ผลของการเมื่อยล้าจากการออกกำลังกายในที่ร้อนเปรียบเทียบกับการออกกำลังกายในอุณหภูมิปกติต่อความมั่นคงในการทรงตัวภายหลังจากการกระโดดขาเดียว

นายทัศน์พล คีระสมบูรณ์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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Effect of exercise-induced fatigue in hot environment compared with thermoneutral environment on postural stability after single-hop jump

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A Thesis Submitted in Partial Fulfillment of the Requirements
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Field of Study	Sports Medicine
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ทัศน์พล คีระสมบูรณ์ : ผลของการเมื่อยล้าจากการออกกำลังกายในที่ร้อนเปรียบเทียบกับการออกกำลังกายในอุณหภูมิปกติต่อความมั่นคงในการทรงตัวภายหลังจากการกระโดดขาเดียว (Effect of exercise-induced fatigue in hot environment compared with thermoneutral environment on postural stability after single-hop jump) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: รศ. นพ. สมพล สงวนรังศิริกุล, 60 หน้า.

การเมื่อยล้าจากการออกกำลังกายเป็นปัจจัยสำคัญที่ทำให้ความมั่นคงในการทรงตัวลดลง ยิ่งไปกว่านั้นผลของการเมื่อยล้าจะเพิ่มมากขึ้น เมื่ออยู่ในภาวะที่อุณหภูมิร่างกายสูงกว่าปกติหรือการออกกำลังกายในที่ร้อน อย่างไรก็ตามยังไม่มีงานวิจัยที่ศึกษาเปรียบเทียบความแตกต่างระหว่างผลของความเมื่อยล้าในที่ร้อนกับในอุณหภูมิปกติต่อการทรงตัว

วัตถุประสงค์ : เพื่อศึกษาผลของการเมื่อยล้าจากการออกกำลังกายในที่ร้อนเปรียบกับในอุณหภูมิปกติต่อความมั่นคงในการทรงตัวภายหลังการกระโดดขาเดียวและศึกษาลักษณะของการเมื่อยล้าระหว่างในที่ร้อนเปรียบเทียบกับในอุณหภูมิปกติ

ระเบียบวิธีการวิจัย : ในงานวิจัยนี้ทำการศึกษาในชายสุขภาพดีทั้งหมด 23 คน โดยผู้เข้าร่วมงานวิจัยทำการออกกำลังกายโดยการปั่นจักรยานเป็นระยะเวลา 20 นาทีทั้งในที่ร้อน(อุณหภูมิ 31-33 องศา ความชื้นสัมพันท์ 60 %)และในที่อุณหภูมิปกติ(อุณหภูมิ 23-25 องศาความชื้นสัมพันท์ 50 %) โดยใช้ตัวชี้วัด คือ ความมั่นคงในการทรงตัวภายหลังการกระโดดขาเดียว(DPSI) ในขณะก่อนทำการออกกำลังกายและภายหลังการอออกกำลังกาย และใช้ตัวชี้วัด (IEMG/CMAP) ในการแยกลักษณะของการเมื่อยล้าจากการออกกำลังกายในที่ร้อนเปรียบเทียบกับในอุณหภูมิปกติ

ผลการทดสอบ: พบว่า DPSI จากการออกกำลังกายในที่ร้อน (0.99 ± 0.15) มีค่าสูงกว่าอย่างมีนัยสำคัญทางสถิติ ($P \leq 0.05$) เมื่อเปรียบเทียบกับการออกกำลังกายในอุณหภูมิปกติ (0.48 ± 0.10) และพบว่า IEMG ในที่ร้อนลดลงอย่างมีนัยสำคัญทางสถิติเมื่อเปรียบเทียบกับที่อุณหภูมิปกติ แต่ไม่พบความแตกต่างของ CMAP

สรุปผลการทดลอง : ผลของการเมื่อยล้าจากการออกกำลังกายในที่ร้อนส่งผลเสียต่อความมั่นคงในการทรงตัวมากกว่าในอุณหภูมิปกติ และลักษณะของการเมื่อยล้าเป็นการเมื่อยล้าจากส่วนกลาง

สาขาวิชา เวชศาสตร์การกีฬา	ลายมือชื่อนิสิต ....
ปีการศึกษา 2559	ลายมือชื่อ อ.ที่ปรึกษาหลัก ....

5674033930 : MAJOR SPORTS MEDICINE
KEYWORDS: DYNAMIC POSTURAL STABILITY / EXERCISE-INDUCED FATIGUE / HOT ENVIRONMENT / THERMONEUTRAL ENVIRONMENT

TASPOL KEERASOMBOON: Effect of exercise-induced fatigue in hot environment compared with thermoneutral environment on postural stability after single-hop jump. ADVISOR: ASSOC. PROF. SOMPOL SAGUANRUNGSIRIKUL, M.D., 60 pp.

It's well-known that muscle fatigue is a key factor to deteriorate postural stability. In addition to, hyperthermia is enhancing the effect of muscle fatigue when exercise performed in hot environment compared with thermoneutral environment.

Objective: To study the effect of exercise-induced fatigue on the dynamic postural stability in hot environment compared with thermoneutral environment and estimate the relative contributions of central and peripheral factors development of muscle fatigue.

Method: twenty three-active male performed exercise-induced fatigue by 20-minute cycling exercise both in hot environment (31-33 C 60% relative humidity) and thermoneutral environment (23-25 C 50% relative humidity). Postural stability was measured by Dynamic postural stability index (DPSI) Integrated electromyography/compound muscle action potential (IEMG/CMAP) method was used to estimate the relative contributions of central and peripheral factors development of muscle fatigue.

Results: DPSI after exercise-induced fatigue in hot environment (0.99 ± 0.15) was significantly ($P < 0.05$) higher than in thermoneutral environment (0.48 ± 0.10) For the IEMG/CMAP values, the (iEMG) signal after exercise-induced fatigue significantly decrease compared with before exercise, while the CMAP amplitude was unchanged.

Conclusion: Effect of exercise-induced fatigue in hot environment had worse postural stability than in thermoneutral environment and the contribution factors relate to changes in central nervous system (CNS) which involve to central fatigue.

Field of Study: Sports Medicine
Academic Year: 2016

Student's Signature ....
Advisor's Signature ....

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LIST OF ABBREVIATIONS

APSI	Anterior-posterior postural stability index
BMI	Body mass index
CMAP	Compound muscle action potential
CNS	Central nervous system
COG	Center of gravity
COP	Center of pressure
DPSI	Dynamic postural stability index
IEMG	Integrated electromyography
GC	Gastrocenemius
GRF	Ground reaction force
Hot	Hot environment
MLSI	Medial-lateral postural stability index
MVIC	Maximal voluntary isometric contraction
RH	Relative humidity
Thermo	Thermoneutral environment
$VO2_{max}$	Maximal oxygen uptake
VSI	Vertical stability index

CHAPTER 1

INTRODUCTION

Background and Rationale

It's well-documental that postural stability is an essential requirement for the performance of daily tasks and sporting activities (1, 2). In addition to, dynamic postural stability assessment is used to indicate the risk factors of injury (1). Postural stability deficit contribute to the incidence of lower extremity injuries (1, 3) that have been found in populations with musculoskeletal injury such as ankle injury (1, 4, 5). Postural stability or postural control is a function of the body mechanism that relates to keeping the center of gravity (COG) of the vertical direction within the base of support (2). Postural stability can be divided to static and dynamic postural stability. Static postural stability defined as maintaining steadiness which is keeping the body as motionless as possible on fixed, firm unmoving base of support(6). In the other hand, dynamic postural stability can be defined as an ability to maintain balance while transitioning from dynamic to static state(7). The activity relates to dynamic postural stability such as jumping or single-leg hop jump to a new location and immediately attempting to remain as constant as possible.

Considering the factors that affect both static and dynamic postural stability, it is widely accepted that muscle fatigue is the main factor lead to change in postural stability. Muscle fatigue has the effect on the regulating system of postural stability which induces neuromuscular compensatory mechanisms to maintain balance. The physiological adaptations try to compensate for deficit of the postural stability however the effects of muscle fatigue on postural stability are no longer compensated. Therefore postural stability is still disturbed. The central and peripheral fatigue affects sensory inputs and motor output of the postural stability (3). These effects of the neuromuscular system involve changes in muscle strength and in neuromuscular control (3)

Several studies investigate the disturbing effects of muscle fatigue on the static postural stability. Paillard T et al,2012 reported that the mean velocity of the center of pressure(COP) significantly increase when the strength loss reaches 30% of the maximal voluntary contraction (MVC) of a specific muscle group (3). In another study observed that MVC losses of 50% affect the postural stability (4). Most of the studies showed that a muscular exercise on a short duration induce a reduction of postural control when the MVC loss is superior or equal to 30 %(3).

Muscle Fatigue defined as any exercise-induced reduction in the ability to exert muscle force or power, regardless of whether or not the task can be sustained (5). When fatigue occurs, the normal functionality of the nerves and the muscles that are contracting are impaired, meaning that the muscle’s ability to exert force is declining due to the inability of the body to meet the increased energy demand in the contracting muscles. Fatigue can be divided into central fatigue and peripheral fatigue. Central fatigue can be described as the reduction in the nerve-based motor command that activates the muscles, which results in a decrease in the force output. Central fatigue is related to changes in both the nerve system and the muscle causing it to fatigue (8). Peripheral fatigue is a fatigue in the neuromuscular junction and fatigue occurring in the muscle which relates to the ability of the muscle to perform physical work (9).

To classify the contribution factors of relative contributors of muscle fatigue. Integrated electromyography/compound muscle action potential (IEMG/CMAP) method was used to estimate the relative contributions of central and peripheral factors development of muscle fatigue. The iEMG is a measure of the total electrical signal sent from the central nervous system to the muscle which indicate central fatigue (10). The CMAP amplitude is a measure of both the transmission of this signal across the neuromuscular junction and the excitability of the muscle membrane (10, 11). A decrease in the iEMG without a reduction in CMAP amplitude may be interpreted as central activation failure (12).

