurance performance in hot environment (51). The persons with high aerobic fitness perform longer exercise in hot environment and tolerate well at higher level of hyperthermia than subjects with lower aerobic fitness levels (14,51). On the other hands, Sawka and colleagues (1992) found that aerobic fitness level did not influence the core temperature when exhaustion from heat strain occurred (85). As body temperature increased, sweat production was

enhanced as well as sweat evaporation. During prolonged exercise when heat production is higher, the body loses about 80% of its excess heat by evaporation of sweat from the skin surface (29,109). Montain and colleagues (1994) found that sweating rates during high-intensity exercise were significantly higher than during moderate-intensity exercise (69).

Body temperature influences the development of fatigue during exercise in the heat. Jose and colleagues (1999) examined the effect of initial body temperature on the development of fatigue during prolonged exercise in the heat. They found that time to exhaustion was shorter at the higher rate of heat storage. They also found that with different rates of heat storage, all subjects reached exhaustion at similar core temperature and muscle temperature, but with significantly different skin temperature (49). It was later concluded that time to exhaustion in a hot environment is inversely related to the initial temperature but directly related to the rate of heat storage and it also increased after acclimation (49,88,89). However, if the body cannot control the core temperature in homeostatic condition, the heat-related injuries or disorders may occur as follows.

2.3.1 Heat-related disorders

1. Heat Cramps

Heat cramps are the least serious heat disorders. They are characterized by severe uncontrolled tension of the skeletal muscles which generally involve heavily during exercise. They are often present in athletes who perform prolonged strenuous exercise in the heat. This disorder is probably due to the mineral loss and dehydration that accompany high rate of sweating. Symptoms include weakness, fatigue, increased pulse rate, nausea and vomiting with normal range of core temperature (36.5 - 38°C) (22).

2. Heat Exhaustion

Heat exhaustion is a moderate illness characterized by the inability to sustain adequate cardiac output, resulting from strenuous physical exercise and environmental heat stress. Symptoms include extreme fatigue, breathlessness, dizziness, vomiting, fainting, cold and clammy or hot dry skin, hypotension, and weak rapid pulse. It occurs when the blood volume decreases, by either excessive fluid or mineral loss from sweating. For this reason, the efficient thermoregulatory mechanisms cannot function via dissipating heat (22).

3. Exertional Heat Stroke

Exertional heat stroke is a severe illness with central nervous system involvements and potentially tissue damage resulting from elevated body temperatures. This illness is induced by strenuous physical exercise and increased environmental heat stress. It is characterized by a rise in core temperature to a value exceeding 40°C (104°F). The result of this illness is severe and irreversible (22). Symptoms include:

- Cessation of sweating
- Red, hot, and dry skin
- Rapid pulse and respiration
- Usually hypertension
- Confusion
- Unconsciousness

If heat stroke is not efficiently treated, it will progress to coma and death quickly.

2.3.2 Risk factors associated with heat illness (Adapted from 22)

1. Age: old and young
2. Alcohol
3. Asphalt, concrete, artificial turf
4. Diuretic beverages: caffeinated beverages
5. Cardiac disease: atherosclerosis, heart failure
6. Clothing: excessive, non-vapor-releasing
7. Dehydration: gastroenteritis, diuretics, inadequate fluid intake
8. Drugs: amphetamines, antihistamines, bronchodilator, diuretics etc.
9. Environmental conditions:
 - lack of wind, high humidity, high ambient temperature
10. Fatigue
11. Fluid imbalance
12. Hyperthyroidism
13. Intense competitor
14. Low aerobic fitness
15. Obesity
16. Physical or mental disabilities

17. Previous heat illness
18. Recent immunization
19. Skin conditions that interfere with sweat gland function: cystic fibrosis, previous extensive burns, prickly heat rash, scleroderma.

2.4 Respiratory system and exercise

The control of breathing is a critical determinant in providing for gas exchange at rest as well as during exercise. The respiratory system responses to exercise appear by increasing ventilation, tidal volume, and breathing frequency at higher intensity of exercise (11,65,77,104). The tidal volume (V_T) increases to 4-5 times higher than at rest (104). Minute ventilation, the production of breathing frequency (fb) and tidal volume (V_T), is estimated $6 \text{ L}\cdot\text{min}^{-1}$ at rest. During heavy exercise, it increases about 17 times the resting value ($\sim 100 \text{ L}\cdot\text{min}^{-1}$) and may increase to $160\text{-}200 \text{ L}\cdot\text{min}^{-1}$ in well-trained endurance athletes (64). This increase in ventilation closely matches the increase in O_2 uptake (98). The O_2 consumption ($\dot{V}\text{O}_2$) and the carbon dioxide production ($\dot{V}\text{CO}_2$) increase more than any other physiologic stress (60). Astrand and Rodahl (1986); Gaesser and Poole (1996) found that oxygen consumption ($\dot{V}\text{O}_2$) increased from its resting value to a steady state value in 1 to 2 minutes and there was a linear increase in the $\dot{V}\text{O}_2$ with increases in power output. Bergh and Ekblom (1979) found that peak $\dot{V}\text{O}_2$ was positively correlated to both esophageal and muscular temperature ($r=0.91$) (7).

Ventilatory equivalent for oxygen ($\dot{V}_E/\dot{V}\text{O}_2$), which indicates breathing economy, is usually maintained and increases during exercise (65). Its value at rest can range from 23 to 28 litres of air per litre of oxygen consumed and changes very little during mild exercise, but it can be greater than 30 litres of air per liter of oxygen consumed when work intensity increases to near maximum (65). The ventilatory equivalent for carbon dioxide ($\dot{V}_E/\dot{V}\text{CO}_2$) remains relatively constant because pulmonary ventilation eliminates the carbon dioxide produced during cellular respiration (64).

Mahler and colleagues evaluated ventilatory control in long-distance runners and its possible role in athletic performance and found no significant difference in $\dot{V}_E/\dot{V}\text{O}_2$ and $\dot{V}_E/\dot{V}\text{CO}_2$ between athletic and control groups. They also found poor

correlation between ventilatory responses at rest as well as during exercise and the best marathon running time (60). In contrast, Byrne-Quinn and colleagues found that there was a positive correlation between resting hypoxic and hypercapnic ventilatory drives. Increased ventilation in the athletes was not significantly different from the nonathletes (11).

There are many factors that can stimulate ventilation in both anesthetized animals and awaked men such as passive movement of the limb, oscillations in arterial pressure for oxygen (PO_2) and arterial pressure for carbon dioxide (PCO_2), or the addition CO_2 load (78,103). Another factor that can stimulate ventilation is the increase in body temperature during exercise. It is well established that the respiratory tract of human partially participates in thermal homeostasis (58). Measurement of the temperature fluxes that occur within the tracheobronchial tree demonstrate that, whenever ventilation rises, the intrathoracic airways are called upon to heat and humidify the incoming air to full saturation at body temperature before it reaches the alveoli. Throughout inspiration, the air is actively warmed by conduction and convection as it moves down the tracheobronchial tree (53). An elevated body temperature results in an increase in respiratory frequency and decrease in tidal volume with a net increase in ventilation (33,41,48,98).

White and Cabanac (1995) examined whether respiratory heat loss contributes significantly to cranial cooling in hyperthermic submaximally exercising human. It was investigated by examining the time course of core temperatures during the transient inhalation of super-saturated air to suppress respiratory evaporative heat loss in the upper airways. They found a significant elevation in tympanic temperature and a significant decrease in esophageal temperature during exercise with inhalation of supersaturated relative to low-air-humidity air. Forehead skin temperatures significantly decreased during humidified air inhalation supporting that this treatment induced greater thermolytic responses that cooled the skin. The results were concluded that heat loss from the upper airways directly influenced human cerebral temperatures as indexed by tympanic temperatures (106).

High environmental temperatures also affect on the respiratory ventilation as to elevate body temperature (48). Pandolf and Kamon (1974) determined respiratory responses to intermittent and prolonged exercise in a hot-dry environment and found that oxygen consumption ($\dot{V}O_2$) and minute ventilation (\dot{V}_E) did not differ in the heat,

whereas breathing frequency (f_b), rectal temperature (T_{re}), heart rate (HR) and respiratory dead space were higher in the hot ambient environment. Conversely, the respiratory exchange ratio (RER) value at the last period of exercise in neutral condition was higher as compared to the hot ambient condition. It was concluded that heat was more effective than time in lowering the RER (78). Similarly, Ingram and Legge (1969) observed the effect of environmental temperature on respiratory ventilation in animals and found that at high environmental temperatures, tidal volume fell to about a quarter of the value in the thermoneutral zone and frequency increased (47).

Controlling of the normal automatic process of breathing originates from the brain stem, pons and medulla. It regulates the rate and depth of breathing in response to metabolic needs. The effectors of ventilation are the muscles of respiration include the diaphragm, intercostal muscles, abdominal muscles, and accessory muscles such as sternomastoids. The sensors of ventilatory control consist of central chemoreceptors, peripheral chemoreceptors, lung receptors, and other receptors such as nose and upper airway receptors, joint and muscle receptors, arterial baroreceptors, or pain and temperature (105).

Anxiety prior to exercise causes an abrupt increase in ventilation that exceeds the metabolic need for oxygen that is known as hyperventilation. Coast and colleagues (1993) found that work of breathing during exercise was lower than during hyperventilation at the same minute ventilation. As work of breathing increases, it involves more and more total body energy, which in turn diminishes energy providing for exercise (18).

2.5 Cardiovascular system and exercise

Physical exercise has wide-ranging effects on the cardiovascular system in order to carry out the body functions with maximal efficacy (64,108). The cardiovascular system responds to exercise by increasing blood flow and oxygen delivery to exercising muscles where heart rate increases directly in proportion to the increase in exercise intensity (5,64,69,108). The maximal heart rate might possibly reflect the $\dot{V}O_{2\max}$ for that individual (64,108). The heart rate response is influenced by several factors, including age, type of exercise, previous training, body position, blood volume, medications, and presence or absence of heart disease (104). Stroke volume, which refers to the amount of blood ejected by the left ventricle during each heartbeat, increases 50 to 60% above resting value for trained endurance athletes but slightly increases for untrained individuals (64,108). On the other hand, there is approximately 40% fall in stroke volume during change from the supine to upright position (108).

Montain and colleagues (1994) determined the influence of exercise intensity, protective clothing level, and climate on physiological tolerance to uncompensable heat stress. They found that homeostasis of blood flow to the tissue was well regulated by increasing of the stroke volume and heart rate (69).

Cheung and McLellan (1998) performed a cross-sectional study comparing the responses of active endurance-trained ($\dot{V}O_{2\max}$ of 60 ml.kg⁻¹.min⁻¹) vs inactive untrained individuals ($\dot{V}O_{2\max}$ of 43 ml.kg⁻¹.min⁻¹) during light exercise at 40°C and 30% relative humidity while wearing a protective clothing ensemble. The ethical limit for the increase in rectal temperature (T_{re}) was 39.3°C. They found that exercise-heat tolerance was greater in the fit compared with unfit individuals, with tolerance times averaging 110 and 88 min. respectively. The rate of increase in T_{re} was similar during the heat-stress exposure between groups but significant differences were observed for both the initial T_{re} and the final T_{re} at which subjects terminated the experiment. These data indicated that differences in aerobic fitness have an impact on both the initial and final core temperatures (14).

Conversely, Sawka and colleagues (1992) found no relationship between the range in $\dot{V}O_{2\max}$ of 45-65 ml.kg⁻¹.min⁻¹ and the core temperature that could be tolerated at exhaustion for 17 heat-acclimated subjects during uncompensable euhydrated and hypohydrated heat-stress trials. The T_{re} was limited at 40°C in this study, which involved subjects wearing shorts and exercising in a hot and dry environment (49°C and 20% relative humidity). They also found that high core temperatures tolerated at exhaustion for subjects of high aerobic fitness were consistent before and after a 10-day heat acclimation program (85).

Changes in cardiac output, the product of heart rate and stroke volume, appears by increasing directly with exercise intensity. For untrained individuals, the acceleration in heart rate produces the major increase in cardiac output but both heart rate and stroke volume augment cardiac output for trained individuals (64). Blood pressures, systolic and diastolic, during rest and submaximal exercise decrease with aerobic exercise intensity. They generally decline approximately 6 to 10 mmHg with regular aerobic exercise for sedentary men and women regardless of age (64,65). Increased blood flow during moderate exercise increases systolic blood pressure in the first few minutes according to work rate while the diastolic blood pressure remains relatively unchanged (64).

Kramer and colleagues (2001) studied the characteristics of cardiovascular responses to muscular contraction in anesthetized mice. They found that mice demonstrated significant increases in blood pressure and heart rate in muscle contraction in a contraction-intensity-dependent manner. This study presented the neural regulation of the cardiovascular function during exercise-related drives such as muscle contraction (54).

Horowitz (2003) studied heat acclimatory responses to the circulatory system. He found that the process of heat acclimation conferred long-term intrinsic circulatory adaptation to match peripheral hemodynamic load during both heat acclimation and heat stress. He concluded that heat acclimation enhance cardiac work efficiency and increased cardiac reserves. It also conferred cardioprotection upon ischemia/reperfusion insulted, involving ionic, metabolic, and cytoprotective adaptation (45).

2.6 Rating of perceived exertion, thermal sensation, and thermal comfort

In the hot environments, heat stress or heat strain indices have been developed and used as tools for predicting subjective tolerance time for maintaining activities for over most of the last century (96). Exercise, environmental conditions, and clothing indicate the level of heat stress, whereas heat strain indicates the physiological consequences of the stress. Belding identified core temperature and heart rate as the two primary determinants of the physiological strain associated with heat (6). Borg identified scale of rating of perceived exertion (RPE) as an indicator of somatic stress (10) and Gagge et al. identified scales of thermal comfort and thermal sensation (28).

Perceived exertion has been defined as the act of detecting and interpreting sensations outcomes of the body during physical exercise. Rating of perceived exertion (RPE) scales have been used as reliable and valid measurements of exercise intensity for nearly 4 decades (96). This concept has concerned about the quantifying subjective feelings of fatigue and exercise tolerance during submaximal exercise. It also has been used to prescribe exercise intensities for the development and maintenance of cardiovascular fitness for healthy and at-risk groups. Borg also suggested that the RPE could be used as a measure of the physical activity's intensity. Exercise intensities that produced greater energy expenditure and physiological strain yield higher rating of perceived effort. Rating of perceived exertion related to a variety of physiological measures (e.g. heart rate, ventilatory drive, blood lactate concentration, creatine) and psychological measures and dispositions (e.g. personality types) (10). Chen et al. determined the strength of the relationship between RPE scores and the six physiological measures: heart rate, blood lactate concentration, $\% \dot{V}O_{2\max}$, $\dot{V}O_2$, ventilation, and respiratory rate. The weighted mean validity coefficients were in range of 0.5-0.7: 0.62 for heart rate, 0.57 for blood lactate, 0.64 for $\% \dot{V}O_{2\max}$, 0.63 for $\dot{V}O_2$, 0.61 for ventilation, and 0.72 for respiratory rate. The results of this study suggested that respiratory rate is probably the best indicator of physical exertion (nearly all coefficients ≥ 0.70). However, this high validity coefficients were produced with small sample size ($n = 12$), so they suggested that future studies should consider using larger samples such that the validity coefficients produced are more stable (12).