Considering the factor that affect muscle fatigue, the evidence indicated that effect of fatigue can be more stimulated by hyperthermia when exercise performs in hot environment which involved elevation of core temperature above the normal active state of human (38 ℃) during moderate-intensity exercise (13). Hyperthermia-induced fatigue originates from perturbations of the brain’s ability to sustain adequately activation of the muscle. The physiological mechanisms of hyperthermia-induced fatigue involve with several factors but it relates mainly to reduce in the nerve-based motor command of central-nervous system (CNS) that lead to central fatigue (14). The hyperthermia-induced fatigue occurs during core temperature at exhaustion over a range of 38–40°C and to be independent of exercise intensity (15).

Previous study confirmed that exercise-induced hyperthermia in hot environment decrease voluntary activation during a sustained maximal knee extension more than exercise in thermoneutral environment (8). Moreover, they found that the subjects in hot environment trial were unable to sustain the same activation and the voluntary force production as well as the rectified integrated surface electromyogram (EMG). The mechanics that involve the decline in central activation during the sustained muscle contraction are the depletion of substrates and metabolic disturbance within the CNS and/or alterations in the release or synaptic levels of neurotransmitters (15).

Most studies have examined the effects of muscle fatigue on static postural stability (1, 3). However, there are only few studies that investigate the effect of muscle fatigue on dynamic postural stability (1). The dynamic postural stability can be mostly quantified by dynamic postural stability index (DPSI) which are an objective measure that is used in together with a jump protocol such as single-hop jump. The dynamic postural stability index (DPSI), has been developed by Wikstrom et al (16). The DPSI is a measure of motor control for the lower extremity and is dependent on proprioceptive feedback (17).DPSI measurement showed how well a subject can dissipate resultant ground reaction forces (GRF) from a jump landing. Previous investigations have reported that the DPSI is a more reliable ($r = 0.95$) and precise ($SEM = 0.03$) measure than the previous technique of calculating time to stabilization during a single-leg-hop stabilization maneuver (16).

As dynamic postural stability is more closely to exercise and sport activity than static postural stability, this study is interesting to investing the effect of muscle fatigue on dynamic postural stability. Moreover, there is no evidence regarding the effect of muscle fatigue on dynamic postural stability and the relative contribution factors of muscle fatigue in hot environment compared with thermoneutral environment. Therefore, the purpose of this study is to examine the effect of muscle fatigue on dynamic postural stability and estimate the relative contributions of central and peripheral factors development of muscle fatigue in hot compared with thermoneutral environment.

Research questions

Primary question: Are the effects of exercise-induced fatigue on postural stability after single-hop jump different between in hot environment and thermoneutral environment?

Secondary question: What are the relative contributions of central and peripheral factors development of muscle fatigue in hot environment compared with thermoneutral environment?

Objective: To study the effect of exercise-induced fatigue on the dynamic postural stability in hot environment compared with thermoneutral environment and estimates the relative contributions of central and peripheral factors development of muscle fatigue.

Conceptual framework

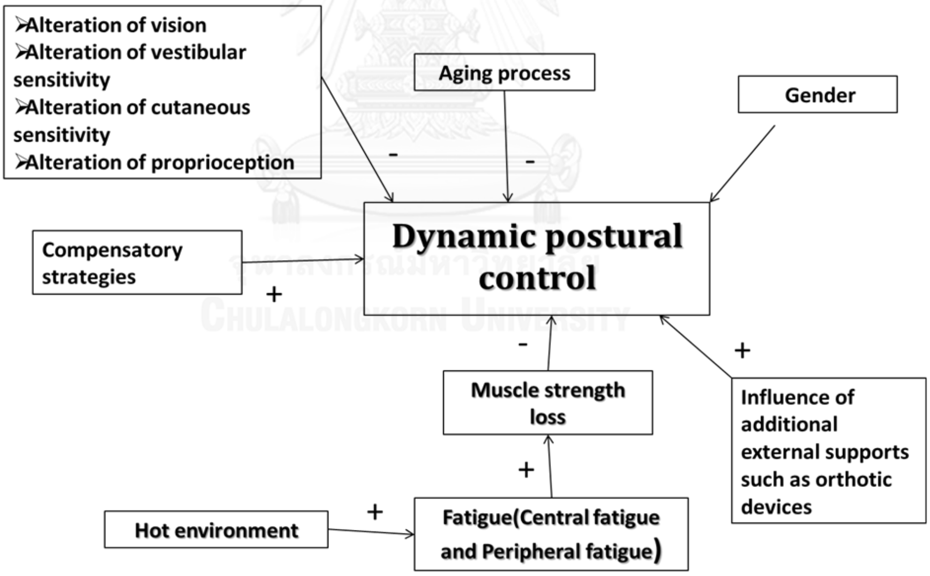


Figure 1. Conceptual framework of the study

Hypotheses

1. Effect of exercise-induced fatigue in hot environment would greater deteriorate postural stability after single-hop jump than in thermoneutral environment.
2. The relative contribution of exercise-induced fatigue in hot environment would relate to change in the central nervous system more than in thermoneutral environment.

Scope of research

The design of this study is a randomize crossover trial design in which the exercise-induced fatigue conducted in hot and thermoneutral environment.

The study approval was obtained from the Institutional Review Board of the Faculty of Medicine, Chulalongkorn University. Written informed consent was obtained from the subjects after the experimental details and risk involved were explained, and they were reminded of their right to withdraw at any stage.

Assumptions

1. The equipment was calibrated to meet the standard of accuracy and reliability.
2. Postural stability measured by Force plate reflects in ground reaction force which used to calculate dynamic postural stability index (DPSI).

Limitation

1. This study had been done in healthy men with 20-25 years of age. They volunteered to join the research and pass the recruitment criteria. The results of this study may be specific to the population similar to sampling participants.
2. Although it’s hard to control all of the factor, this study try to control as possible. The subjects were explained, and asked to follow the information about physical activities during the research participation.

Operational definition

1. Muscle fatigue defined as exercise-induced reduction in the ability to exert muscle force or power, regardless of whether or not the task can be sustained (5) measured by the maximal iEMG during MVIC after exercise-induced fatigue. The iEMG amplitude decline 50% which refer to the muscle fatigue.

2. Central fatigue defined as the reduction in the nerve-based motor command that activates the muscles, which results in a decrease in the force output measured by (iEMG/CMAP ratio). A reduction in the iEMG without a reduction in CMAP amplitude can be interpreted as central activation failure which is the effect of central fatigue (10).

3. Peripheral fatigue defined as a decreasing of maximal force which occurs in the neuromuscular junction and muscle measured by (iEMG/CMAP ratio). CMAP amplitude indicates the failure of neuromuscular transmission. When the peripheral fatigue occur, the CMAP amplitude declines with no change in iEMG (11).

4. Postural stability defined as a function of the body mechanism that relates to keeping the center of gravity (COG) of the vertical direction within the base of support (2).

5. Static postural stability defined as an ability to maintain steadiness which is keeping the body as motionless as possible on fixed, firm unmoving base of support (6). The static postural stability can be mostly quantified by measuring the displacement of the center of foot pressure (COP) which involves the task of standing quietly or standing with one leg as still as possible (18)

6. Dynamic postural stability defined as an ability to maintain balance while transitioning from dynamic to static. Dynamic postural stability can be mostly quantified by measuring Dynamic postural stability index (DPSI) which is an objective measure that is used in together with a jump protocol such as single-leg jump (15, 16).

7. Hyperthermia defined as an increase in core temperature above the set range of specified for the normal active state of human is ~38 ^{O}C during moderate-intensity exercise (15).

8. Hot environment defined as an ambient temperature 31-33 ^{O}C 60% relative humidity.

9. Thermoneutral environment defined as an ambient temperature 23-25 ^{O} C 50% relative humidity

Expected Benefits and Applications

1. To address the different effect of exercise-induced fatigue between in hot and thermoneutral environment on dynamic postural stability as initial information and practical application for prevent injury in hot environment.
2. To address the relative contributions of central and peripheral factors development of muscle fatigue in hot environment compared with thermoneutral environment. This ground information may provide important insight onto future research regarding lifestyle intervention for specific population.

CHAPTER II

REVIEW LITERATURES

Postural stability defined as a complicate function that relates maintaining the vertical direction of the center of gravity (COG) within the base of support. The postural stability involved to liquid movements and cardiac and respiratory muscular contractions. These physiological functions induce continuous body sways (2). Postural stability is an important component in evaluating the efficacy of exercise interventions for balance assessment. In addition, postural stability is not only involved to avoid loss of balance but also provide for the execution of other movement which relates to allow the execution of goal-directed actions. Postural stability deficit contribute to the incidence of future lower extremity injuries (McGuine (16)that have been found in populations with musculoskeletal injury such as ankle injury(1, 4, 5).

Postural stability can be dividing to static and dynamic postural stability. Static postural stability defined as maintaining of the center of foot pressure (COP) which involves the task of standing quietly as still as possible (6). Dynamic postural stability can be defined as an ability to maintain balance while transitioning from dynamic to static state (7). The dynamic postural stability can be mostly quantified by dynamic postural stability index (DPSI) which are an objective measure that is used in together with a jump protocol such as single-hop jump. The dynamic postural stability index (DPSI), has been developed by Wikstrom et al (16). The DPSI is a measure of motor control for the lower extremity and is dependent on proprioceptive feedback (17).

Exercise is a cause of aggravation of postural sway since the increase of energy needs amplifies liquid movements and cardiac and respiratory muscular contractions. In addition, when exercise generates muscle fatigue, it affects the regulating system of postural stability by its effects on the quality and treatment of sensory information, as well as motor command. Indeed, exercise induces perturbations of the neuromuscular system that involve changes in muscle strength and postural stability (4).

Muscle fatigue

Muscle fatigue defined as any exercise-induced reduction in the ability to exert muscle force or power, regardless of whether or not the task can be sustained (5). The impairment process that causes fatigue is not caused by only single process but several mechanisms (motor and sensory). The variation in responsible has been defined as the task dependency of muscle fatigue (19). The task variables that influence the duration of stress among the process include the level of subject motivation, the pattern of muscle activation and motor command, the intensity and duration of the activity, the speed of a contraction and the extent to which an activity is sustained continuously. Electromyography (EMG) is one of the most widely indirect method to assess the physiological response resulted from the muscle fatigue. EMG can measure the electrical activity of superficial muscles and amplitude and the power spectrum of the signal. The amplitude of EMG shows the size and the number of action potentials in the muscle over a given time period. The change of number of active muscle fiber or excitation rate can reflect the changes in muscle activation which can indicate the physiological changes induced by fatigue.