Misic and colleagues used Borg's RPE scale for determining exercise intensities at three different levels in the investigation of blood lactate level reproduction during a continuous exercise bout: RPE of 11, 14, and 16 and compared blood lactate concentration between the estimation and production trials. The results indicated that there were no significant difference ($p>0.05$) in blood lactate concentration between the estimation and production trials at RPE of 11, 14, and 16. The correlations and coefficients were $\sim 0.45-0.6$ for $\dot{V}O_2$, $0.2-0.6$ for blood lactate concentration. The results from this study suggested that: 1) RPE may be used as a means to reproduce blood lactate concentrations, but ability to do so varies by individual, 2) RPE may be used to set exercise intensity in situations where workloads are changing, and 3) Intra- and inter-subject variability in reproduced blood lactate concentration warrants research on appropriate perceived exertion scale, and influence of additional practice (66).

However, Baildon and Ulmer (1993) investigated the time course of effort perception (Borg's RPE scale) and influence of strain on RPE by performing exercise with bicycle ergometer at different power level for periods of 0.5, 1.0 and 1.5 minutes. They found that a strong influence of strain on RPE was observed at the high power level. At the low power output the influence of strain on RPE was less apparent and interindividual variability was higher. The results suggested that the Borg's scale did not reflect strain very well in a sport or industrial setting with submaximal exertion (8).

Thermal sensation is the way to describe how the body temperature feels or to detect the rate of thermal sensation. Science has found that thermal sensitivity is mediated by a number of different neuronal receptors (62). These receptors are dorsal root ganglion neurons with all bodies located near the spinal cord. Thermal sensation may depend as well on the disordered processes involved in the flow of thermal energy object being thermally sensed.

Thermal comfort is a method to describe how comfortable subjects feel with the changes in body's temperature or to measure the rate of body's thermal discomfort. A person experiencing thermal discomfort will feel either too hot or too cold. While thermal discomfort may not directly harm people. People may feel tired or irritable that could result in injuries. Factors influencing thermal comfort include; air temperature, humidity, radiant heat, air speed, physical activity, and clothing.

Other factors may affect thermal comfort such as age, body weight, state of health, and the use of alcohol or prescription/recreational drugs.

2.7 Fluid supplementation and exercise

Water and electrolyte balance are critical for the function of all organs and for maintaining health in general. Total body water can have a critical influence on thermoregulation and exercise performance. It is essential for maintaining an adequate blood volume in the cardiovascular system. Because physical exercise and heat stress can increase total body metabolism to 10 to 20 times the resting rate, thus both fluid and electrolyte imbalances can be occurred. A person's sweating rate is dependent upon the climatic conditions, clothing worn and exercise intensity (63). Runners and athletes performing vigorous exercise in the heat often have sweating rates of 1.0-2.0 L/h but for the persons in tropic climates can have sweating rates that vary from 0.3-1.5 L/h (63,85). However, such high sweating rates are not adequately maintained throughout the entire day. Fluid replacement ranges (for sedentary to very active persons) from 2 to 4 L/day in a cool climate up to 8 to 16 L/day in very hot climates (63,85). Fluid supplementation is known to subside fluid loss during exercise in the heat (Figure 3).

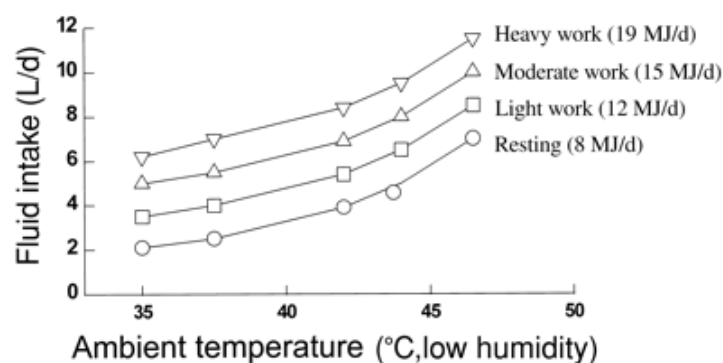


Figure 3 Influence of climatic temperature and daily metabolic rate on daily fluid requirements (84).

During exercise in the heat, sweat output often exceeds water intake, resulting in a body water deficit or hypohydration (31,64,85,108). This water deficit lowers both intracellular and extracellular fluid volumes, and causes a hypotonic-hypovolemia of the blood. Strenuous exercise intensity and hot climate cause the greater body dependence on evaporative cooling and a substantial volume of body water may be lost via sweating (63). Sweat is hypotonic to extracellular fluid and contains electrolytes, primarily sodium, chloride and to a lesser extent potassium, calcium and magnesium. Normally, sweat sodium and potassium concentrations average ~35 and 5 mEq/L and vary depending upon diet, sweating rate, hydration level and heat acclimation state (63). Hypohydration must be avoided by matching fluid consumption with sweat loss but it is difficult because thirst is not a good indicator of body water requirement (85). In general, thirst is not perceived until a person has incurred a water deficit of about 2% body weight loss (4,85) whereas water deficit as low as 1% of body weight loss can impair thermoregulation and reduce physical work capacity (31).

2.7.1 Hydration before exercise

Adequate water ingestion prior to exercise is essential to prevent dehydration once exercise begins. However, the concept of trying to store water prior to exercise to offset the effects of sweating during exercise has not been successful. Consuming a liter of water 30 minutes before a 2-hour bout of exercise in the heat (35°C) failed to affect the core temperature rise during exercise (31). Latzka and colleagues (1998) studied the efficacy of glycerol and water hyperhydration on tolerance and cardiovascular strain during uncompensable exercise-heat stress. They found that there was no difference between glycerol and water hyperhydration methods for increasing total body water. Glycerol hyperhydration endurance time was significantly longer than control but hyperhydration did not alter any cardiovascular parameters. They concluded that 1-hour pre-exercise glycerol hyperhydration did not provide physiological advantage over water hyperhydration and hyperhydration only provided the advantage of delaying hypohydration during uncompensable exercise-heat stress (58).

2.7.2 Hydration during exercise

It is well accepted that drinking fluids during exercise can attenuate the rise in body core temperature by 0.5-0.8°C (69) and drinking fluids during exercise lasting greater than 1 hour is certainly beneficial to performance and to thermal and circulatory function (31). However, the value of ingesting fluids during exercise lasting less than 1 hour has been questioned. Montain and Coyle (1992) studied the effects of fluid replacement at 20, 50, and 80% of subjects fluid lost in sweat during exercise at 62-67% $\dot{V}O_{2max}$ in a warm environment (33°C, 50%RH). They found that impairment in thermal and circulatory function was directly proportional to dehydration (68). One of the most important aspects of ingesting fluid during exercise is to reduce the rate of rise of core temperature (Figure 4) (31). The magnitude of core temperature elevation ranges from 0.1 to 0.25°C for every percent body weight lost (63,69). Body water deficit or hypohydration not only elevates core temperature, but it negates the core temperature advantages conferred by high aerobic fitness and heat acclimation. Sawka et al.(1985) determined core temperature responses during exercise-heat stress in euhydrated and hypohydrated (5% body weight loss) persons both before and after being heat acclimated. They found that the core temperature penalty induced by hypohydration was greater in heat acclimated than unacclimated persons (63).

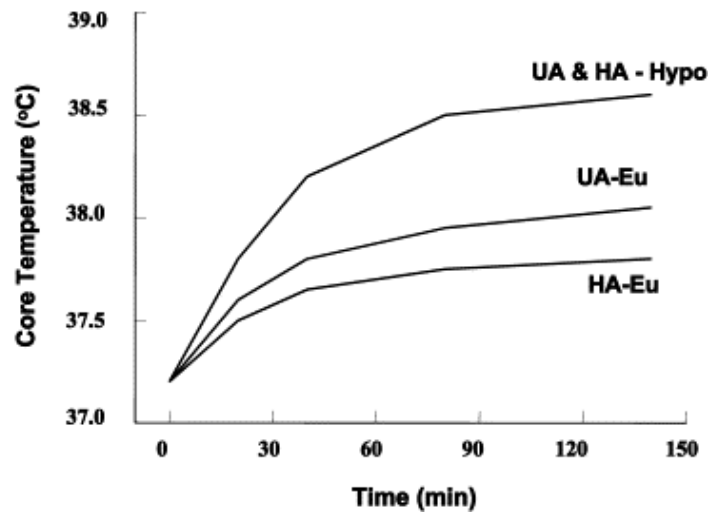


Figure 4 Core temperature responses during exercise-heat stress in euhydrated (Eu) and hypohydrated (Hypo) (5%BWL) persons both before (UA) and after (HA) being heat acclimated (83).

However, in a recent study, it was clearly shown that drinking fluids during fatiguing exercise of 50-60 minutes was not only beneficial but the effects of fluid and carbohydrate were additive (31). If a fluid deficit occurs during exercise, plasma volume and stroke volume are reduced, Heart rate is increased, and cardiac output decreased, because of the inability of the heart rate to compensate the reduction in stroke volume, and core temperature is elevated (81).

CHAPTER 3

METHODS

3.1 Instrumentation

1. Standard sauna room (1.90 m x 2.50 m x 2.05 m) (College of Sports Sciences and Technology, Mahidol University) with adjustable temperature (43-45°C) and relative humidity (55-60 %)
2. Portable metabolic test system (Metamax, Leipzig, Germany)
3. Two-ways non-rebreathing valves (Hans Rudolph, Kansas City, MO)
4. Electrical skin thermistors and rectal thermistor probe (Grant Instruments Ltd., Cambridge, England)
5. Data logger (Grant Squirrel, Cambridge, England)
6. Telemetry Heart rate monitor (Polar, Finland)
7. Pneumatic sphygmomanometer
8. Stethoscope
9. Cycle ergometer (model 828 E, Monark, Germany)
10. 2-digit precision weight balance (AD 1021, Japan)
11. Height meter
12. Mercurial thermometer
13. Hygrometer
14. Lubricant gel (K-Y jelly)
15. Waterproof plastic tape (Tigerplast, Thailand)
16. Continuous water dipping
17. Non-allergic anti-microbacterial cleanser (BIOGUARD, UK)
18. Towels
19. Short pants
20. Clock
21. Plastic bags and rubber bands

22. Pure drinking water
23. Borg RPE scale
24. Thermal sensation scale
25. Thermal discomfort scale

3.2 Subjects

Six healthy Thai males, age range between 20-28 years, voluntarily participated in this study. They were preliminarily recruited and interviewed by the investigator to identify their sedentary lifestyle (sedentary is defined as the one who exercise once or less per week for the last 10 years, or for more than 2 years continuously since turning 20 years). All subjects were screened and excluded using a specific-purpose designed questionnaire. Prior to participate in this study, the purposes, experimental processes and possible risks and discomforts associated with the experiments were clearly explained to each individual. Moreover, all details mentioned were also printed clearly in the informed consent form submitted to each subject. Voluntary decision was made prior to signing. The studies were approved by the Ethics Committee of Mahidol University. Clinical examination by a qualified medical physician was needed in some cases. After obtaining the consents, complete physical examination was provided. The personal history of health, family and other aspects related were recorded and kept confidentially.

3.3 Exclusion Criteria

The clinical exclusion criteria for each subject were listed below;

1. Never had or has had coronary heart disease
2. Never had or has had any respiratory problems
3. Never had or has had hypertension or hypotension
4. Never had or has had chest injury or operation
5. Never had or has had history of exertional heat illness
6. Never had or has had history of epilepsy
7. Never had or has had any endocrine dysfunction e.g. hyperthyroidism (2)
8. Never had or has had any urogenital dysfunction
9. Never had or has had psychic or neurotic problems
10. Has had no infectious or communicable diseases

11. Has had no joint, muscle and bone injury which may affect the exercise test
12. Has had no hemorrhoid or rectal infection
13. Has had no fever, skin conditions (e.g. sunburn, skin rash, etc.)
14. Has not been a drug addict
15. Has not been in course of certain medication (e.g. antihistamine, diuretics, etc.)
or dietary supplements
16. Has no AIDS

3.4 Methods

Each subject had to visit the laboratory on two occasions, approximately two weeks apart for each test to avoid learning experience from repetitive test. Trials were randomly assigned and counterbalanced across subjects. Firstly, twenty-four hours before doing the experiment, subjects were requested to consume their usual meals and drinks, avoid caffeine-based diet and alcoholic beverages, avoid smoking, avoid or limit any heavy physical activities and rest adequately (not less than seven hours sleep). Especially, each subject was controlled the amount of body water by drinking only 1.5 liters of provided water after 6 p.m. on the day before the test.

Secondly, on the experimental day, all of the equipment that used in this study were prepared, set up and calibrated before the experimental time to ensure that they can run perfectly and correctly. When subject arrived the laboratory, the details of the procedure were re-explained to decrease the possible anxiety. Then, nude body weight, body height, resting heart rate, resting blood pressure, rating of perceived exertion, thermal sensation, and thermal discomfort were measured from the subject. The towel and the short pant were weighed before and after collecting of sweat, and the amount of sweat was estimated using the differences of wet-dry weights method. The specific gravity of urine before testing was determined to know the hydration status of the subject. Then, the subject had to ingest temperate water (1.5% of body weight) one hour prior to the experimental time for maintaining euhydrated status. To avoid the effects of circadian variation of internal body temperature, the experiment was started at the same time of the days (about 10.00-11.00 a.m.).

Heart rate and blood pressure were measured using the heart rate monitor (Polar) and the pneumatic blood pressure monitor, respectively. Respiratory rate, respiratory

exchange ratio, minute ventilation, tidal volume were measured using the portable metabolic test system (Metamax, Germany) (Figure 5). T_{core} was detected by inserting a rectal thermistor probe, 10 cm deep into the rectum (2,54,84). Skin temperatures were measured 4 sites by skin thermistors taped to the upper back (the tenth thoracic body), left upper arm (anterior part), left thigh (anterior mid-femur), and left leg (posterior mid-calf) (54). All thermistors and the rectal probe were connected to the data logger (Grant Squirrel, Cambridge, England) (Figure 6). Rating of perceived exertion scales (Table 3), thermal sensation (Table 4), and thermal discomfort (Table 5) were clearly shown to the subject for determining his psychological responses. Each subject pointed the scales in the charts for the researcher's recording.

Table 3 The Borg perceived exertion scales (5)

Scale	Verbal Expression
6	
7	Very, very light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Very, very hard
20	

Table 4 The 13-point thermal sensation scale (17)

Scale	Verbal Expression
1	Unbearable cold
2	Extremely cold
3	Very cold
4	Cold
5	Cool
6	Neutral
7	Slightly warm
8	Warm
9	Hot
10	Very hot
11	Extremely hot
12	Unbearable hot

Table 5 The thermal discomfort scale (17)

Scale	Verbal Expression
1	Comfortable
2	Slightly uncomfortable
3	Uncomfortable
4	Very uncomfortable
5	Extremely uncomfortable

Each subject was permitted to wear a loose-fitting comfortable underwear during in sauna. After preparing the equipment needed for the experiment, subject and a co-researcher entered the sauna room. The main researcher remained outside the sauna to observe changes in characteristics of displaying variables and recorded the data obtained from the test. Prior to each experiment, portable metabolic test system (Metamax, Germany) was calibrated for volume transducer by 3-litre calibration syringe, standard gas mixture by known concentration gas of oxygen and carbon dioxide, and calibrated for ambient air. Hygrometer and room thermometer had calibrated and certified by meteorological instruments division of Thai Meteorological Department.