Central fatigue and peripheral fatigue

Muscle fatigue can be divided into central fatigue and peripheral fatigue as shown on the Figure 2 (9). Central fatigue can be described as the reduction in the nerve-based motor command that activates the muscles, which results in a decrease in the force output. Central fatigue is progressive failure to drive motorneuron voluntary and relate to reduction in voluntary activation during exercise. Central fatigue can be the result of changes in various neurotransmitters in the brain that are secondary to changes that occur in the body and brain. Peripheral fatigue defined as a fatigue in the neuromuscular junction and occurring in the muscle which relates to the ability of the muscle to perform physical work.

Central and peripheral fatigue measurement

Integrated electromyography/compound muscle action potential (iEMG/CMAP) method was used to estimate the relative contributions of central and peripheral factors development of muscle fatigue. Integral of rectified EMG (iEMG) defined as the area under the curve of the rectified EMG signal which is the mathematical integral of the absolute value of the raw EMG signal. iEMG method has been involved with muscular force more than other form of EMG. The iEMG is a measure of the total electrical signal sent from the central nervous system to the muscle (10). Compound muscle action potential (CMAP) is the synchronous activation of a group of motor neurons within a nerve bundle producing a composite activity in the target muscles. The CMAP amplitude is a measure of both transmission of this signal across the neuromuscular junction and the excitability of the muscle membrane which reflect the effect of peripheral fatigue (11).Therefore, changes in central activation during prolong exercise can be compare by the change of iEMG signal during exercise with the change of CMAP (iEMG/CMAP ratio).A reduction in the iEMG without a reduction in CMAP amplitude can be interpreted as central activation failure which is the effect of central fatigue (12). In order to examine separately central and peripheral activation during exercise we have to compare this change.

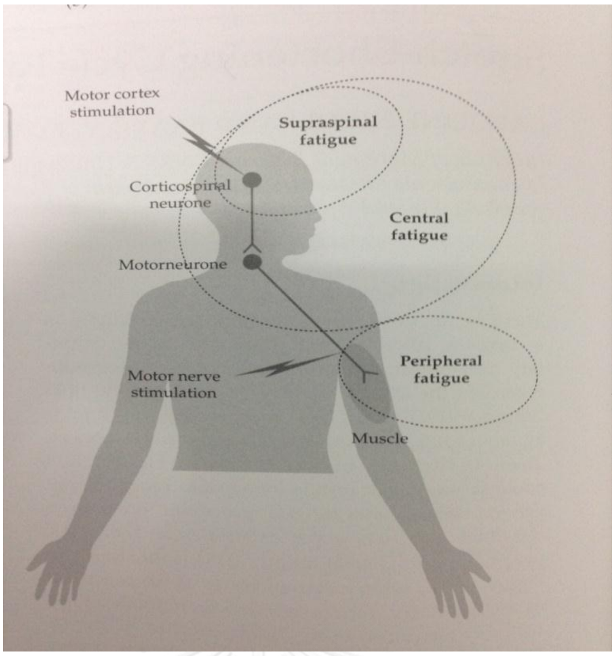


Figure 2. Division of muscle fatigue into peripheral and central fatigue by motor nerve stimulation. Supraspinal fatigue is a subset of central fatigue (9)

Exercise-induced fatigue on postural stability

Exhaustive voluntary exercise induces peripheral and/or central (spinal and/or supraspinal) fatigue. This physiological consequence characterizes peripheral disturbances at the level of the active muscles (e.g. propagation of the action potential, neuromuscular junction, excitation–contraction coupling, metabolite accumulation, glycogen depletion, muscle damage) and/or the central nervous system fails to drive the motoneurons adequately. These perturbations of the neuromuscular system involve changes in muscle strength and in neuromuscular control (9). Hence, postural control is inevitably affected. It can be assumed that although the deterioration of the sensory input and motor output can be partially or completely compensated for up to a certain state of fatigue, as soon as central fatigue is established, compensation for the disturbance to postural control is no longer possible (Figure 3).

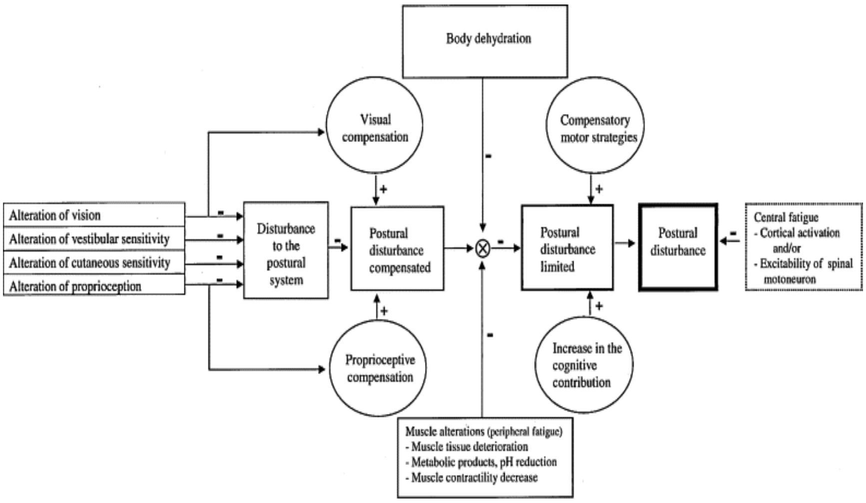


Figure 3. The process of the deterioration of postural control induced by exercise. Initially, postural alterations are compensated but, when physiological disturbances occur, the compensatory effects no longer takeplace (- indicate a disturbance; + indicates compensation)(16)

Most of the studies analyzed the disturbing effects of muscle fatigue on postural stability found the relation with strength loss. Harkins et al, 2005 observed that MVC losses of 50% and 70% affect postural stability (4). Most of the studies showed that a local muscular exercise on a short duration induce a reduction of postural control when the MVC loss is superior or equal to 30 %(Figure 2.3)(16). If the voluntary exercise induces a strength loss, it must take a long time to generate a deterioration of postural control that the central component of fatigue maybe contributes to this effect. It can conclude from this study that the more strength loss, the more decline on static postural stability.

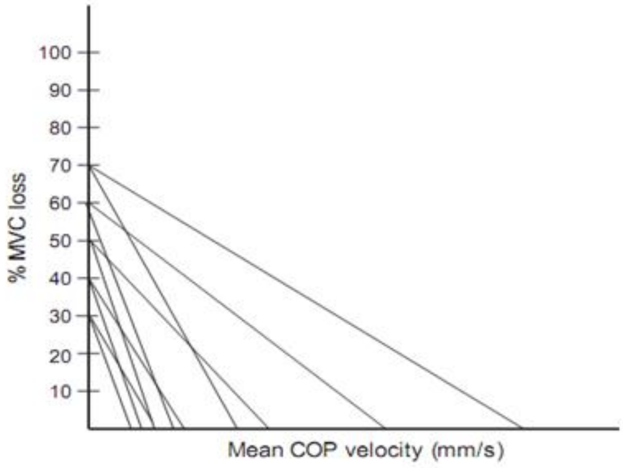


Figure 4. The relation between the percent of loss of the maximal voluntary contraction (MVC) of particular muscle group and the velocity of the displacement of the center of foot pressure (COP) after a short localized muscular exercise. The mean velocity of the COP significantly increase when the strength loss reaches 30% of the MVC (16).

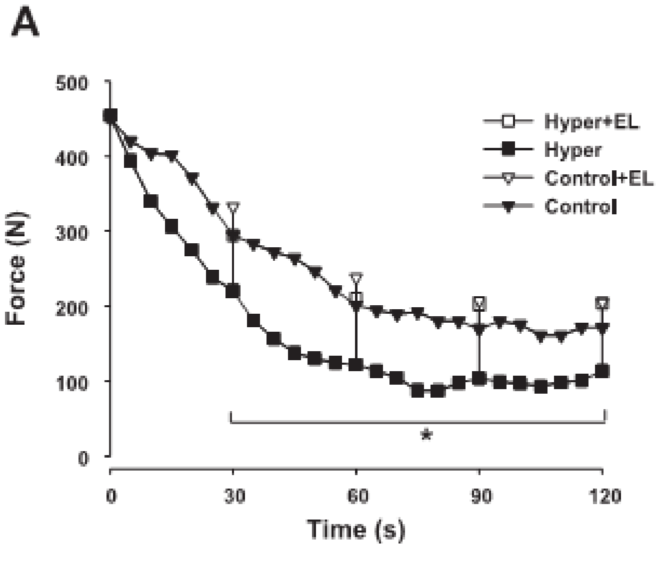
Hyperthermia and muscle fatigue

Hyperthermia defined as an increase in core temperature above the set range of specified for the normal active state of human is 38° C during moderate-intensity exercise (13) and during repeated sprint which can reduce exercise performance (13). Exercise in hot environment accelerated onset of muscle fatigue greater than exercise in thermoneutral environment

Nybo L, 2008 reported that when exercise performs in hot environment where heat production surpasses the capacity for heat release to the surroundings, the effect of fatigue can be more stimulated by hyperthermia (20). The physiological mechanisms involve hyperthermia-induced fatigue involve with several factors but it relate mainly to changes in the central-nervous system (CNS) that lead to central fatigue (8). During prolong exercise hyperthermia-induced fatigue originates from perturbations of the brain's ability to sustain adequately activation of the muscle. The increasing brain temperature can be the main factor affecting motor activation. Due to progressive hyperthermia, the brain temperature increases related to the core temperature. The CNS of hyperthermia-induced fatigue seen to relevant during prolonged exercise, where the core temperature and brain may excess 40° C(20).However, there are some of the studies reported that fatigue in untrained subjects occur during light exercise hot environments at core temperatures of

38°C. They also indicated that core temperature at exhaustion from heat strain occur over a range of 38–40°C and to be independent of exercise intensity (12).

There are several studies that support the important of fatigue during exercise in the hot environment. Nybo and Nielsen stimulated fatigue by bicycle exercise at 60% VO_2max , which in hot environment trial increased the core temperature 40 ^{O}C and exhausted the subject s about 50 min, whereas during control trial the core temperature about 38 ^{O}C and exercise was maintained for 1 h without exhausting the subject (8).The result of this study showed that exercise-induced hyperthermia reduced voluntary activation during a sustained maximal knee extension(Figure 5). In the hot environment trial, the subjects were unable to sustain the same activation and the voluntary force production as well as the rectified integrated surface electromyogram (EMG). From vastus lateralis muscle became low (Figure 5).The mechanics that involve the decline in central activation during the sustained muscle contraction are the depletion of substrates and metabolic disturbance within the CNS and/or alterarations in the release or synaptic levels of neurotransmitters (14).



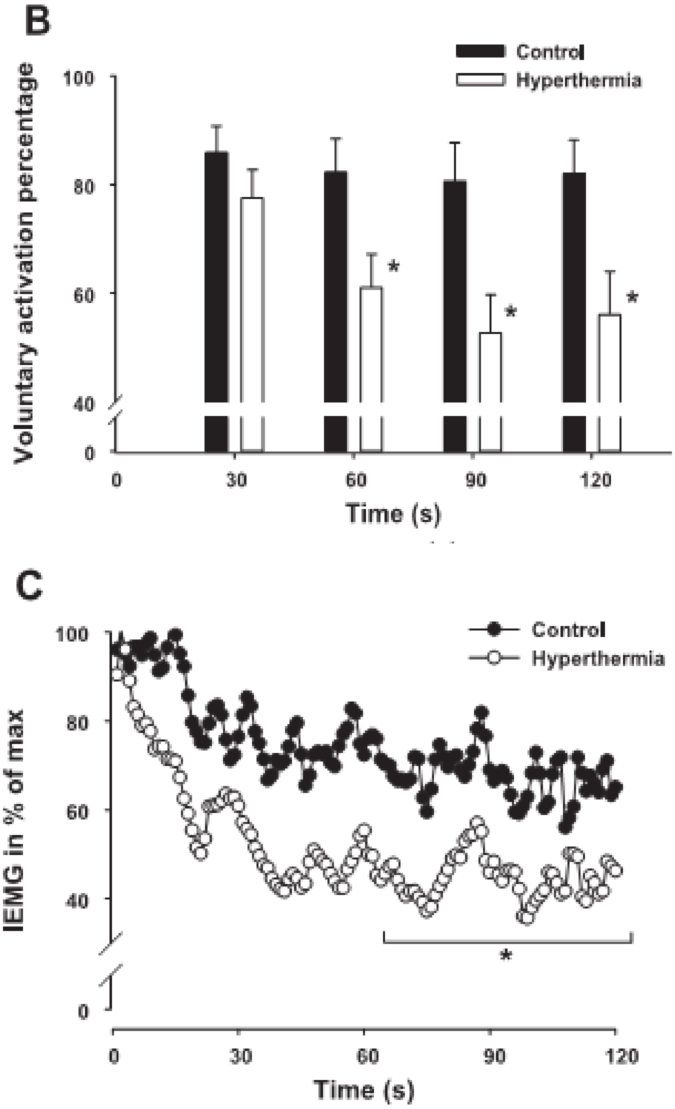


Figure 5. Force production(A), voluntary activation level(B) and rectified integrated surface electromyography(IEMG:C) from the vastus laterlis muscle during 2 min of sustained maximal knee extension during hyperthermia(hyper, core temperature of 40 °C and control (core temperature of 38 °C) The subjects were instructed to make a maximal effort throughout the contraction, and electrical stimulation(EL) was superimposed every 30 s to assess the level of voluntary activation which was calculated as voluntary force divided by the force elicited when EL was superimposed. Values are mean ± SE for 8 subjects *All values in this period are significantly lower than control. $P < 0.05$.(8)

According to the fact that exercise in hot environment accelerated onset of fatigue greater than exercise in the temperature environment, it has a possibility that exercise in the hot environment greater generate deterioration of postural control than exercise in the temperature environment. In addition, Most of the studies analyzed the disturbing effects of muscle fatigue on static postural stability found the relation with strength loss. However, there are no study investigated the effect of fatigue on the dynamic postural stability especially in the hot environment. Because of dynamic postural stability measures closely to the sport participation, it is interesting to study about the effect of fatigue on the dynamic postural stability when exercise perform in hot environment compared with exercise in thermoneutral environment to provide an overview of the effects of fatigue on exercise in the hot environment and thermoneutral environment on the dynamic postural stability to prevent the unpredictable injury.

CHAPTER III

Research Methodology

Research design

This study is a cross over analytic research which examined the effect of exercise-induced fatigue on postural stability after single-hop jump between hot and thermoneutral environment in healthy males. The experimental design composed of three visits. For visit1, subjects were performed preliminary testing. For visit 2 and visit3, All subjects were required to attend 2 identical experimental trials using a 20-minute cycling exercise in both hot and thermoneutral environmental conditions that had a wash-out period for 4-6 days between environmental conditions (Figure 6). Dynamic postural stability index was employed to evaluate postural stability after single-hop jump. Integrated electromyography/compound muscle action potential (iEMG/CMAP) method was used to estimate the relative contributions of central and peripheral factors development of muscle fatigue. These measurements was assessed at baseline before starting the experiment and immediately after the completion of cycling exercise. Rectal temperature was ascertained at rest and throughout the cycling exercise. All variables measured were compared between hot and thermoneutral conditions and between pre-exercise and post-exercise. The study protocol was approved by The Institutional Review Board of the Faculty of Medicine, Chulalongkorn University.

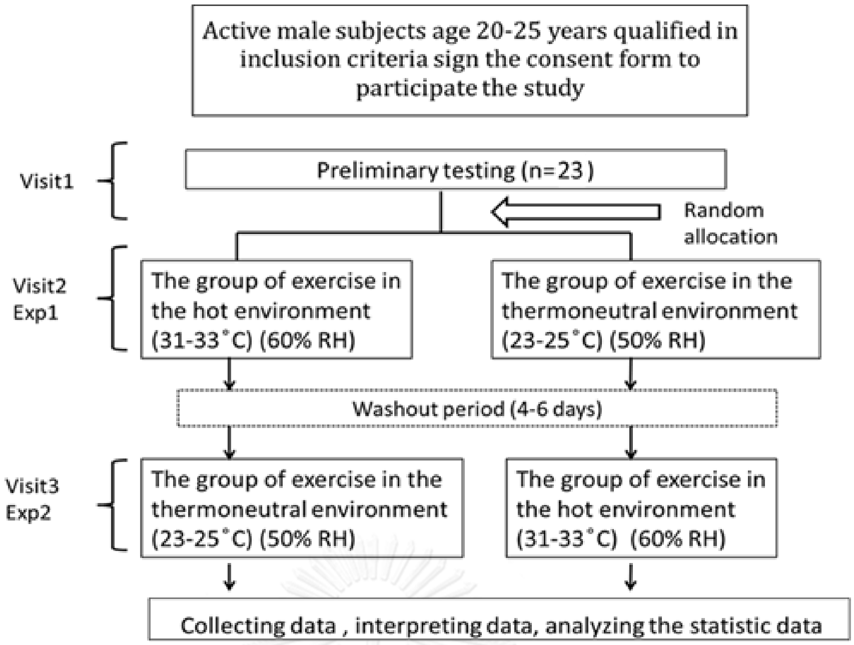


Figure 6. A cross over analytic research examined the effect of exercise-induced fatigue on postural stability after single-hop jump between hot and thermoneutral environment in healthy males.

Population

Target population

In this study, the target groups were healthy men whose age were between 20-25 years. All subjects met the inclusion and exclusion criteria of the study.

Study subjects

Men whose age were between 20-25 years, who were healthy and no vestibular disorders. The study participants were recruited according to the following criteria and all were initially contacted by telephone to determine their initial qualification before including in this study.

Inclusion Criteria

1. Male age between 20-25 years
2. Normal blood pressure (BP = 120±10/80±10 mmHg.)
3. Normal weight status, body mass index (BMI) 18.5-24.9 kg/m^2, Normal percent body fat
4. Performing physical activity less than 30 minutes at a time and less than 3 times per week.
5. Subjects were free from lower extremity and head injury for 3 months
6. Were self-reported no vestibular disorders or in the previous 6 months

Exclusion Criteria

1. Had a risk that would be restricted to exercise
2. An open wounded or muscle tendinitis that will be restricted to performance and measurement
3. Ankle instability
4. Abnormal proprioceptive sense
5. Conditions that put the subjects at risk or are exercise limitation
6. Incomplete participation of all experimental conditions

Subjects recruitment and screening

Subject were recruited by personal contact. The study participants were recruited according to the following criteria and all subjects were initially contacted by telephone to determine their qualification and inform about the purpose of the study, study protocol and risk of the study before included in the study. Moreover, this study provided a screening test related to the inclusion criteria of this study before participation.

Sample size determination

In this study, the sample size determination was obtained from a pilot study. The parameter of the pilot study is Dynamic postural stability index (DPSI). Researcher recruited 4 male volunteers who study sport medicine program at faculty of medicine, Chulalongkorn University. The volunteershad a good healthy aged 20-25 years, normal weight status body mass index (BMI) 18.5-24.9 kg/m^2, Normal percent body fatand exercise at least 3 days per week. Researcher asked the volunteers to do this pilot study in the laboratory at 4 floorPadthayapatana building, faculty of medicine Chulalongkorn University. In order to prevent an injury, researcher also asked the medical intern to look after the volunteers during doing the experiment. The volunteers were asked to perform exercise in the hot environment (33°C, 60% RH) and thermoneutral environment (25°C, 50% RH) again in separately by 4-6 days. Researcher measured the ground reaction force in three directions before and after exercise protocol by jumping protocol on force plate in each trails. In order to calculate the sample size of the pilot study between exercise in hot environment and thermoneutral environment, researcher selected sample size calculation method which is suitable for the cross over research design.