The two trials of the test were: (1) Sitting comfortably in the sauna and (2) Exercising in the sauna. For sitting in the sauna, the subject was let to acclimate in the heat by sitting comfortably for five minutes. Then, the subject sat comfortably for another twenty-five minutes exposing to heat ranged approximately from 43 to 45°C where the relative humidity (RH) was kept about 55 to 60%. In the sauna room, the researcher had to monitor subject's blood pressure, thermal sensation, thermal discomfort, and rating of perceived exertion every five minutes until the end of experiment. The researcher outside recorded heart rate, blood pressure, RPE, TS, and TC of the subject in the data recording form. When the time was completed, all of sweat areas were dried using soft towel with known weight. Wet towel and underwear were kept separately in plastic bags fastened tightly with rubber bands and brought to estimate differences between wet-dry weights in the laboratory using a 2-digit balance. The subject's specific gravity of urine was re-determined after the test. The researcher outside observed the subject's body temperature, expiratory gas values (\dot{V}_E , V_T , $\dot{V}O_2$, $\dot{V}CO_2$, \dot{RER}), and respiratory rate from the computer's monitors outside the sauna room.

For exercising in the sauna, subject was let to acclimate in the heat by sitting comfortably for fifteen minutes. Then, subject performed exercise on cycle ergometer (model 828 E, Monark, Germany) (Figure 7) with constant workload of 75 watts. The subject had to control the velocity at 50 ± 5 rpm thorough the test. Subject continuously exercised until reached 30%, 50% and 70% HRR, respectively. Afterthat, the researcher inside adjusted the workload of ergometer to be freeloading and the subject performed another five minutes exercise with freeloading cycle for cooling down. Psychological aspects and blood pressure were recorded every five minutes

similarly to the first trial. After the test, sweat and urine's specific gravity were also determined. This experiment was terminated when the subject's T_{core} exceeded 39°C (36). Other criteria for the termination included nausea, dizziness, chills, exhaustion, or headache (13). Subject had the right to volunteer terminate the test at any time.

When the experiment was complete, the subject was brought outside the sauna room, towed dry and re-measured his nude body weight. Finally, he could then drink water, take a bath, or rest comfortably in cooled environment. Means temperature and relative humidity of ambient and sauna room were recorded (Table 6).

-Heat storage (HS) in body tissues was calculated by

$$HS = 0.97 BW_{pre} (T_{body(post)} - T_{body(pre)}) \quad (4)$$

-Body temperature (T_{body}) was calculated by

$$T_{body} = 0.21 \bar{T}_{skin} + 0.79 T_{re} \quad (17)$$

-Mean skin temperature (T_{sk}) was calculated by

$$T_{skin} = 0.3 T_{back} + 0.3 T_{arm} + 0.2 T_{thigh} + 0.2 T_{calf} \quad (64)$$

-Body density (D_b) was calculated by

$$D_b = 1.1631 - 0.0632 \log(x_4) \quad (\text{Durnin and Warmersley, 1974})$$

[x_4 = sum of triceps brachii, biceps brachii, supriliac, and subscapular (mm)]

-Percent body fat (%BF) was calculated by

$$\%BF = [(4.95 / D_b) - 4.5] \times 100 \quad (\text{Siri, 1963})$$

-Body surface area (BSA) was calculated by

$$BSA = (Wt^{0.425} \times Ht^{0.725}) \times 0.007184 \quad (23)$$

Table 6 Mean and SEM of temperature and relative humidity inside and outside sauna room throughout both-trial study.

Factor	Inside	Outside
Temperature ($^{\circ}\text{C}$)	44.19 \pm 0.13	31.00 \pm 0.20
Relative humidity (%)	58.62 \pm 0.47	88.69 \pm 1.26



Figure 5 Portable metabolic test system (Metamax, Germany)



Figure 6 Data logger, skin thermistors, and rectal thermistor probe (Grant Squirrel, England)



Figure 7 Cycle Ergometer (Ergomic 828E, Monark, Germany)

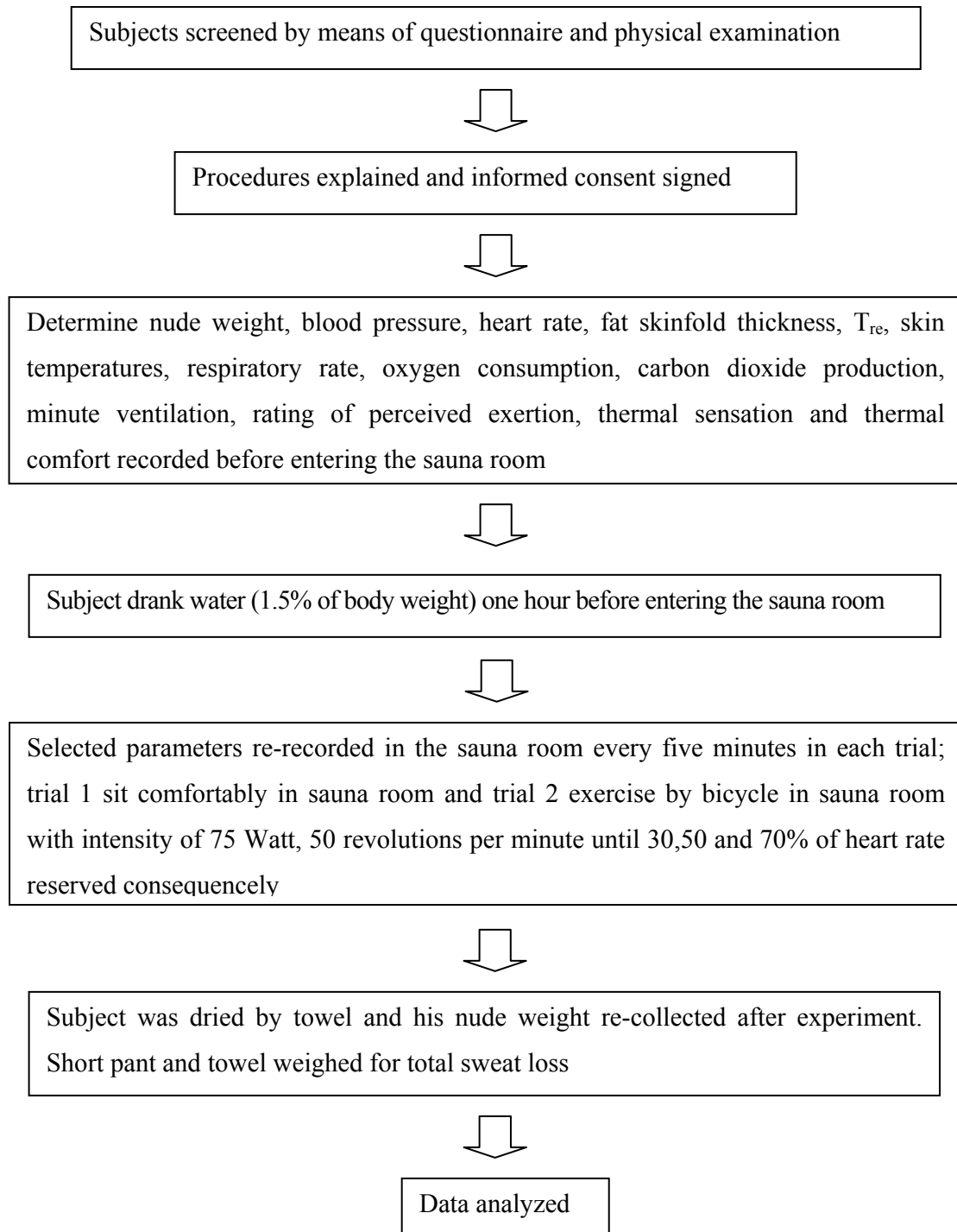


Figure 8 Sauna room (College of Sports Science and Technology, Mahidol University)

3.5 Statistic analysis

Statistical analyses were performed with the SPSS 11.5 for Window. Data were expressed as mean and standard error of the means (mean \pm SEM) values otherwise will be stated. GLM-repeated measure was analyzed to determine the effects of within-subject and Pair *t*-test was used to analyze the effect of between subjects. Linear regression was used to find the relationship between ventilatory and thermoregulatory parameters. The level of statistical significant difference was accepted at $\alpha < 0.05$.

3.6 Experimental protocol



CHAPTER 4

RESULT

The objectives of this study were to investigate the effects of heat and continuous exercise on ventilatory and thermoregulatory responses under thermal stress in healthy Thai males, to compare the relationships between ventilatory and thermoregulatory responses at rest and during exercise in the heat and to investigate the ventilatory and thermoregulatory responses at different exercise intensities in the heat. The investigator hypothesized that there are different ventilatory and thermoregulatory responses among at rest and during exercise and among different exercise intensities under heat exposure. The investigated parameters included rectal temperature, skin temperatures (back, upper arm, thigh, calf), respiratory rate, minute ventilation, oxygen consumption, carbon dioxide production, respiratory exchange ratio, mean arterial pressure, rating of perceived exertion, thermal sensation and thermal comfort. Results would be shown and discussed into three topics as physiological responses (thermoregulatory responses, ventilatory responses, cardiovascular responses and psychological responses) at rest, physiological responses during exercise, and the comparison between physiological responses at rest and during exercise, respectively.

All of subjects were healthy 4th year students in undergraduate level of Mahidol University who could understand clearly all of the procedures of each experiment. They had no history of coronary disease, respiratory disease, exertional heat illness, chest injury or operation, joint, muscle or bone injury. Data obtained from physical activity questionnaire revealed that they were physically inactive. During exercise, none of them showed any signs or symptoms, which may affect the exercise test. The general physical characteristics of subjects were shown in Table 7. It revealed that all of them were in range of normal BMI (18.5-24.9) of Thai population (110). Thus this study successfully recruited normal healthy subjects within the study.

Table 7 General physical characteristics of all subjects (n = 6, mean \pm SD).

Variables	Characteristics
Gender	Male
Age (year)	23.33 \pm 1.02
Weight (kg)	64.74 \pm 3.00
Height (cm)	166 \pm 1.88
BMI (kg/m ²)	23.45 \pm 0.89
BSA (m ²)	1.71 \pm 0.04
% Body fat	18.16 \pm 1.82
Education	4 th yr.University students*

* Undergraduate level.

4.1 Physiological responses

Physiological responses at rest and during exercise in the heat, which included all body temperatures (T_{re} , T_{back} , T_{arm} , T_{thigh} , T_{calf} , \bar{T}_{skin} , T_{body}), lung and cardiac functions were presented.

4.1.1 Thermoregulatory responses

The initial rectal temperature and skin temperatures obtained from various parts of the body in ambient environment were measured before starting the experiment and presented in Table 8.

Table 8 Initial body temperatures ($^{\circ}\text{C}$) at ambient environment obtained from various body parts in rest and during exercise trials. Values are means and the standard errors of the means.

Temperature	Resting ($^{\circ}\text{C}$)	Exercise ($^{\circ}\text{C}$)
T_{re}	37.39 ± 0.06	37.25 ± 0.11
T_{back}	33.94 ± 0.23	34.13 ± 0.20
T_{arm}	34.51 ± 0.27	34.11 ± 0.20
T_{thigh}	34.34 ± 0.29	33.96 ± 0.16
T_{calf}	33.66 ± 0.23	33.48 ± 0.22
\bar{T}_{skin}	34.14 ± 0.21	33.96 ± 0.15
T_{body}	36.71 ± 0.08	36.62 ± 0.08

All body temperatures (T_{re} , T_{back} , T_{arm} , T_{thigh} , T_{calf} , T_{skin} , \bar{T}_{body}) at rest trial in the heat with temperature of $44.19 \pm 0.13^{\circ}\text{C}$ and $58.62 \pm 0.47\% \text{RH}$ were illustrated in Figure 9a. When compared to the corresponding temperatures at time 0, subjects' rectal temperature was kept stable throughout the trial except the last data point (at 25 min) where T_{re} was significantly increased above its resting level ($p < 0.05$). Similar to T_{core} , T_{body} was kept constant for the entire period of the study except the significantly higher at 25 min ($p < 0.05$). T_{back} , T_{arm} , T_{thigh} , and T_{calf} in the same pattern since entering the chamber and gradually rose around 1 celcius within 25 minutes. \bar{T}_{skin} , on the other hand, increased at the slower rate than those skin temperatures ($p < 0.05$). The final temperatures across the body were in the range of 35.5 to 37.3 $^{\circ}\text{C}$.

For comparison between groups at the same period of time, there was no significant difference throughout the study between $T_{\text{back}} - T_{\text{arm}}$, $T_{\text{back}} - T_{\text{thigh}}$, $T_{\text{back}} - T_{\text{calf}}$, and $T_{\text{thigh}} - \bar{T}_{\text{skin}}$, as well as $T_{\text{back}} - T_{\text{body}}$ and $T_{\text{arm}} - T_{\text{thigh}}$ at 25 min ($p > 0.05$).

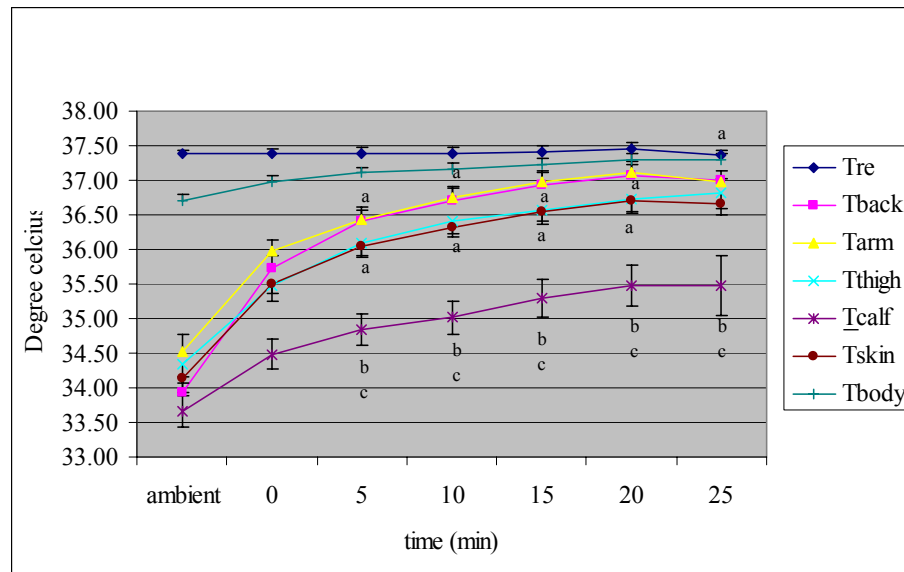


Figure 9a Rectal temperature (T_{re}), back temperature (T_{back}), arm temperature (T_{arm}), thigh temperature (T_{thigh}), calf temperature (T_{calf}), mean skin temperature (T_{skin}), and body temperature (T_{body}) at rest in the heat as function of time measured at every five minutes interval.

^a Significant different from the initial value (0 min) within the group ($p < 0.05$).

^b Significant different among the groups at the same period of time ($p < 0.05$).

^c Significant different from the previous value within the same group ($p < 0.05$).