Researcher presents in the result of DPSI at 10 second after exercise in hot environment and thermoneutral environment as shown in the Table 1

	Thermoneutral environment	**Hot environment**
	DPSI at 10 second	**DPSI at 10 seconds**
Subject1	0.290	0.510
Subject2	0.308	0.351
Subject3	0.280	0.295
Subject4	0.278	0.310
Mean($\bar{X}$)	0.289	0.366
standard deviation(S.D)	0.013	0.098

Table 1. Dynamic postural stability at 10 second

Mean and standard deviation of DPSI at 10 second on the thermoneutral environment trial is 0.289 and 0.013

Mean and standard deviation of DPSI at 10 second on the hot environment trial is 0.366 and 0.098

Researcher calculated correlation coefficient(r) by using Intraclass correlation coefficient (ICC) method on SPSS statistics 16.0

Correlation coefficient (r) = 0.587

The formula that we used to calculated sample size in the pilot study

$$n = \frac{(Z_{\alpha/2} + Z_{\beta})^2 \sigma^2}{d^2}$$

$\alpha = 0.05$

$Z_{\alpha/2} = Z_{0.05/2} = 1.96$ (two tail)

$\beta = 0.10$

$Z_{\beta} = Z_{0.10} = 1.28$

n = sample size

$d = \bar{x}1 - \overline{X2}$ mean of difference = 0.077

σ= standard deviation of difference = 0.368

The formula of Variance of difference as following

$\sigma^2 = \sigma^2_1 + \sigma^2_2 - 2r\,\sigma_1\sigma_2$

σ^2= Variance of difference

σ^2_1 = Variance of difference Pre-exercise in hot environment

σ^2_2= Variance of difference Post-exercise in hot environment

r = Correlation Coefficient = 0.587

$\sigma^2 = (0.013)^2 + (0.098)^2 - 2(0.587)(0.013)(0.098)$

$\sigma^2 = 0.008$

$\sigma = 0.091$

Standard deviation of difference = 0.091

$$n\ \text{pair} = \frac{(1.96+1.28)^2(0.008)^2}{(0.006)^2}$$

= 14.574 ~15

DPSI at 10 second

The result of sample size (n) of DPSI at 10 s = 15

To ensure a reliable result of the study and cover the questions of this research, number of subjects is total 15 persons were recruited. A dropout rate of 50 % was estimate, and then recruit 15 volunteers, total 23 persons were recruited.

Instruments

1. Bertec Force plate FP4060-08
2.6 Qualisys camera oqus 5-series: Marker capture frequency 120Hz
3. Qualisys motion capture system and Visaul-3D
4. Infrared heater, SL Heater Co., Ltd., Bangkok, Thailand
5. BIOPAC Systems MP100A, Inc Santa Barbara, California, U.S.A
6. Thermometer(FLUKE 52 II THEROMETER, 2004-2011 Fluke Corporation, China)
7. Wet and dry thermometer, FUJI, Taiwan)
8. POLAR FS1 Dark Blue, Polar Electro Oy, Professorintie 5, Kempele, Finland
9. Thermistor (TSD 102A Fast response thermistor and BIOPAC System withAcqKnowledge® software version, Inc Santa Barbara, Califormia, U.S.A)
10. Bioelectrical ImpedenceAnaysis(BIA) Inbody 230 Biospace co., ltd., Korea
11. Stethoscope Classic II S.E. 3M Litmann, U.S.A
12. Air conditioner (Trane MCX518 EBOTBA, Thailand)
13. Cycle ergometer (Monark Ergomedic 839 E)

Preparation of the research participants

For eliminate confounding factor prior to the experimental day, the participants are asked to do as the following

- Hydration is standardized though instructions to consume a liter of water the evening before testing for those tested in the tomorrow and 500ml during 2-3 hours before each trial.
- Participants are not allowed to drink the beverage that contain alcohol at least 48 hours
- Participants are not allowed to drink the beverage that contain caffeine at least 8-12 hours
- Participants are asked to avoid the vigorous activity or the activity that will affect the test at least 24 hours

Procedures

The experimental design composed of three visits. Before each visit, all Subjects wore sport clothing and their own running shoes. All of them were required to rest 4-6 days between each visits

Visit1 (Preliminary testing)

General data such as age, weight, height and body mass index (BMI) are collected from each subject by (Bioelectrical Impedance Analysis Inbody 230 Biospace co., ltd., Korea). Maximal oxygen uptake (VO_2max) is predicted by submaximal YMCA test protocol to determine the intensity of the exercise protocol by using constant-load cycle ergometer (Monarkergomedic 839E) (21). Jump height was measured by asking each subject to jump with the jump protocol.

Submaximal YMCA test protocol

In order to determine the intensity of the exercise protocol, subjects are asked to test the Submaximal test (YMCA) (21). Each subject is asked to perform submaximal cycle ergometer test using constant-load cycle ergometer (Monarkergomedic 839E) (Figure 7). Initially, subjects are taken a resting heart rate measurement. Seat height and handlebars are adjusted to fit the subject before testing. Then, subjects are asked to perform using three or four consecutive 3-minute workloads. Subjects perform cycle ergometer at a cadence of 50 rev/min and the initial work load is 25 Watts. According to the YMCA protocol, the heart rate during the last 15 seconds is used to determine subsequent workloads. The test is terminated the three or four workloads are completed with heart rates between 110 and 150 beats/min. In order to estimate VO_2max , HR are plotted against work(Watts) on a graph by drawing a line connecting heart rates and estimate to the subject's age-predicted maximum heart rate and followed by dropping a vertical line form the maximal heart rate to the x-axis. At this point, it represents the estimated maximal power(Watts) at VO_2max. The calculation is used following the equation (ml min-1) = (Watts x 6kpm/Watt)x2 ml/kpm+300 (21).

Figure 7. YMCA test protocolconstant-load cycle ergometer (Monarkergomedic 839E)

Visit 2 and Visit3

All subjects were randomized to perform either cycling exercise in hot environment or thermoneutral environment. On the day of experiment, subjects were required to arrive about 60 min before testing. Subjects emptied their bladder, change clothes into cycling clothes and perform the pre-jump protocol test. After the pre-jump protocol test, subjects moved to take a seat for 30 min in a thermoneutral environment (23-25 C 50% relative humidity) while being instrumented of the electrodes for electrical stimulation (EL). The electrodes were placed over in the superior portion of the popliteal fossa behind the knee over the tibial branch of the sciatic nerve. Electrical stimulation of sciatic nerve was superimposed before exercise intervention and after post jump protocol. To measure electromyography, subjects were placed the electrodes on the lateral head over the area of greatest muscle bulk on the lateral calf. Electromyography (EMG) data of gastrocnemius muscle was collected continuously every 5 min during cycling exercise intervention. Core temperature were measured by inserted a thermistor 10-12 cm inside the rectum. After instrumentation, subjects were required to move to the cycle ergometer to perform cycling exercise. After completion of each exercise intervention, subjects are weighed, exited the climate room and repeated the post-jump protocol.

Visit3 (Experimental protocol2) After resting for 4-6 days, subjects were performed the same exercise protocol as the visit2 but performed cycling exercise in another environment that described in Figure8

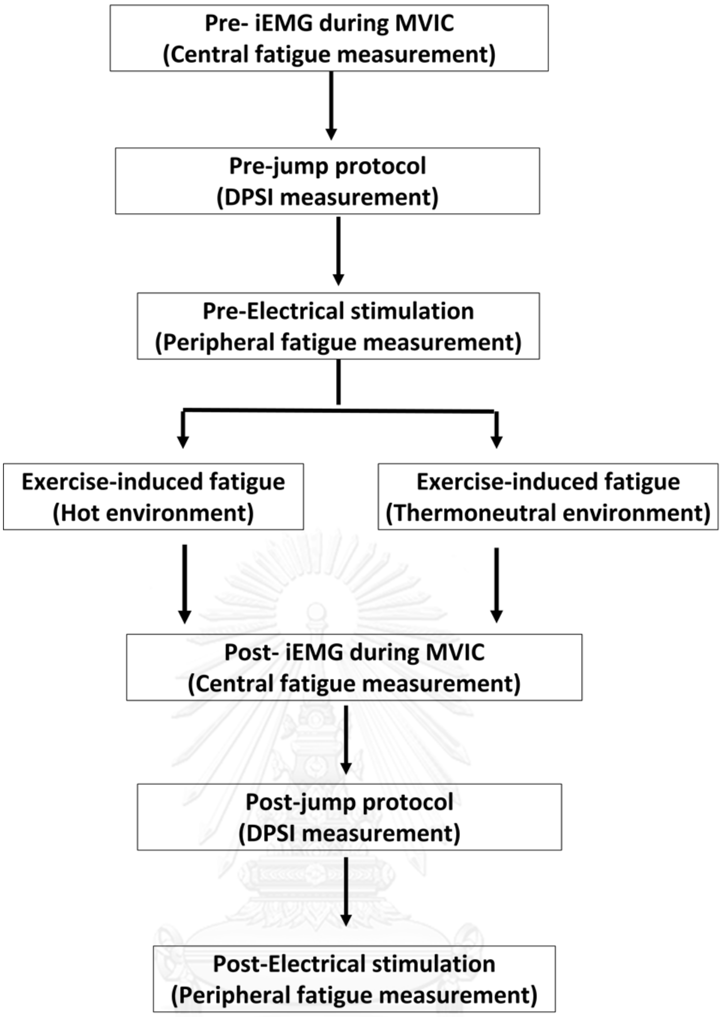


Figure 8. Flowchart of experimental procedure in visit 2 and 3

iEMG during MVIC (Central fatigue measurement)

EMG was measured by BIOPAC (EMG100C, BIOPAC Systems MP100A, Inc Santa Barbara, California, U.S.A). SEMG signals were recorded from lateral gastrocnemius (GC) muscle using electrodes with an interelectrode distance of 10mm (EL258 series) which are connected to robust and pliable lead wires (1 mm OD). The SEMG signals are amplified (gainx500), sample at 2000 Hz and bandwidth filtered (10 Hz to 500 Hz) (22). Subject lay down to the adapted bed to perform Maximal sustained voluntary isometric contraction (MVIC) by plantar flexion with maximal effort for 10 seconds . The raw EMG data was collected before and after exercise induced fatigue. Surface electromyography (SEMG) signals were recorded by using a silver-

silver chloride(Ag-AgCI) electrodes with an interelectrode distance of 10mm (EL258 series) which are connected to robust and pliable lead wires(1 mm OD).The SEMG signals are amplified (gainx500), sample at 2000 Hz and bandwidth filtered (10 Hz to 500 Hz). Initially, the subjects are prepared for placement by cleaning the skin of each electrode site with alcohol wipe. Two electrodes and one ground electrodes per muscle are placed on the lateral gastrocnemius (GC) muscle on the lateral head over the area of greatest muscle bulk on the lateral calf (Figure 9).