Body temperatures (T_{re} , T_{back} , T_{arm} , T_{thigh} , T_{calf} , \bar{T}_{skin} , T_{body}) during the exercise trial were illustrated in Figure 9b. T_{back} , T_{arm} , T_{thigh} , T_{calf} , \bar{T}_{skin} , T_{body} increased in the same pattern since entering the chamber. There was gradually increased of these temperatures at the approximate rate of 3 celcius in 25 minutes. Significant differences from the previous and initial values were found in T_{back} , T_{arm} , T_{thigh} , T_{calf} , \bar{T}_{skin} , and T_{body} throughout the study and T_{re} from 10 min to the end of the experiment ($p < 0.05$). The final temperatures across the body were in the range of 36.8 to 37.2 °C.

For comparison between groups, many pairs were significant differences except $T_{back}-T_{arm}$, $T_{re}-T_{back}$, $T_{re}-T_{arm}$, $T_{back}-T_{body}$, $T_{arm}-T_{body}$, and $T_{thigh}-\bar{T}_{skin}$ at 10 and 15 min, and $T_{re}-T_{arm}$, $T_{re}-\bar{T}_{skin}$, $T_{back}-T_{arm}$, $T_{thigh}-T_{calf}$, and $T_{skin}-T_{body}$ at 20 and 25 min ($p > 0.05$).

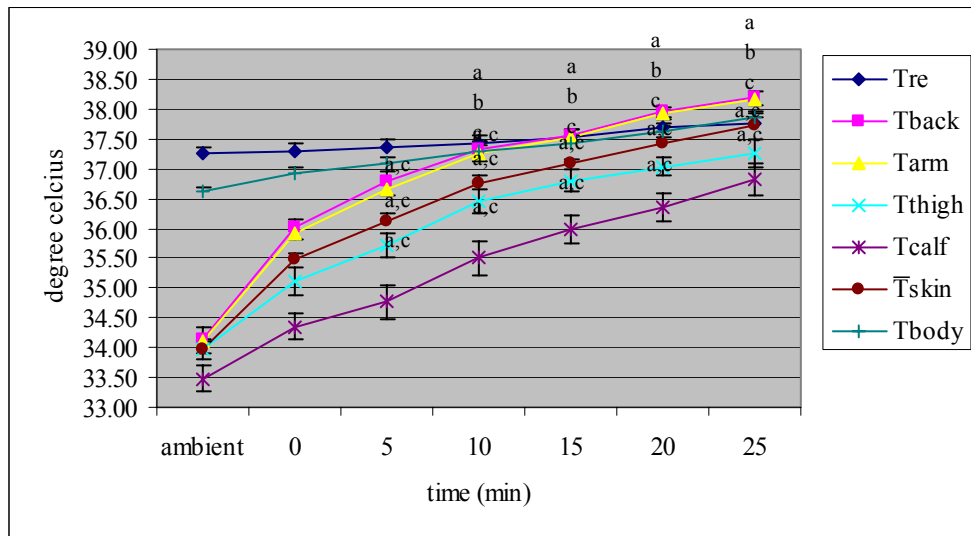


Figure 9b Rectal temperature (T_{re}), back temperature (T_{back}), arm temperature (T_{arm}), thigh temperature (T_{thigh}), calf temperature (T_{calf}), mean skin temperature (T_{skin}), and body temperature (T_{body}) during exercise as function of time in the heat measured at every five minutes interval.

- ^a Significant different from the initial value (0 min) within the group ($p < 0.05$).
- ^b Significant different among the groups at the same period of time ($p < 0.05$).
- ^c Significant different from the previous value within the same group ($p < 0.05$).

Body temperatures during exercise trial as function of workload were presented in Figure 10. The present investigation was designed to compare body temperature regulation at the same workloads of 30, 50, and 70% heart rate reserved. It was found that at 30%HRR, T_{back} , T_{arm} , T_{thigh} , and T_{calf} , as well as T_{body} , increased suddenly from min 0 and steeply increased thorough the trial. These temperatures further increased significantly as workloads were increased to 50% ($p < 0.05$) and 70% HRR ($p < 0.05$). T_{re} during exercise at 30%HRR in the heat was kept stable ($p > 0.05$). As exercise intensity increased to 50 and 70%HRR, T_{re} showed significant greater than before ($p < 0.05$).

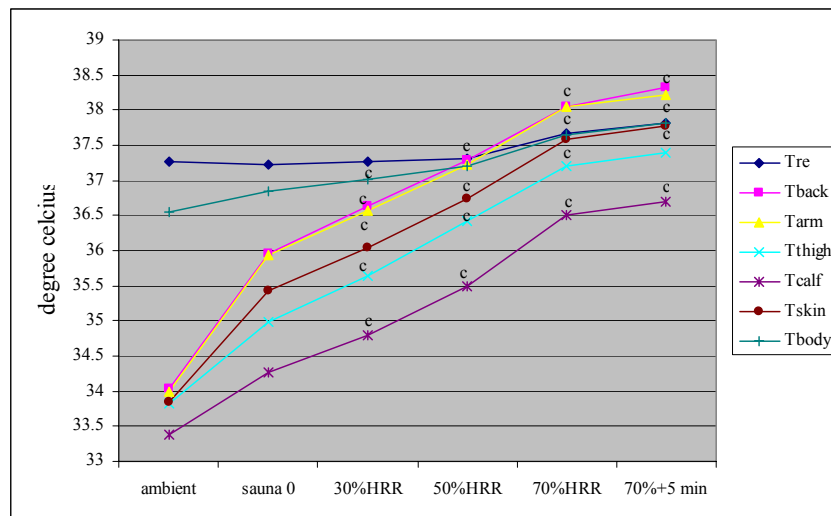


Figure 10 Rectal temperature (T_{re}), back temperature (T_{back}), arm temperature (T_{arm}), thigh temperature (T_{thigh}), calf temperature (T_{calf}), skin temperature (T_{skin}), and body temperature (T_{body}) during exercise, as function of workload in the heat conducted at 30%, 50%, 70%, and 5 min after 70% heart rate reserved (HRR).

- ^a Significant different from the initial value (0 min) within the group ($p < 0.05$).
- ^b Significant different among the groups at the same period of time ($p < 0.05$).
- ^c Significant different from the previous value within the same group ($p < 0.05$).

4.1.2 Ventilatory responses

1. Minute ventilation (\dot{V}_E)

Minute ventilation (\dot{V}_E) during rest and exercise in the heat, as function of time, was shown in Figure 11. Subjects' \dot{V}_E in ambient environment, of at resting condition and prior to exercise trial, were 11.21 ± 1.21 and 9.4 ± 1.21 L/min, respectively. No significant differences were found during 25-min rest in the heat chamber ($p > 0.05$). In exercise trial, \dot{V}_E abruptly increased at 5 min ($p < 0.05$) in the heat and continuously rose until the end of the trial ($p < 0.05$). Within the group comparison revealed the significant differences of \dot{V}_E at every 5-min interval from 0 min to 25 min when compared to initial value ($p < 0.05$). For comparing to the previous value, there were significant differences throughout the exercise trial except the last data point ($p > 0.05$). Correlation analysis indicated that there was significant

relationship between exercise duration within the sauna and \dot{V}_E during exercise with $r = 0.88$ ($p < 0.05$).

Comparison between resting and exercise in the heat showed that \dot{V}_E during exercise was remarkably higher in exercise trial than resting condition since the beginning of physical activity ($p < 0.05$). The highest \dot{V}_E during exercise trial was about 40 Liters/min.

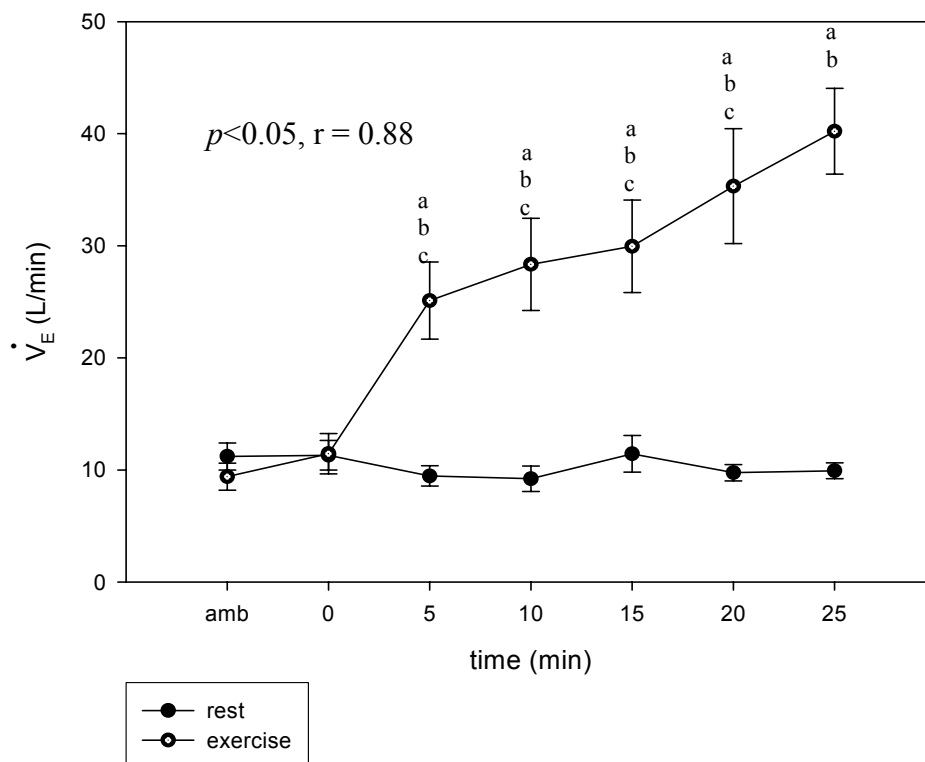


Figure 11 Minute ventilation (\dot{V}_E) during 25-min period at rest and during exercise in the heat measured at every five minutes interval.

- ^a Significant different from the initial value (0 min) within the group ($p < 0.05$).
- ^b Significant different among the groups at the same period of time ($p < 0.05$).
- ^c Significant different from the previous value within the same group ($p < 0.05$).

For comparison within the group of exercise as function of workload between indicated data point and the previous value measured at each exercise intensity (Figure 12), minute ventilation increased up to +97% at 30%HRR ($p < 0.05$), then further increased for another +26% at 50%HRR ($p < 0.05$), and lastly \dot{V}_E further increased to another

+26% for 70%HRR ($p<0.05$). The correlation between workload and \dot{V}_E was significantly high ($r = 0.856, p<0.05$).

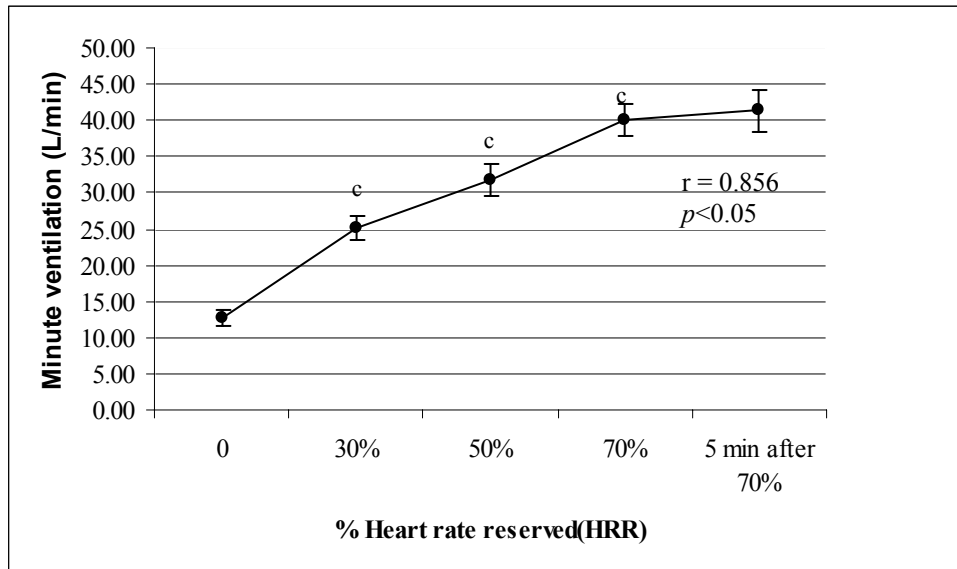


Figure 12 Minute ventilation during 25-min exercise in the heat chamber conducted at 30, 50, 70%, and 71% heart rate reserved (HRR).

^a Significant different from the initial value (0 min) within the group ($p<0.05$).

^c Significant different from the previous value within the same group ($p<0.05$).

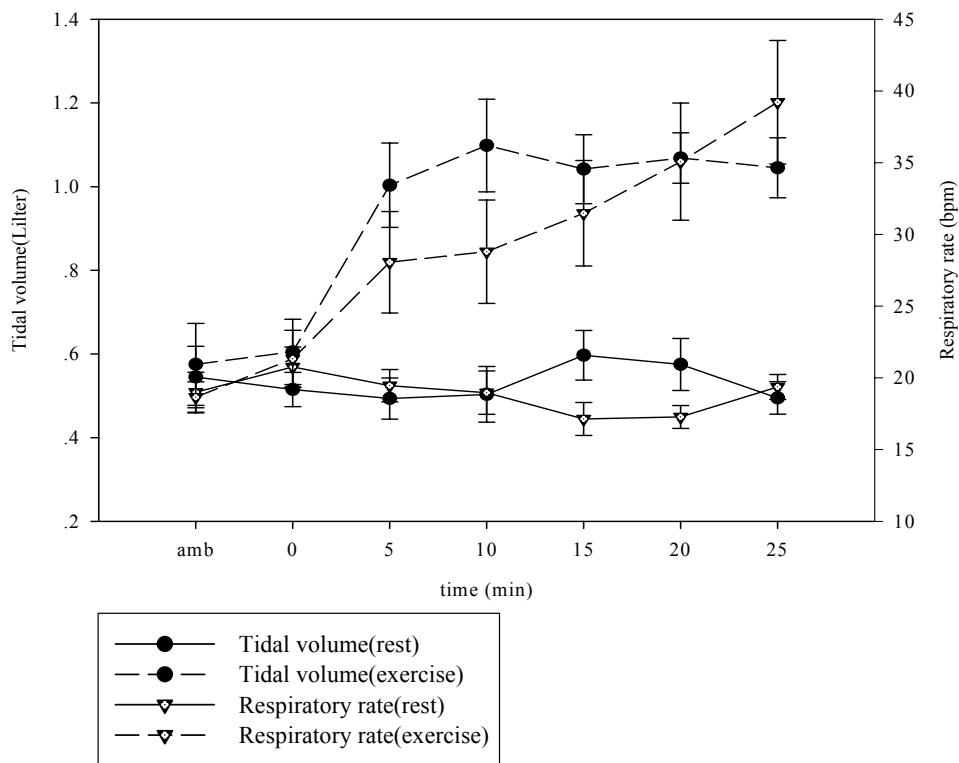


Figure 13 Tidal volume (V_T) and respiratory rate (RR) at rest and exercise in heat chamber measured at every five minutes interval.

- ^a Significant different from the initial value (0 min) within the group ($p < 0.05$).
- ^b Significant different among the group at the same period of time ($p < 0.05$).
- ^c Significant different from the previous value within the same group ($p < 0.05$).

Exercise showed tendency, but not significant, to abruptly increase in tidal volume and became approach plateau after 10 min. Tidal volume, of either at rest or during exercise, increased in the similar fashion, which were lower magnitudes than respiratory rate. Respiratory rate, on the other hand, increased in a stepwise fashion throughout the study. When compared between resting condition and during exercise results revealed that neither tidal volume nor respiratory rate showed significant change ($p > 0.05$).

2. Oxygen consumption ($\dot{V}O_2$) and Carbon dioxide production ($\dot{V}CO_2$)

Oxygen consumption ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) at rest and during exercise in the heat were illustrated in Figure 14. Oxygen consumption's value at rest was approximately 0.3 L/min throughout the study. After entering the sauna in exercise trial, oxygen consumption increased to the level about 0.4 L/min and there was a remarkable increase when compared to its initial value during the first 5 min of exercise under heat exposure. It appeared that oxygen consumption approached 0.8 L/min at 5 min. From 5-25 min thereafter, there were significant increase of oxygen consumption approximately 1.2 L/min.

For comparison between 2 conditions, there were significantly different of oxygen consumption between resting and exercise trial from 5 min to the end of the study. Obviously, oxygen consumption in exercise condition was greater than resting condition ($p < 0.05$).

Carbon dioxide production ($\dot{V}CO_2$) from the body at rest in the ambient air was approximately 200 ml/min and slightly lower. No significant carbon dioxide production of resting with heat exposure throughout the study was found.

Carbon dioxide production among exercise in the heat was the result of higher metabolic activities. Throughout 25 min of exercise under heat exposure, both oxygen consumption and carbon dioxide production showed the similar pattern of increasing according to the metabolic demand.

When carbon dioxide production was compared between 2 trials, like oxygen consumption, there were higher differences significantly in the study of exercise from 5 min to the end of the study ($p < 0.05$).

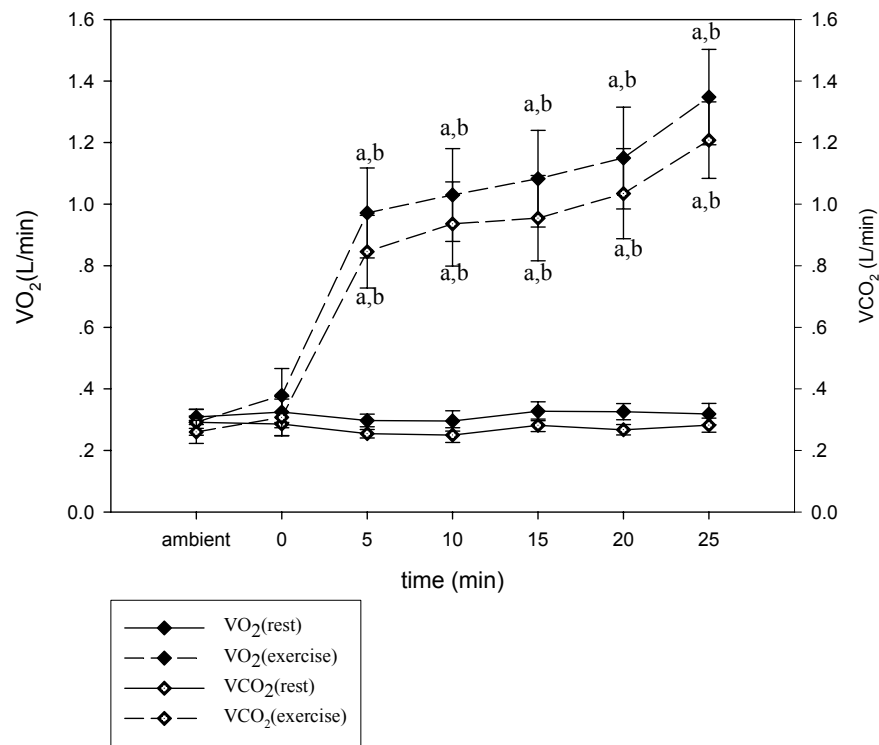


Figure 14 Oxygen consumption ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) at 25-min rest and during exercise in the heat chamber measured at every five minutes interval.

- ^a Significant different from the initial value (0 min) within the group ($p < 0.05$).
- ^b Significant different among the group at the same period of time ($p < 0.05$).
- ^c Significant different from the previous value within the same group ($p < 0.05$).

Oxygen consumption and carbon dioxide production during 25-min exercise in the heat chamber, as function of workload, at different exercise intensities were illustrated in Figure 15. Like those found in minute ventilation, both $\dot{V}O_2$ and $\dot{V}CO_2$ were significantly different at 30, 50 and 70%HRR, respectively compared to the previous value of each data points ($p < 0.05$).

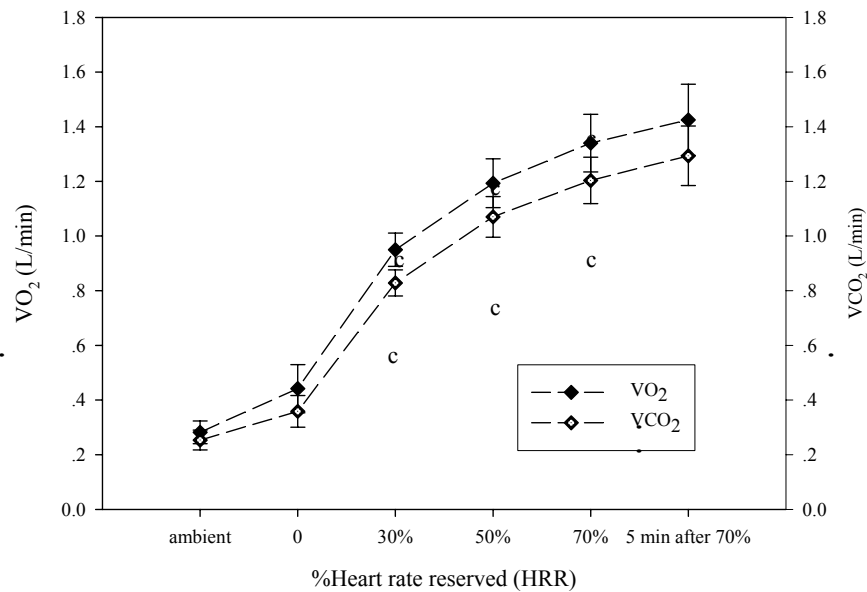


Figure 15 Oxygen consumption ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) during exercise in the heat conducted at 30%, 50%, 70%, and 5 min after 70% heart rate reserved (HRR).

- ^a Significant different from the initial value (0 min) within the group ($p < 0.05$).
- ^b Significant different among the group at the same period of time ($p < 0.05$).
- ^c Significant different from the previous value within the same group ($p < 0.05$).

3. Respiratory Exchange Ratio

Figure 16 presents respiratory exchange ratio (RER) during rest and exercise in the heat. RER in ambient environment normally appeared to be 0.90 in two trials. Resting RER remained unchanged compared to its initial value in sauna ($p > 0.05$) except at 20 min in sauna where RER was significantly lower than its initial value ($p < 0.05$). On average RER at rest in the heat were approximately about 0.85-0.9.

Exercising RER in the heat showed that this metabolic index increased significantly at 10, 20, and 25 min when compared to its initial value. At time 10 and 20 min, RER from exercising in the heat were significantly higher than RER at rest ($p < 0.05$).

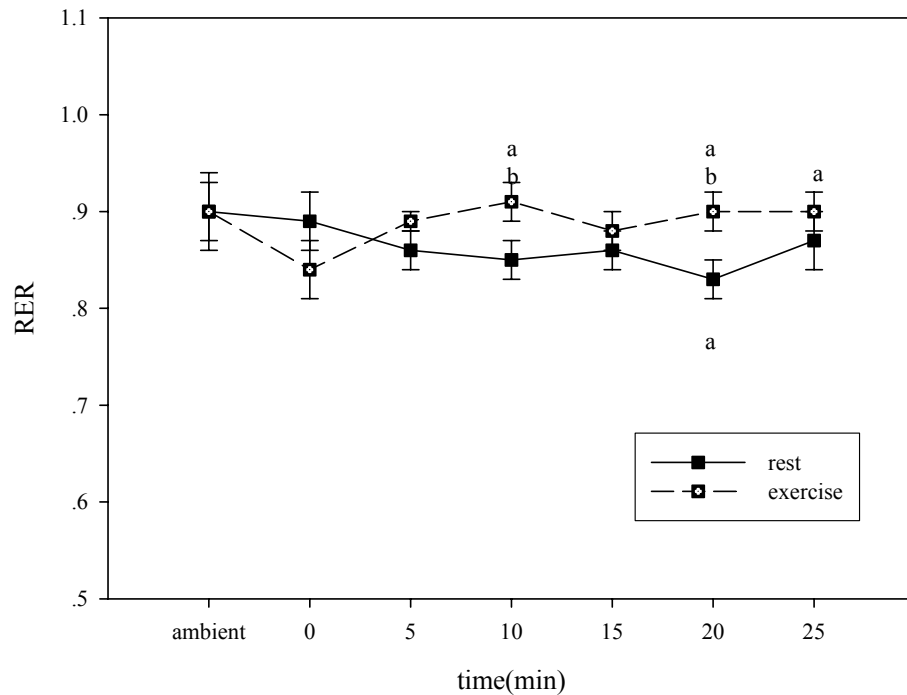


Figure 16 Respiratory exchange ratio (RER) at 25-min rest and during exercise in the heat chamber measured at every five minutes interval.

- ^a Significant different from the initial value (0 min) within the group ($p < 0.05$).
- ^b Significant different among the group at the same period of time ($p < 0.05$).
- ^c Significant different from the previous value within the same group ($p < 0.05$).

4.1.3 Cardiovascular responses

1. Heart rate

Heart rate (HR) at rest and during exercise trials was illustrated in Figure 17. Heart rate at rest in ambient environment was 76.86 ± 3.55 bpm, when entering the sauna was 78.0 ± 3.71 bpm. From 5 to 25 min resting in sauna, HR remained unchanged throughout the study. During exercise in the heat, HR changed abruptly during first 5 min from 80.86 ± 4.42 to 118.86 ± 5.94 bpm which was higher than the initial value and higher than resting HR during sitting quietly in the chamber ($p < 0.05$). When subjects performed further exercise, HR increased to 132.71 ± 6.30 bpm at 10 min, 145.57 ± 3.87 bpm at 15 min, 153.86 ± 3.81 bpm at 20 min, and 157.80 ± 3.31 bpm at 25 min

which showed significantly higher than initial value ($p<0.05$) and higher than without exercise condition ($p<0.05$).

When compared between conditions at the same period of time, exercise in the heat induced significantly higher heart rate responses from 5 to 25 min ($p<0.05$). The final heart rate were 85.67 ± 2.35 and 157.83 ± 2.70 bpm under resting and exercise conditions in the heat respectively (Figure 18).

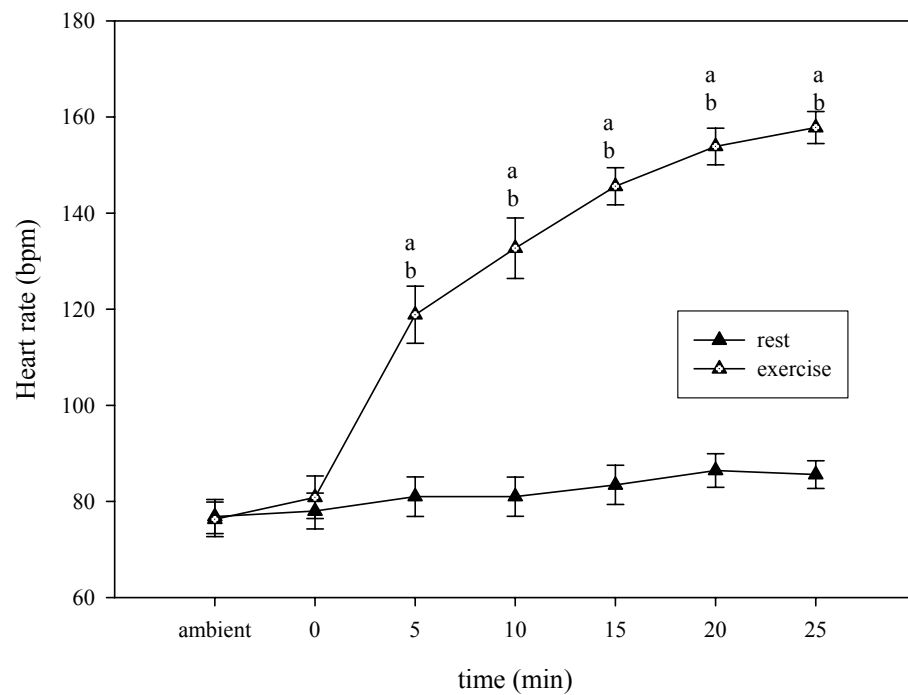


Figure 17 Heart rate (HR) at 25-minute rest and during exercise in the heat chamber measured at every five minutes interval.

- ^a Significant different from the initial value (0 min) within the group ($p<0.05$).
- ^b Significant different among the group at the same period of time ($p<0.05$).
- ^c Significant different from the previous value within the same group ($p<0.05$).

2. Mean arterial pressure

Mean arterial pressure (MAP) at rest and exercise trials were presented in Figure 18. At min 0, MAP at rest and exercise trials were 89.05 ± 3.48 and 84.00 ± 2.18 mmHg respectively which showed no significant difference. Resting in the heat caused non-significant change in MAP, compared to its initial value, throughout 25 min of the study. In exercise study, MAP immediately dropped to 83 mmHg at 0 min in the sauna. Thereafter, MAP fluctuated, but not significantly different throughout the entire period of the study.

When compared between trials, there was no significant different of MAP between trials ($p > 0.05$) throughout the study.

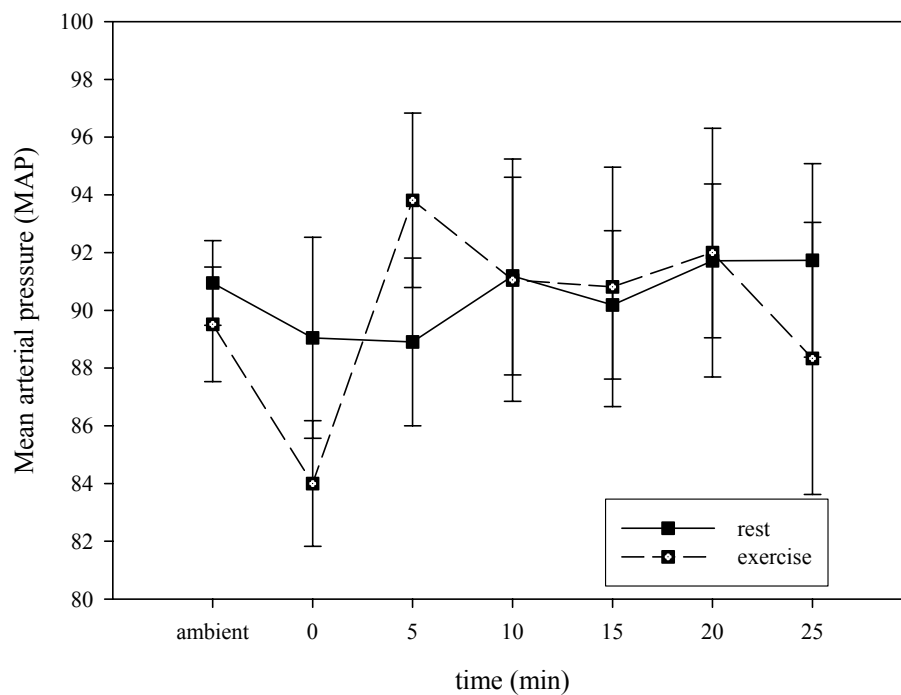


Figure 18 Mean arterial pressure (MAP) at 25-minute rest and during exercise in the heat chamber measured at every five minutes interval.