Figure 9. showed electrode placement on lateral gastrocnemius muscles

Jump protocol for dynamic postural stability index assessment (DPSI)

The jump protocol was performed as first described by Ross and Guskiewicz (17).According to their protocol, subjects stand in front of the center of the force plate and jump with both legs to touch an overhead marker placed at a position equivalent 50% of subject’s maximum vertical leap before landing on one leg on the force plate. Each participates are asked to jump with one’s head up and hands in position to touch the designated marker. Participants are asked to land on the test leg, stabilize as quickly as possible and balance for 10s with hands on one’s hips while looking straight ahead (Figure 10). If a subject lose balance and touch the floor with contralateral limb, excessive swaying of the countralateral limb which is enough sway of the subject stepped off the force plate arms or trunk occurred, the trial is discarded and repeated. Data of the static stance (body weight) is obtained during the first session and used for these for all calculation. A Bertectriaxial force plate(Bertec Force plate FP4060-08) is used to collect the baseline and jump-landing GRF data (reported in Newtons at 120 Hz). The force-plate data undergo an analog-to-digital conversion and are stored on a laboratory computer by using analysis system(Qualisys motion capture system and Visaul-3D).

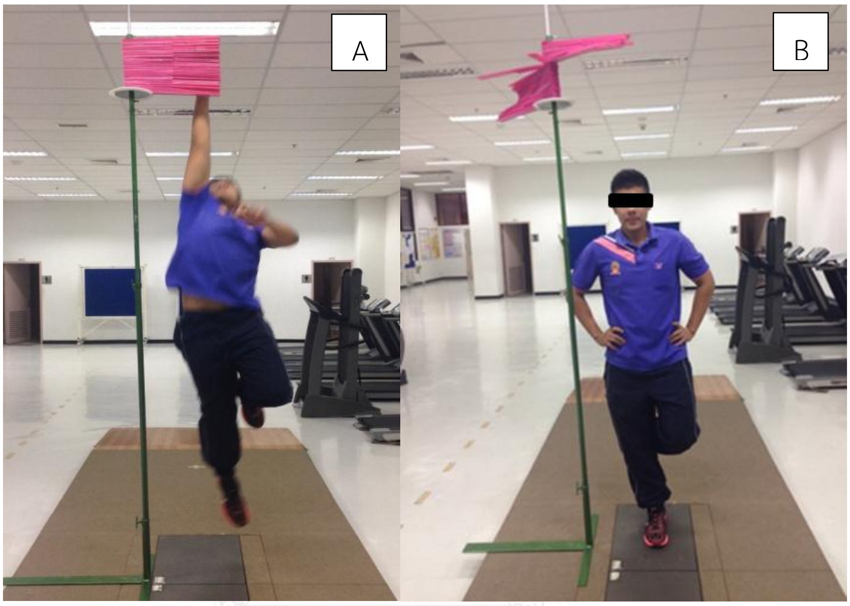


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Figure 10. The dynamic postural stability index (DPSI) protocol(Picture A indicated the subject while jumping with both legs to touch an overhead marker and picture B indicated the subject while landing one dominant leg with hands on one's hips while looking straight ahead

Dynamic postural stability index analysis

All data are collected by Qualisys motion capture system and Visaul-3D and recored at 120 Hz on force plate. Ground reaction force is reduced as described by Wikstrom et al (16). The calculated stability shows in the dynamic postural stability index (DPSI). The data is collected and analyzed at 10 second. This study uses the average values from the successful trials. The postural control measurement (Jump protocol). The data is divided by the number of data points within the time period. The vertical index assesses the swing of the subject's body weight equivalent to standardize the vertical ground reaction force (GRFz) along the z-axis of the force plate. The vertical score is depending on the different of body weights (mass) among individual subjects. The DPSI compose of the medial/lateral, anterior/posterior and vertical stability index.

$$\text{DPSI} = \sqrt{}[\Sigma(0 - \text{x})^2 + \Sigma(0 - \text{y})^2 \\ + \Sigma(\text{body weight} - \text{z})^2/\text{number of data points}]$$

DPSI = Dynamic postural stability index

x = Ground reaction force in medial/lateral direction during the jump-landing sequence

y = Ground reaction force in anterior/posterior direction during the jump-landing sequence

z = Ground reaction force in vertical direction during the jump-landing sequence

Number of data points = Number of data during the time of the jump-landing sequence (16)

The direction components of postural stability protocol (MLSI, APSI and VSI) analysis

A Bertectriaxial force plate (Bertec Force plate FP4060-08) was used to collect jump-landing ground reaction force (GRF) data (reported in Newtons at 120 Hz). Ground reaction force is reduced as described by Wikstrom et al (16). The study used the average GRF values from the 3 successful trials. The MLSI and APSI evaluate the oscillation from 0 along the sagittal and frontal axes of the force plate, respectively. The VSI evaluate the oscillation from the subject's body weight to standardize the vertical GRF along the vertical axis of the force plate.

$$\begin{aligned} \text{MLSI} &= \sqrt{}[\Sigma(0 - \text{x})^2/\text{number of data points}] \\ \text{APSI} &= \sqrt{}[\Sigma(0 - \text{y})^2/\text{number of data points}] \\ \text{VSI} &= \sqrt{}[\Sigma(\text{body weight} - \text{z})^2/\text{number of data points}] \end{aligned}$$

MLSI = Medial-lateral stability index

APSI = Anterior-posterior stability index

VSI = Vertical stability index

x = Ground reaction force in medial/lateral direction during the jump-landing sequence

y = Ground reaction force in anterior/posterior direction during the jump-landing sequence

z = Ground reaction force in vertical direction during the jump-landing sequence

Number of data points = Number of data during the time of the jump-landing sequence (16)

Compound muscle action potential (CMAP)

Compound muscle action potential (CMAP) was stimulated by built in electrical stimulator (NEUROPACK ELECTROMYOGRAPH; MEM-3202) and collected the electrical signal by Biopac MP100 System (EMG100C, BIOPAC Systems MP100A, Inc Santa Barbara, California, U.S.A) which analyzed the signal by AcqKnowledge 3.9.1 program. According to the CMAP protocol, two stimulating electrodes were placed in the superior portion of the popliteal fossa behind the knee over the tibial branch of the sciatic nerve. Electrical stimulation is elicited by a single supramaximal stimulus (0.1 ms duration). The stimulation voltage used was approximately 60 Volt. The amplitude of the CMAP was measured as the peak-to-peak value and showed in millivolts (mV), and the duration of the negative peak is showed in millisecond (ms) (Figure 11).

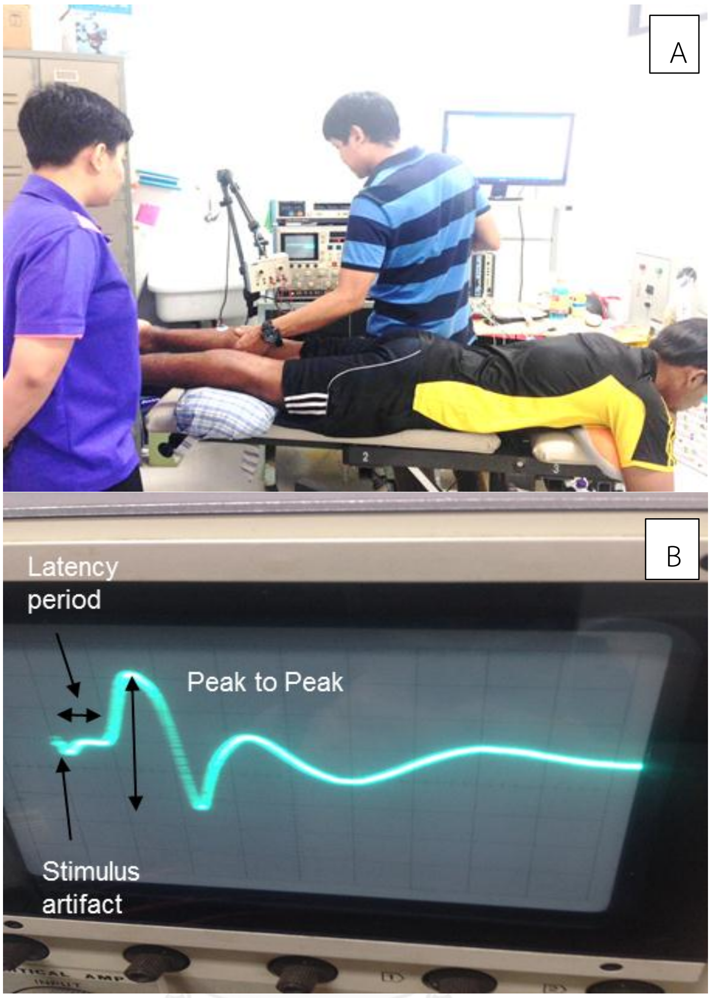

Figure 11. Picture A: showed electrical stimulation protocol of lateral gastrocnemius muscles. Picture B: showed Compound action potential (CMAP) graph

Exercise-induced fatigue protocol

The exercise-induced fatigue was composed of 10 sets of 2-min periods, consisting of 10 s of passive rest, a 5-s maximal sprint from a stationary start against a resistance of 7.5% body mass, followed by 105 s of active recovery (23) (Figure 12). The active recovery intensity of the exercise protocol is equivalent to 35%of predicted VO_2max and calculates from estimated maximal power (Watts) at VO_2max. Before starting exercise protocol, subjects require standardized warm-up of cycling (Monarkergomedic 839E) at 80 rpm at a power output of 95 W for 5 min. Rate of perceived exertion (RPE) is measured by using the Borg category scale and thermal comfort was evaluated using Thermal Comfort Scale. The exercise-induced fatigue protocol is terminated if subjects has a physical disorder, core temperature more than 40°C, RPE more than 17, when power output could no longer be maintained at a determined cadence and ask to stop exercise.