^a Significant different from the initial value (0 min) within the group ($p < 0.05$).

^b Significant different among the group at the same period of time ($p < 0.05$).

^c Significant different from the previous value within the group ($p < 0.05$)

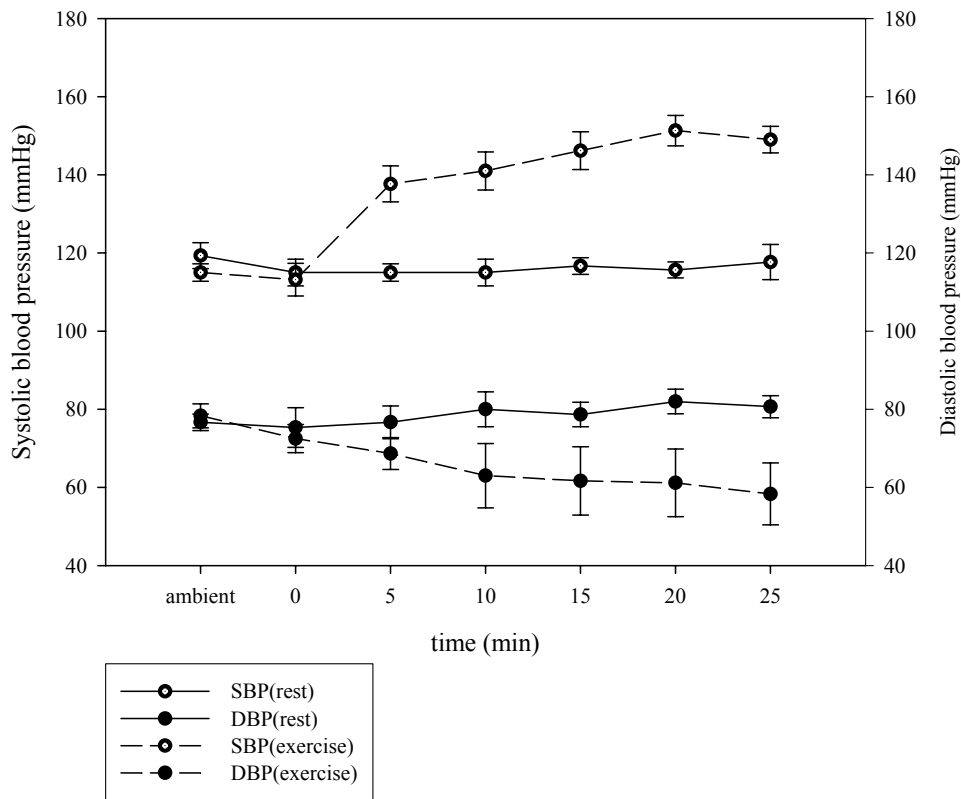


Figure 19 Systolic and diastolic blood pressure (SBP&DBP) at 25-minute rest and during exercise in the heat chamber measured at every five minutes interval.

4.1.4 Total sweat loss

Urine specific gravity before and after each study was determined in order to investigate hydration status of the body and to prevent subjects from heat illness. Table 9 presented changes in body weight, water intake, total amount of sweat, and amount of urine in both trials. Results revealed that total water intake was 933.63 ± 24.42 and 968.89 ± 43.31 cc in resting and exercising conditions respectively, whereas total sweat and urine loss were approximately 340 and 408 cc (gm) in resting and exercising conditions respectively. Thus, water input was 2-3 times greater than weight loss via sweat and urine.

Table 9 Changes of body weight, total amount of sweat and urine, obtained from 25 minute exposure at rest and during exercise trials in the heat chamber.

		Rest	Exercise
BW(pre) (kg)		62.23±3.28	62.49±2.16
BW(post) (kg)		62.37±3.31	62.45±2.17
%change of BW		+0.09±0.19	-0.33±0.2
Water intake (cc)		933.63±24.42	968.89±43.31
Total amount of water output	sweat (g)	170.4±25.5	192.9±21.1
	urine (cc)	170.2±48.4	214.7±36.0
Specific gravity of urine(pre)		1.006 ± 0.004	1.008 ± 0.004
Specific gravity of urine(post)		1.004 ± 0.002	1.002 ± 0.001

4.2 Psychological responses

4.2.1 Rating of perceived exertion (RPE)

RPE is a method to evaluate subjective sensations arising the body during physical exercise on feeling of fatigue and exercise tolerance. Feeling of subjects during exercise under heat exposure is the combination of heat stress and additive stress from internal body metabolism while feeling at rest is the external heat stress alone. Figure 19 presented RPE obtained from two subject groups. RPE at 0 min were 7.29±0.29 and 7.57±0.37 in resting and exercise condition respectively. Gradually increases of RPE were observed in both groups after 5 min in the heat chamber. Control group showed significantly increased RPE, from its initial value, at 10 min after heat exposure ($p<0.05$). These characteristics were observed throughout the study. Exercise group showed significantly higher RPE at 5 min and progressively increase throughout the study ($p<0.01$).

During exercise in the heat, RPE markedly increased from first 5 min ($p<0.05$). Afterthat, the values increased in higher rate compared to the resting trial and further diverged till the end of the study ($p<0.05$).

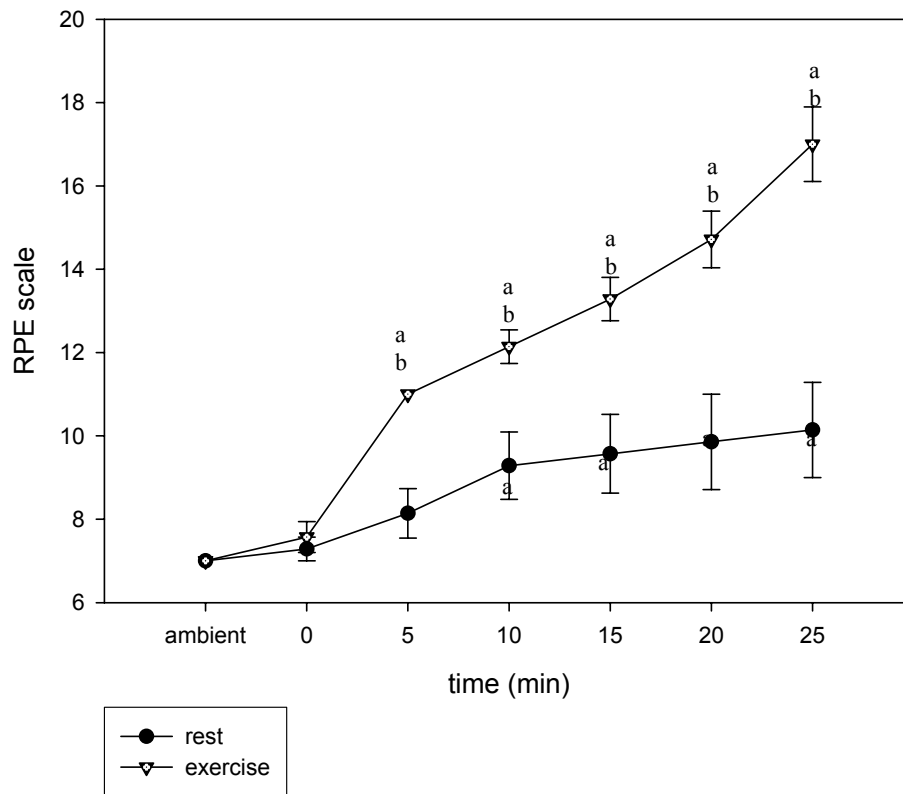


Figure 20 Rating of perceived exertion (RPE) at 25-minute rest and during exercise in the heat chamber measured at every five minutes interval.

- ^a Significant different from the initial value (0 min) within the group ($p < 0.05$).
- ^b Significant different among the group at the same period of time ($p < 0.05$).
- ^c Significant different from the previous value within the group ($p < 0.05$).

4.2.2 Thermal Sensation

Thermal sensation score (TS) at rest and exercise in the heat were illustrated in Figure 20. Thermal sensation score at rest in the ambient temperature was defined as 7. Immediately as subjects entering the sauna, initial values of thermal sensation were 8.43 ± 0.48 and 8.86 ± 0.46 during rest and exercise condition under heat exposure, respectively. Sitting quietly in the heat caused progressively higher TS. During exercise in the heat, like at rest in sauna, thermal sensation changed in the same linear pattern since beginning until the end of the study.

Comparison between the groups showed that within the heat chamber, TS of the two groups have similar, non-significant, pattern throughout the study ($p>0.05$). Final TS in resting condition was 10.0 while in exercise group was 11.0 which revealed that TS remarkably increased about the similar magnitudes in both rest and exercise condition.

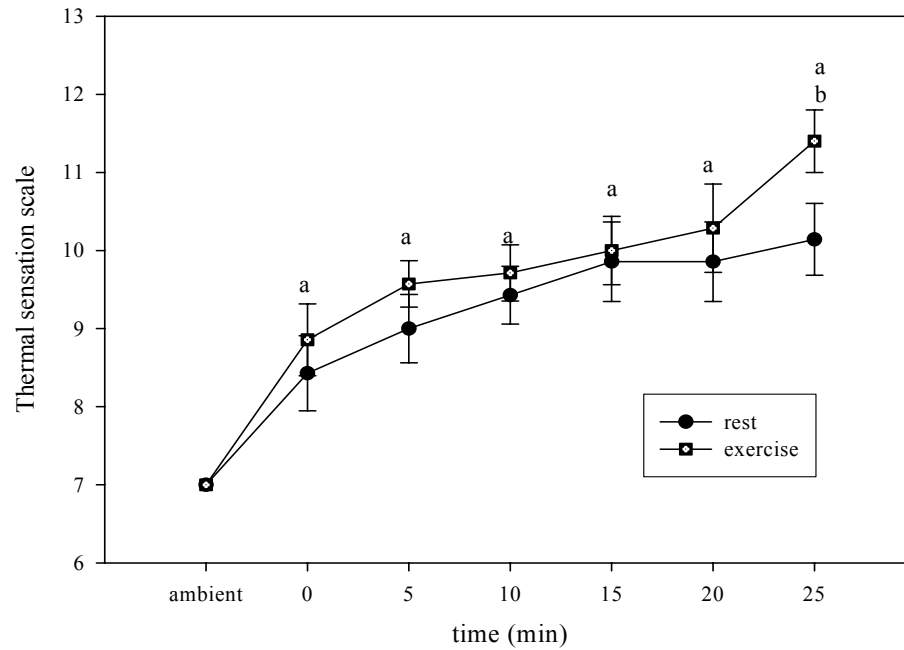


Figure 21 Thermal sensation (TS) at 25-minute rest and during exercise in the heat measured at every five minutes interval.

- ^a Significant different from the initial value within the group ($p<0.05$).
- ^b Significant different between trials at the same period of time ($p<0.05$).
- ^c Significant different from the previous value within the same group ($p<0.05$).

4.2.3 Thermal comfort

Thermal comfort (TC) is a subjective method to evaluate subject’s feeling of comfort in a particular situation of environment. Thermal comfort within and between trials of rest and exercise were shown in Figure 21. At 0 min, the two groups’ thermal comfort scale were 1.21 ± 0.15 and 1.36 ± 0.28 respectively. Feeling of comfort in coping with heat stress and exercise under heat exposure gradually increased in the similar linear pattern throughout the study ($p>0.05$). At 25 min, TC reached 2.4 ± 0.51 and 3.8 ± 0.25 for at rest and exercise, respectively.

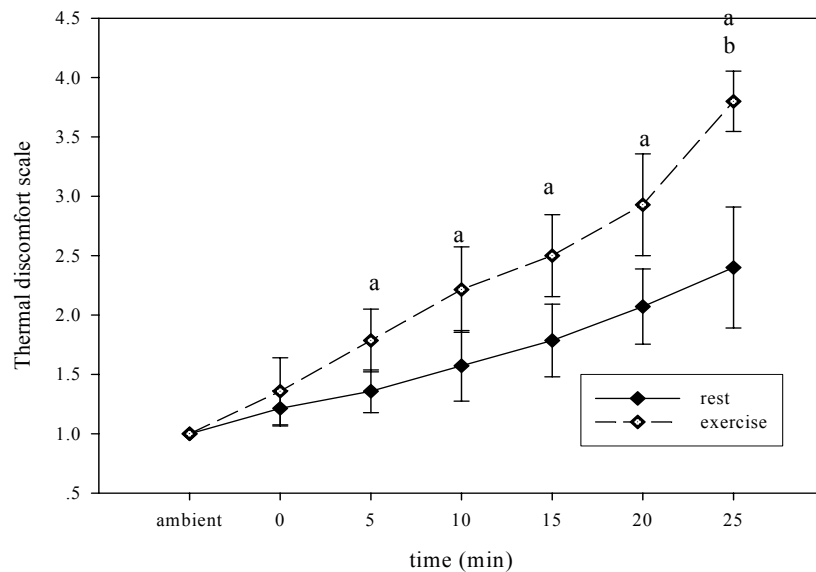


Figure 22 Thermal comfort (TC) at 25-minute rest and during exercise in the heat chamber measured at every at five minutes interval.

- ^a Significant different from the initial value (0 min) within the group ($p < 0.05$).
- ^b Significant different among the group at the same period of time ($p < 0.05$).
- ^c Significant different from the previous value within the group ($p < 0.05$)

4.3 Relationships between thermoregulatory and cardiorespiratory responses

4.3.1 Relationships between thermoregulatory and cardiorespiratory responses at rest trial in the heat.

Most investigators explored the body regulates its heat production and dissipation. It was an attempt of this study to find the relationship between thermoregulatory and cardiorespiratory systems. Correlation coefficients (r) between thermoregulatory and cardiorespiratory variables were presented in Table 10. Some of these coefficients showed positive while some showed negative correlation. At rest, there was no significant correlation between respiratory variables, including minute ventilation, tidal volume, respiratory rate, oxygen consumption, carbon dioxide production and respiratory exchange ratio, and core, skin and body temperatures (T_{re} , T_{back} , T_{arm} , T_{thigh} , T_{calf} , T_{skin} , and T_{body}) ($p > 0.05$). As well as the respiratory variables, cardiac variables, including heart rate and mean arterial blood pressure had no significant correlation with core, skin and body temperatures ($p > 0.05$).

Table 10 Correlation coefficients (r) between thermoregulatory and cardiorespiratory responses during the rest trial in the heat using Regression and Spearman’s Correlation, comparison at $\alpha < 0.05$.

	T _{re}	T _{back}	T _{arm}	T _{thigh}	T _{calf}	T _{skin}	T _{body}
V _E	.327	.337	.098	-.187	-.123	.078	.218
V _T	.328	.339	.094	-.168	-.238	.054	.215
RR	.012	.001	-.026	-.083	.239	.038	.025
VO ₂	.302	.431	.197	-.033	-.052	.183	.251
VCO ₂	.242	.290	.061	-.123	-.159	.059	.103
RER	-.297	-.493	-.292	-.036	-.052	-.257	-.325
HR	.309	.426	.512	.493	.451	.553	.592
MAP	-.226	.098	.070	.083	-.140	.048	-.078

* Significant difference at $p < 0.05$

4.3.2 Relationships between thermoregulatory and cardiorespiratory responses during exercise trial in the heat.

Correlation coefficients (r) between thermoregulatory and cardiorespiratory variables during exercise were illustrated in Table 11. It was found that \dot{V}_E during exercise had high correlation with most of skin and body temperatures but not rectal temperature. There were high correlations between \dot{V}_E with T_{back} (r = 0.793, $p < 0.05$), T_{arm} (r = 0.820, $p < 0.05$), T_{thigh} (r = 0.917, $p < 0.05$), \bar{T}_{skin} (r = 0.808, $p < 0.05$), with T_{body} (r = 0.796, $p < 0.05$). However, there was low correlation between T_{re} and \dot{V}_E with r = .597. V_T had no correlation with all temperatures while respiratory rate had correlation with T_{thigh} (r = 0.772, $p < 0.05$) and T_{arm} (r = 0.721, $p < 0.05$).

It was found that $\dot{V}O_2$ and $\dot{V}CO_2$ had high correlation with most of skin and body temperatures but not core temperature. There were high correlations between $\dot{V}O_2$ and T_{back}, T_{arm}, T_{thigh}, T_{skin} and T_{body} (r = 0.778, 0.757, 0.774, 0.768 respectively). VCO₂ had high correlation with T_{back}, T_{arm}, T_{thigh}, \bar{T}_{skin} and T_{body} (r = 0.767, 0.771, 0.805, 0.773 and 0.734 respectively). Heart rate showed significant correlation with T_{back}, T_{arm}, T_{thigh}, T_{calf}, \bar{T}_{skin} and T_{body} (r = 0.961, 0.961, 0.885, 0.900, 0.969 and

0.865 respectively). RER and MAP did not relate to thermoregulatory responses ($p>0.05$).

Table 11 Correlation coefficients (r) between thermoregulatory and cardiorespiratory responses during the exercise trial in the heat.

	T _{re}	T _{back}	T _{arm}	T _{thigh}	T _{calf}	T _{skin}	T _{body}
V _E	.597	.793 †	.820 †	.917 †	.628	.808 †	.796 †
V _T	.527	.645	.608	.647	.541	.629	.663
RR	.419	.663	.721 †	.772 †	.517	.684	.643
VO ₂	.538	.778 †	.757 †	.774 †	.694	.768 †	.743 †
VCO ₂	.516	.767 †	.771 †	.805 †	.680	.773 †	.734 †
RER	-.197	.054	.187	.239	.049	.136	.007
HR	.598	.961 †	.961 †	.855 †	.900 †	.969 †	.865 †
MAP	.355	.132	.104	.032	.204	.132	.284

† significant difference at $p<0.05$.

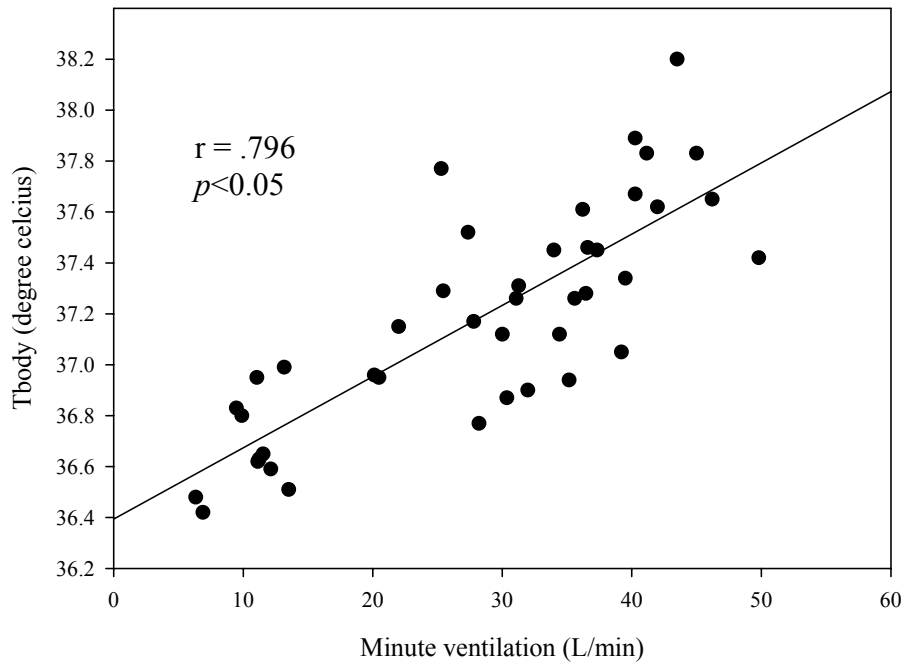


Figure 23 Relationship between minute ventilation (\dot{V}_E) and body temperature (T_{body}) during 25-minute exercise in the heat.

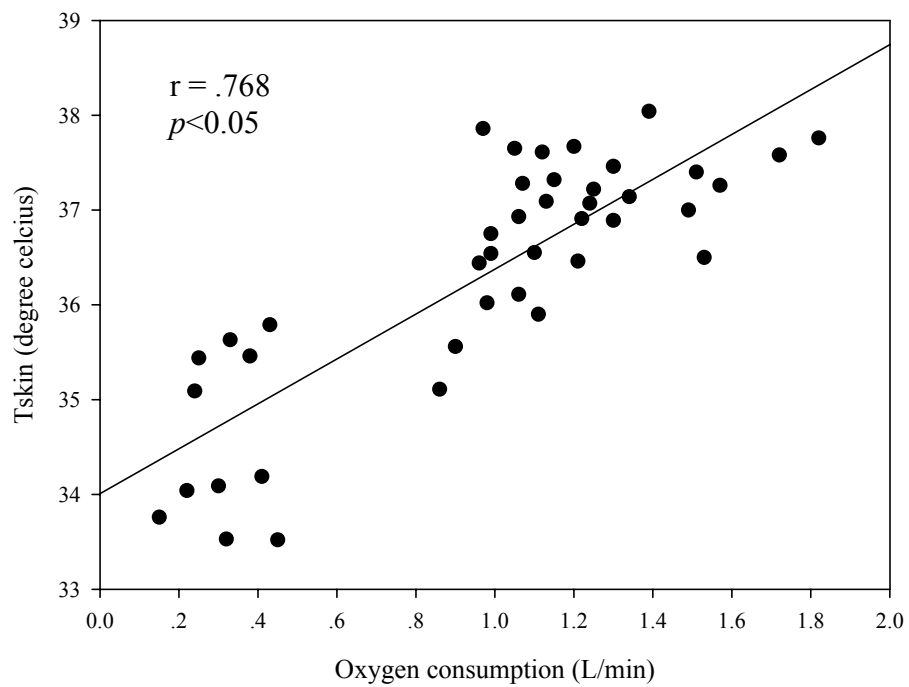


Figure 24 Relationship between oxygen consumption ($\dot{V}O_2$) and mean skin temperature (T_{skin}) during 25-minute exercise trial in the heat

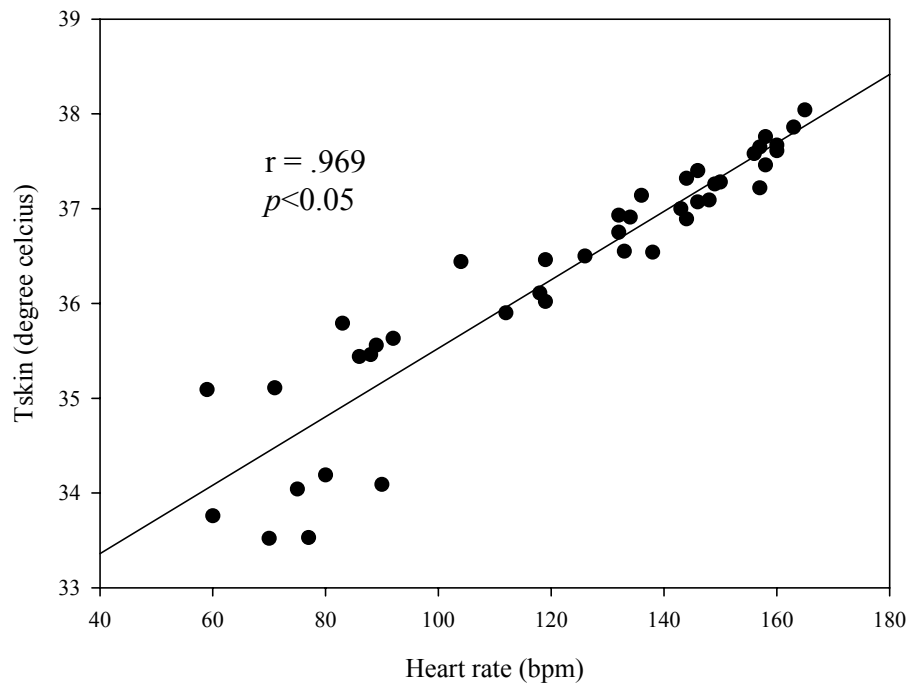


Figure 25 Relationship between heart rate (HR) and mean skin temperature (\bar{T}_{skin}) during 25-minute exercise in the heat

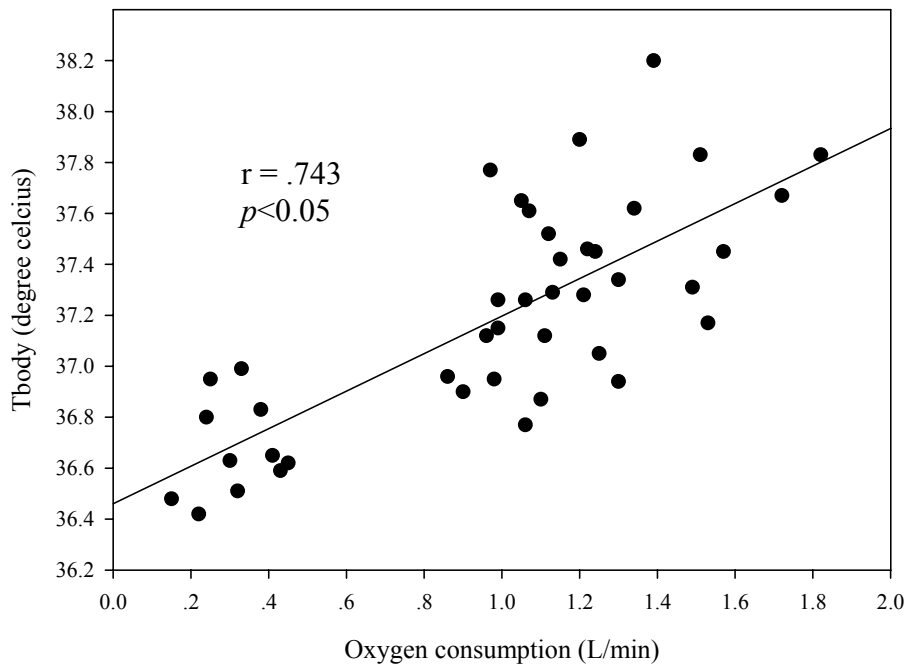


Figure 26 Relationship between oxygen consumption ($\dot{V}O_2$) and body temperature (T_{body}) during 25-minute exercise in the heat.

Table 12 Summary on thermoregulatory and cardiorespiratory responses at rest and exercise trials during heat exposure.

	Rest	Exercise
Thermoregulatory responses		
Rectal temperature (°C)	↔	↑
Back temperature (°C)	↑	↑↑
Arm temperature (°C)	↑	↑↑
Thigh temperature (°C)	↑	↑↑
Calf temperature (°C)	↑	↑↑
Mean skin temperature (°C)	↑	↑↑
Body temperature (°C)	↑	↑↑
Total of sweat loss (g)	↑	↑↑
RPE	↑	↑↑↑
TS	↑	↑↑
TC	↑	↑↑
Cardiorespiratory responses		
HR	↑	↑↑↑
MAP	↔	↔
\dot{V}_E	↔	↑↑
VO ₂	↔	↑↑
$\dot{V}CO_2$	↔	↑↑
RR	↔	↑↑
V _T	↔	↑↑
RER	↔	↔

↔ unchanged, ↑ increased, ↓ decreased

CHAPTER 5

DISCUSSION

For exercise in the heat, it is evident that both endogenous (exercise) and exogenous (ambient) heat load evoke physiological changes. One of the most important factors for thermal acclimation is the elevation of core temperature (1). Accumulated heat is mainly dissipated from the body via blood circulation and skin by radiation, conduction, convection, and evaporation. Skin blood flow and the evaporative water loss are augmented significantly by rate of heat dissipation. This water loss may as high as 1-2 Litre per hour and cause hypohydration (4). Many studies have demonstrated that hypohydration causes an increased core temperature (4,13,14,48). The upper limit of core temperature can safely rise up to 39.5 °C (36).

Animals who are out at midday have special adaptations for dissipating heat. Panting is also an efficient way for many animals to cool the body; evaporative cooling in the nasal passages helps to cool the brain. However, in some animal species such as human do not access dissipating heat by this method. The present study showed that eventhough respiratory system does not contribute for temperature regulation, this physiological system markedly contribute in temperature regulation during exercise.

Temperature regulation at rest and during exercise

Man is an excellent temperature regulator. In a normal climate man loses heat from the body at the same rate as it is formed, and therefore the body temperature remains constant. In very cold surrounding, men tend to lose heat faster. On the other hand, in a hot environment human body tends to become heated, both from the hot surrounding and from its own production of metabolic heat. The only way for man to prevent a rise in body temperature is to be cooled by evaporation.

Jose and colleagues (1999) investigated influence of body temperature on the development of fatigue during prolonged exercise in the heat. The result showed that fatigue during exercise in the heat was related to high internal body temperature. These findings indicated that trained subjects fatigued with core temperatures of ~ 40 °C at 50-60%. There are reports indicating that some untrained subjects fatigued during exercise in uncompensable heat stress with body temperatures of ~ 38 °C (58,74).

In 1998, Entin and colleagues quantified the contribution of exercise intensity, lactic acid, environmental temperature, rectal temperature (T_{re}), and physical conditioning to the variance in arterial CO_2 tension (Pa_{CO_2}) in the exercising sheep. They found that T_{re} rose during all exercise trials, although in the cold environment. During exercise in warm condition, mean skin temperatures invariably indicated that the sheep were vasodilated within 5 min of the onset of exercise.

The present study showed thermoregulatory responses during sitting quietly and exercise under heat stress. Rectal temperatures minimally change or remain unchange throughout both conditions. It is possible that human body tries to keep homeostasis of body temperature during heat exposure by maintain rectal temperatures in a stable fashion. Skin temperatures at any sites of the body, on the other hands, showed the remarkable overshooting after entering the sauna room both trials and more increase in exercise trial. In conclusion, while there was increasing in T_{back} , T_{arm} , T_{thigh} , T_{calf} , \bar{T}_{skin} , T_{body} , no change in core and total body temperatures were observed during 25-min trial of heat exposure. It is generally known that heat produced during exercise will be dissipated in order to preserve body core temperature (64). Heat dissipation at rest is normally regulated via i) conduction, ii) convection, iii) radiation, iv) evaporation (64). During heat exposure, heat dissipation via evaporation is known to be the most effective mode, which is dependent upon the size of exposed skin area (64,108). Since subjects sat quietly in the chamber with no extra heat was being produced, it was indicated from the present study that T_{back} , T_{arm} , T_{thigh} , T_{calf} , \bar{T}_{skin} , played major role in heat manipulation. During exercise trial, there was parallel increase in T_{back} , T_{arm} , T_{thigh} , \bar{T}_{calf} , T_{skin} , T_{body} , with higher core and total body temperatures were observed during 25-min trial of heat exposure. Since subjects exercised in the heat chamber, additional heat was being produced from working muscles. It was indicated from the present study that as exercise was

proceeded T_{back} approached the borderline of safety limit of 39 celcius where the other temperatures remained lower than 37 °C. Increasing in T_{back} may represent temperature changes of the thorax and central blood volume. Since venous return during exercise is about 5 times of resting value (64). As more blood is moving back to the thorax, temperature of this area is supposedly increased which may trigger both the temperature and ventilatory responses.