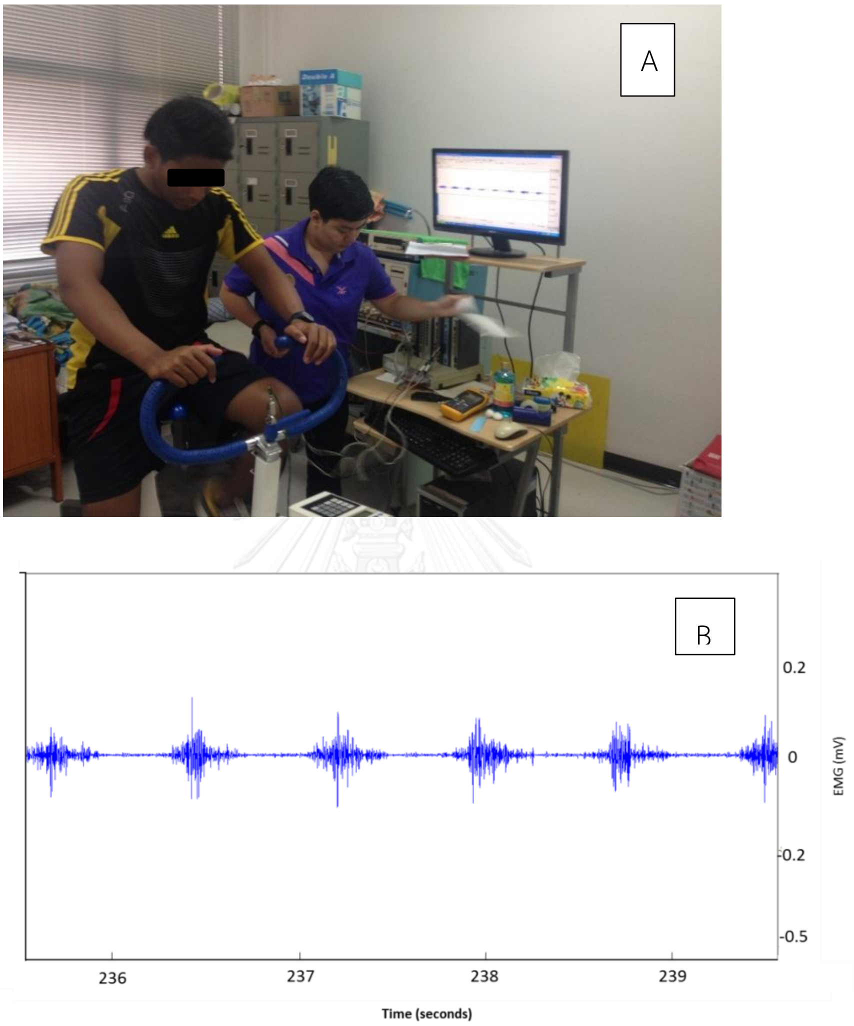

Figure 12. picture A showed Electromyography (EMG) record during cycling exercise. Picture B showed electromyography data extracted every 2 minutes during cycling exercise

The EMG is recorded continuously during exercise. The SEMG data is transmitted to the electromyogram amplifier module(EMG100C). The SEMG data converted into digital form at a rate of 2000 Hz.The SEMG signals are amplified (gainx500), sample at 500 Hz and bandwidth filtered(10 Hz to 500 Hz). It is rectified and down sampled at 120 Hz. After data from SEMG signal is full-wave rectified, the data is integrated to the iEMG which is calculated from a 500-ms. The iEMG value from the first 10 s of exercise compared with the last 10s of exercise to indicate the effect of muscle fatigue

Core temperature

Core temperature was measured in the rectum by using a Biopac MP100 system with an SKT100C transducer module (BIOPAC Systems Inc., Santa Barbara, California, USA) and thermistor probe (TSD102A, Biopac Systems Inc.). The thermistor probe was wrapped in a plastic film, and lubricant gel was applied before inserting it into the rectum at a depth of 10-12 cm (Figure 13). The software program for collecting data was AcqKnowLedge 3.9.1 for Life Science Research Program (Biopac Systems Inc). All thermistors were calibrated against a mercury thermometer before using in the experiment. The core temperature is placed thermistor inside a thin latex sheath and insert 10-12 cm inside the rectum and collected every 5 minutes.

Figure 13. Core temperature measurement into the ractum

Statistical analysis

Analysis of the outcomes was conducted using a linear mixed model which allowed (in addition to treatment effect) to determine whether treatment was a carry-over (period) effect or sequence effect. Modally was performed using the R statistical package(V.3.2.1) and the R library was used to run linear mixed models (Bates et al, 2015) R core team, 2016. The significance was set when p was $\leq$ 0.05. Descriptive statistical analysis were performed using computer software SPSS version 13.0 for windows (SPSS, Chicago, IL, USA).

CHAPTER IV

RESULTS

23 of healthy males who met inclusion/exclusion criteria volunteered to participate the study. All 23 subjects completed the experimental protocols and measurements.

Characteristics of the subjects

The characteristics of the subjects are summarized in Table 2 Age of 23 healthy subjects ranged from 20-25 years (mean 21.8 ±2 years). The mean height, weight, predicted VO_2 max, percent body fat and body fat mass of 23 healthy subjects were 173.65 ± 5.38 cm, 66.21 ± 8.18 kg, 46.35±6.56 ml/kg/min, 14.07±5.39% and 8.78±3.7 kg respectively.

Variable	Subjects (n=23)
Age (years)	21.8 ± 1.2
Height (cm)	173.65 ± 5.38
BMI (kg/m^2)	21.8 ± 2.43
Predicted VO_2 max (ml/kg/min)	46.35 ± 6.56
Percent body fat (%)	14.07 ± 5.39
Maximal jump height (cm)	275.26 ± 4.27
Targeted jump marker (cm)	266.63 ± 2.13
Body fat mass (kg)	8.78 ± 3.7
Fat free mass (kg)	57.41 ± 4.88

Table 2. Basic characteristics of 23 subjects

Dynamic postural stability index (DPSI)

The DPSI of 23 health males in hot compared with thermoneutral environment were presented in mean±SD shown in figure 14 DPSI in hot climate group (31 ± 2 ^{O}C 60% relative humidity) after exercise (0.99± 0.15) was significantly (P < 0.05) higher than before exercise (0.48± 0.11). DPSI after exercise (0.55± 0.1) in temperate climate group (23-25 ^{O} C 50% relative humidity) tend to higher than before exercise (0.44± 0.18) but was not significant as showed in figure 14 When compare DPSI after exercise between hot and temperate climate group, DPSI in hot climate (0.99±0.15) was significantly (P < 0.05) higher than in temperate climate group (0.48±0.1) as showed in figure 14

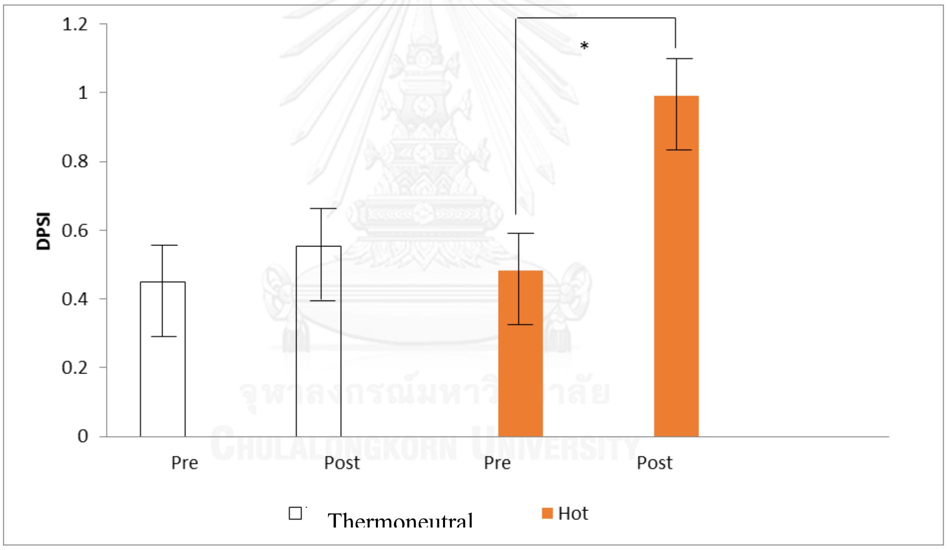

Figure 14. Dynamic postural stability index (DPSI) between hot and thermoneutral environment (n=23). * Indicate significant between Pre and Post.

Directional components of postural stability

The directional component of 23 health males in hot compared with thermoneutral environment were presented in mean±SD shown in Table 3 The results showed that anterior-posterior stability index (APSI) after exercise-induced fatigue in hot environment group (0.18±0.05) was significantly higher than in thermoneutral environment group (0.09±0.04). However, there were no significantly difference in medial-lateral stability index (MLSI) and vertical stability index (VSI) between hot and thermoneutral environment group (Table3).