Respiratory adjustment and temperature regulation

The body exquisitely regulates the rate and the depth of breathing in response to metabolic needs. During all exercise intensities in healthy individuals, arterial pressures for oxygen and carbon dioxide, and pH remain essentially at resting values. Neural information from higher centers in the brain, from the lungs, and from mechanical and chemical sensors throughout the body regulate pulmonary ventilation (64).

Nybo and colleagues (2001) studies effects of marked hyperthermia with and without dehydration on $\dot{V}O_2$ kinetics during intense exercise. The results showed that marked hyperthermia alone or combined dehydration and hyperthermia do not alter $\dot{V}O_2$ on-kinetics, but led to an augmented HR_{max} . The unaltered initial rate of rise in pulmonary $\dot{V}O_2$ during exercise in hyperthermia implies that the rate of muscle mitochondrial respiration was unchanged at the onset of exercise. These results reported that hyperthermia has no effect or increase $\dot{V}O_{2 \text{ max}}$. The large thermal stress experienced by subjects might also the finding that superimposing dehydration on hyperthermia did not lead to additional reductions in $\dot{V}O_{2 \text{ max}}$ (75).

Entin and colleagues (1998) found that Pa_{CO_2} tended to rise during exercise and remained higher in the warm environment than in the cold environment. These results suggested that the need to increase respiratory evaporation and dissipate metabolic heat during exercise contributes to the development of alveolar hyperventilation and hypocapnia. Similarly, White and Cabanac found that, once a threshold core temperature was reached, minute ventilation in exercising humans increased in proportion to increase in body core temperature. The latter authors attributed the increased ventilation to thermoregulatory drive that particularly served to cool the brain. On the basis of data collected in the exercising pony, Forster and Pan speculated that nonhuman mammals might exhibit fewer alveolar-capillary adjustments to exercise

than do humans (who generally maintain isocapnia during low- and moderate-intensity exercise), thus rendering these nonhuman species dependent on and increased alveolar Pa_{O_2} to maintain Pa_{O_2} homeostasis (25).

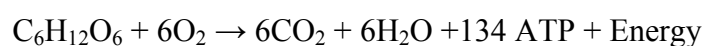
The present study showed that there was no significant change in minute ventilation during sitting the sauna but remarkable increase progressively in a stepwise fashion since the beginning of the exercise study. It is likely that physiological compensation of human sat quietly in sauna is appropriate for body heat regulation. Thus, no need of respiratory compensation under this condition. Minute ventilation when exercise under heat stress diverged from corresponding control value. Cells metabolism generate energy that is appeared as heat 75% of total energy generated from cells metabolism is dissipated as heat and another 25% is converted to be mechanical work. Heat produced by working muscles were dissipated by two ways; skin and blood circulation. First, heat is dissipated via skin thorough the body. After all of the skin worked completely, accumulated heat is conducted via blood circulation to heart and lung, respectively. It is possible that lung may get rid of risen heat by respiration. Thus, there was rapidly increase of minute ventilation during exercise under heat exposure since the activity was started and continuously climbed up to terminate at about 40 L/min where the minute ventilaion of rest trial was not significantly change throughout the study. It is possibly to be the neurogenic stimuli from the cerebral cortex and exercising limbs cause the initial, abrupt increase in breathing when exercise begins (64). As we known that resting minute ventilation of normal person is about 6 L/min (64), the anticipatory responses on physiological change may caused the increased initial minute ventilation (16). During the first 5 minutes of exercise, increased minute ventilation more affected by tidal volume than by respiratory rate. Afterthat, respiratory rate increased continuously whereas tidal volume was kept constant until the end of the study (Figure 13). Additional heat production was dissipated appropriately via the skin and respiration but when the activity go on, more heat production from increased metabolism cannot be dissipated thoroughly and remains accumulated in the body that cause core temperature rise up. However, it was indicated from the present study that ventilation does not participate in heat dissipation during 25-min sitting quietly under heat exposure. Correlation between minute ventilation and heart rate reserved during exercise (Figure 12), it is

revealed that there is high correlation between respiratory and cardiovascular system ($r = 0.85$). It means that whenever cardiovascular system work hard, respiratory system will also work hard. Linear regression was used to analyze correlation between minute ventilation and heart rate reserved. The equation calculated from the present collected data as follow: $\dot{V}_E = 11.78 + 0.41(\%HRR)$.

Oxygen consumption at rest in the sauna were steady at approximately 0.3 L/min and carbon dioxide production at rest in the heat were also in steady state of approximately 0.2 L/min. Previous investigation indicated that oxygen consumption is 300 ml/min and carbon dioxide production is 200 ml/min at rest in neutral environment. Therefore, the present study indicated oxygen consumption and carbon dioxide production at rest under heat exposure are not different to the values in neutral environment and carbon dioxide production is slightly lower than oxygen consumption. The correlation between oxygen consumption and heart rate reserved calculated from the present collected data as follow: $\dot{V}O_2 = 0.55 + 0.01(\%HRR)$.

It means that the greater exercise intensity, the higher oxygen is being consumed. During exercise in the heat, oxygen consumption and carbon dioxide production increased in similar pattern. However, they showed tendency to increase in higher rate at 20 to 25 min. It is expected that there will be the dynamic increasing of these two gases as the study was extended.

RER when exercising in the heat increased significantly from its initial value as well as from resting without exercise. It revealed that when exercise in the heat, the body showed tendency to utilize more carbohydrate which is the energy substrate that easily consumed. From the aerobic energy pathway:



It is described that oxygen and carbon dioxide change in the same rate, which is the function of mitochondria. 75% of additional energy occurred will be changed to be heat and gotten rid of the body via circulatory and respiratory systems. That is the reason why human body has well regulation in heat dissipation.

Weight loss via sweat and urine was less than water intake (Table 9). Body weight change after the test was minimal (0.09 and 0.33% in resting and exercise conditions). Thus, it is believed that large amount of water loss, in form of moist heat, via respiratory tract might account for this balance.

Cardiovascular Adjustment and Exercise in the heat.

Increased energy expenditure requires rapid readjustments in blood flow that affect the entire cardiovascular system. During exercise, the vascular portion of active muscles increases through dilation of local arterioles and vessels shut down blood flow to tissues that can temporarily compromise blood supply (64).

Jose and colleagues (1999) also investigated cardiovascular responses to exercise in the heat. The result showed that the combined elevations in mean skin temperatures, core temperature (2.4-3.1 °C), and skin blood flow reduced cardiac output during moderately intense exercise in untrained subjects. Significantly lower cardiac output (1.0-1.2 L/min), central blood volume (0.1-0.2 liter), and stroke volume (~20 ml) were observed when subjects exercised in a 43 °C than in a 26 °C environment at 63-73% $\dot{V}O_{2\text{ peak}}$. The decrease in cardiac output with hyperthermia is attributed to the larger decline in stroke volume. It is possible that reduction in stroke volume with heat stress are due to increased skin blood flow and volume. Rowell (1969) speculated that increased skin blood flow reduces stroke volume by reducing ventricular filling as a result of displacement of blood from the central circulation to peripheral skin veins as core temperature increases. However, this manipulation alters not only skin blood flow and mean skin temperatures, but also core temperature, which have been shown to alter heart rate and stroke volume independently. An increase in core temperature of 1 °C has been shown to increase heart rate by 9 ± 1 beats/min and reduce stroke volume by 11 ± 3 ml when skin blood flow was unchanged. These results demonstrate that high body temperature per se causes fatigue in trained subjects during prolonged exercise in uncompensable hot environments. Increases in heart rate and reduction in stroke volume paralleled the rise in plateaus at core temperature of ~ 38 °C (49).

Nybo and colleagues (2001) also mentioned to cardiovascular responses during exercise in the heat. Hyperthermia increased HR_{max} by ~ 5 beats/min. Possible reasons could be a direct effect of temperature on intrinsic heart rate, an increased sinus-atrial node depolarization rate secondary to reduced stretching of the heart owing to declined stroke volume (Frank-Starling mechanism), or an elevated sympathetic β -receptor activation of the heart in response to high body temperature (75).

The present study, similarly to the previous studies, showed that cardiac function adjust itself via increase in heart rate and stroke volume. However, there is

no evidence of change in stroke volume. This study showed only the abrupt increasing in heart rate. At the first 5 min of exercise, heart rate rapidly increased. It might be the anticipatory response by the activation of motor cortex and higher areas of brain causes increase in sympathetic outflow and reciprocal inhibition of parasympathetic activity. After that, heart rate continuously increased, varied to exercise intensity. Mean arterial pressure did not change significantly throughout the studies of at rest and exercise in the heat. In fact, mean arterial pressure should rise during exercise in the heat but in this study systolic blood pressure increases while diastolic blood pressure decreases (Figure 19). Thus, mean arterial blood pressure which is calculated by $DBP + 1/3$ pulse pressure fluctuated but did not change significantly throughout the study. It is possible that exercise load and time in this study were not so hard that body can compensate itself or the cardiovascular system tries to maintain blood pressure in response to the metabolic and physiologic demands of increased physical activity.

Psychological Responses and Exercise in the heat

Psychological assessments related to physiological responses have been observed widely. Rating of perceived exertion (RPE), thermal sensation (TS), and thermal discomfort (TC) are usually used for psychological assessments in exercise (96). Core temperature and heart rate are the two primary determinants of the physiological strain associated with heat stress (6). In the present study, rating of perceived exertion rapidly increased in stepwise fashion during exercise in the heat while at rest, RPE gradually increased throughout the study. It is suggested that the combination of external (hot environment) and internal (body's metabolism) heat stress influence to feeling of fatigue and endurance more than resting comfortably in the heat. Thermal sensation, like to thermal discomfort, gradually increased insignificantly in the same pattern between at rest and exercise in the heat. It is possible that body adapt feeling of hot and discomfort continuously in that environment until the end of the study. The present study agreed with the previous study that these variables were the subjective method to assess feeling of subjects, it may not reflect strain very well in a sport (8).

However, RPE is the subjective body's feeling, which depends upon many factors: external and internal factors. Changes in environmental temperature as well as humidity

may affect on body's feeling. Subjects, who sat quietly in the heat chamber, might exhibit high RPE score than in ambient temperature. Apart from physiologic responses, any internal changes, which deviate body homeostasis, will alter body's feeling. During exercise, heat production from higher body metabolism gives rise in additionally higher RPE. Thus, higher RPE at this state is not only the feeling of tiredness but also from metabolic heat production. This higher RPE is progressively enhanced as exercise in the heat was extended.

For further investigation, it would possible to investigate ventilatory and thermoregulatory responses during exercise in the heat compared between athlete and sedentary or compared between exercise in ambient and hot environments in each group of subjects.

CHAPTER 6

CONCLUSION

The present study of ventilatory and thermoregulatory responses during continuous exercise in the heat can be concluded as following:

1. Continuous exercise in the heat effects on cardiorespiratory function by increasing in minute ventilation, oxygen consumption, respiratory rate, and heart rate.

1.1 Oxygen consumption and carbon dioxide production change in the same pattern throughout the study of at rest and exercise. It means that whether the high body metabolism, human body can adjust itself properly.

1.2 Increased minute ventilation is the effect of increased tidal volume in the first 10 min, and the effect of increased respiratory rate thereafter.

1.3 Anticipatory responses occur in first few minutes of exercise by abruptly increasing in heart rate, minute ventilation, and oxygen consumption.

2. Thermoregulatory responses of human body to continuous exercise in the heat effect by increasing skin temperature in every sites of skin especially in T_{back} .

2.1 Core temperature is kept stable eventhough exercise under heat stress. It shows that human body tries to regulate in homeostasis.

2.2 Human body dissipates heat out of the body via skin by evaporation and via respiration.

3. There is no relationship between body ventilation and thermoregulation at rest but high relationship of minute ventilation-core temperature, minute ventilation-body temperature, oxygen consumption-core temperature, and oxygen consumption-body temperature during exercise in the heat.

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APPENDIX

Specific-purpose Designed Questionnaire for Screening Subjects
“Ventilatory and thermoregulatory responses during
continuous exercise in the heat”

Direction : Please answer these questions and fill your actual data in the blanks provided.

Date..... **Research ID CODE**.....

Name.....**Surname**.....**Age**.....

Present address.....

Phone number.....**E-mail address**.....

Body mass.....kg **Height**.....cm

BMI = (for officer)

(A). MEDICAL HISTORY

1. Do you have this (or these) illness(es)? (Please tick)

- | | |
|---|--|
| <input type="checkbox"/> Coronary heart disease | <input type="checkbox"/> Hypertension |
| <input type="checkbox"/> Hypotension | <input type="checkbox"/> Rheumatic fever |
| <input type="checkbox"/> Nervous problem | <input type="checkbox"/> Liver problem |
| <input type="checkbox"/> Urogenital dysfunction | <input type="checkbox"/> Joint/Muscle problem |
| <input type="checkbox"/> Respiratory defect | <input type="checkbox"/> Epilepsy |
| <input type="checkbox"/> AIDS | <input type="checkbox"/> Hemorrhoid/Rectal infection |
| <input type="checkbox"/> Endocrine problem (e.g. DM)..... | |
| <input type="checkbox"/> Infectious/Communicable disease..... | |
| <input type="checkbox"/> Genetic disease (e.g. hemophilia,
thalassemia)..... | |
| <input type="checkbox"/> Psychic/Neurotic problem..... | |

2. Current medications (prescribed by physician).....

3. Do you have any medical conditions, which you feel the current researchers should be made aware of?

(.....) yes (.....) no, give details.....

4. Has a doctor ever said you have a heart condition and recommended only medically supervised physical activity?

(.....) yes (.....) no

5. Do you have chest pain brought on by physical activity?

(.....) yes (.....) no

6. Have you developed chest pain within the past month?

(.....) yes (.....) no

7. Do you tend to lose consciousness or fall over as a result of unexplained dizziness?

(.....) yes (.....) no

8. Has a doctor ever recommended medication for your blood pressure or a heart condition?

(.....) yes (.....) no

9. Do you have a bone or joint problem that could be aggravated by the proposed physical activity?

(.....) yes (.....) no

10. Are you aware, through your own experience or a doctor’s advice, of any other physical reason against your exercising without medical supervision?

(.....) yes (.....) no

(B). NARCOTIC CONSUMPTION HISTORY

Please tick and specify:

Alcohol drinktime(s) / week

Smoking cigarettes(s) / day

Other narcoticstime(s) / week

Please specify.....

Caffeine-based food/drinktime(s) / week

Please specify.....

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