	Thermoneutral environment		Hot environement	
Directional Components	Pre	Post	Pre	Post
Medial-lateral stability index	0.16±0.02	0.16±0.02	0.15±0.03	0.17±0.04
Anterior-posterior stability index	0.07±0.16	0.09±0.04*	0.09±0.25	0.18±0.05*
Vertical stability index	0.6±0.50	0.70±0.42	0.68±0.38	0.71±0.59

Table 3. Dynamic postural stability index (DPSI) and its directional components between temperate and hot climate (Mean ± SD) *Indicate significant between hot and thermoneutral environment

Integrated electromyography (iEMG) during exercise

The IEMG of 23 health males in hot compared with thermoneutral environment were presented in every 2 minutes shown in Figure 15 The iEMG in hot and thermoneutral environment decrease continually during cycling exercise. There was a significant decrease in the iEMG from the first 10 s of exercise in hot (672.5 ± 223.51 μV) and thermoneutral environment (642.5 ± 170.36 μV) to the last 10s of exercise in hot (250 ± 35.59 μV) and thermoneutral environment 258.5 ± 82.19 μV). These results confirm the effect of exercise-induced fatigue in both hot and thermoneutral environment.

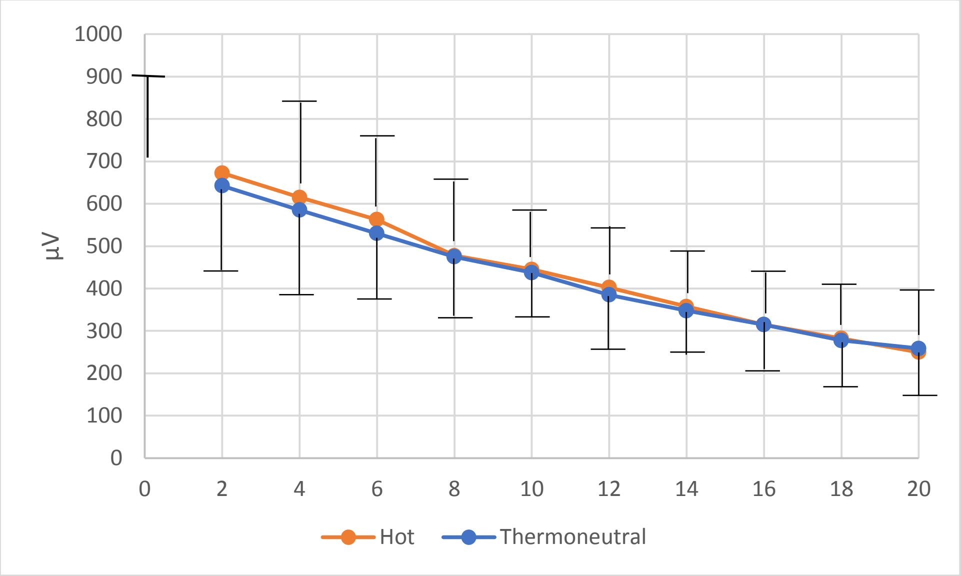

Figure 15. Integrated electromyography (iEMG) values of healthy males in hot (n=23) and thermoneutral environment (n=23) during cycling exercise every 2 minutes.

IEMG during sustained maximal voluntary isometric contraction (MVIC)

The maximal IEMG during sustained maximal voluntary isometric contraction (MVIC) of 23 health a significant decrease in the iEMG from Pre-MVIC (before exercise-induced fatigue) in hot (725.89±401.12 µV) and temperate climate (809.26 ± 429.27 µV) to the Post-MVIC (after exercise-induced fatigue) in hot (328.1 ± 193.3 µV) and temperature climate (374.91 ±202.5 **µV**) (Figure 16).

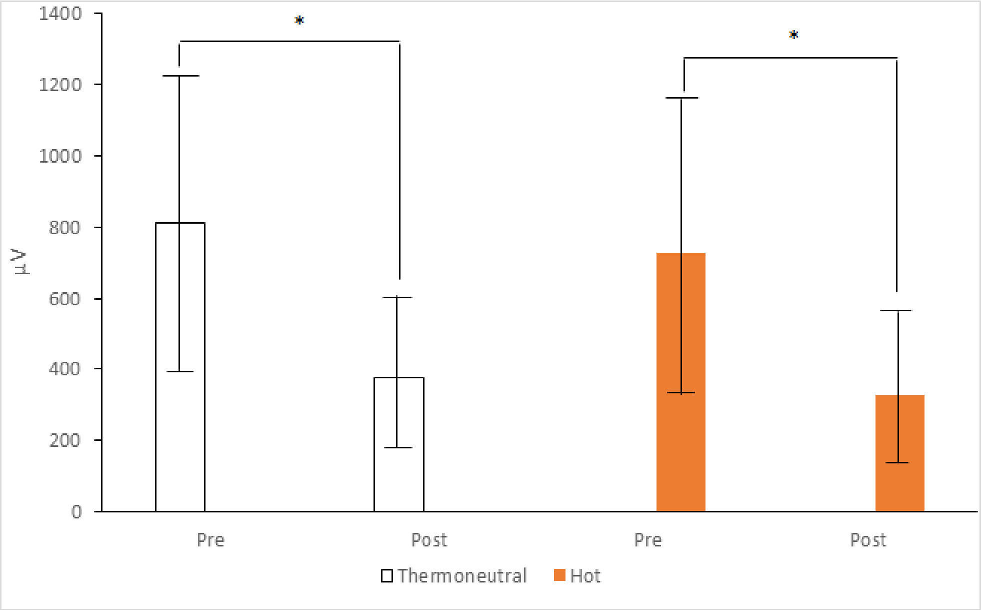

Figure 16. Maximal iEMG during sustained maximal voluntary isometric contraction (MVIC) between thermoneutral and hot environment (Mean ± SD) *Indicate significant between Pre and Post

Compound muscle action potential (CMAP)

The CMAP of 23 health males in hot compared with thermoneutral environment were presented in mean±SD shown in Figure 17 There were no significantly ($P > 0.05$) difference in CMAP between hot environment and thermoneutral environment and no significantly ($P > 0.05$) difference within group.

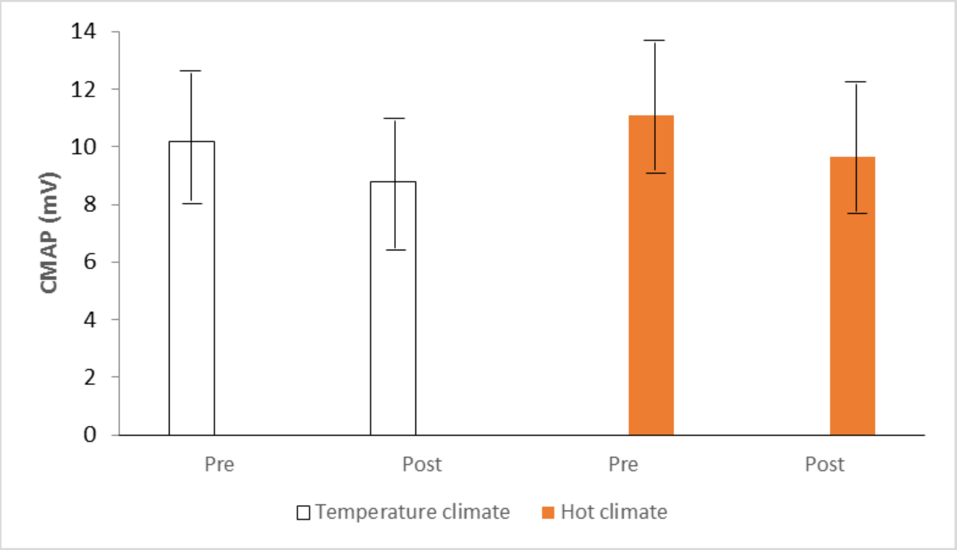

Figure 17. Compound muscle action potential (CMAP) of healthy males in hot (n=23) and thermoneutral environment (n=23).

Core temperature changes

The core temperature of 23 health males every 5 minutes in hot compared with thermoneutral environment were presented in mean ± SD shown in Figure 18 The core temperature in hot environment was significantly higher than in thermoneutral environment at 5, 10, 15, 20 minutes during exercise. But there were no significantly difference between hot and thermoneutral environement in rest and warm-up.

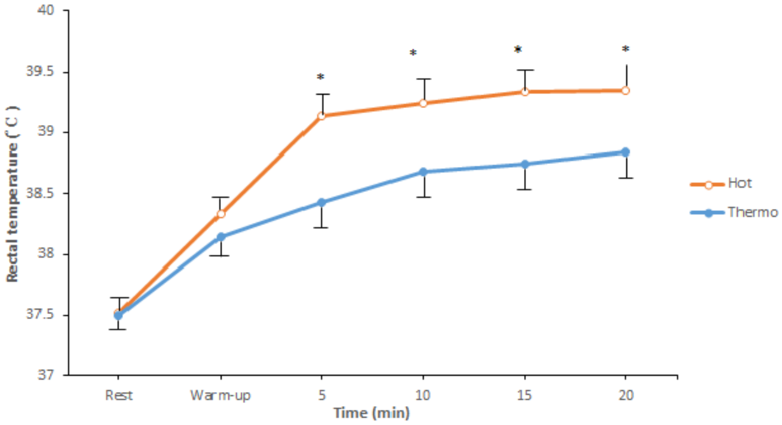

Figure 18. The core temperature of healthy males at rest and every 5 minutes in hot (n=23) and thermoneutral environment (n= 23) during exercise intervention. *Indicate significant between hot and thermoneutral environment.

CHAPTER V

DISCUSSION AND CONCLUSION

In this study, we compare the effect of exercise-induced fatigue on postural stability after single-hop jump between hot and thermoneutral environment. It was hypothesized that postural stability after single-hop jump in hot environment would be greater impaired than in thermoneutral environment, as indicated by a greater increase of dynamic postural stability index (DPSI) scores in hot environment than in thermoneutral environment. The result showed that exercise-induced fatigue in hot environment produce significantly higher dynamic postural stability scores than in thermoneutral environment while completing a jump-landing protocol. This finding indicated that exercise-induced fatigue in hot environment group had worse dynamic postural stability than in thermoneutral environment group that confirm our hypothesis. In the other hand, the result showed that after exercise-induced fatigue in both groups produce higher dynamic postural stability scores than in before exercise but not significant.

Effect of hyperthermia on postural stability

The present study clearly demonstrates that hyperthermia leads to a marked reduction on postural stability after single-hop jump. Although, postural stability was negatively affected by muscle fatigue which disrupts the afferent feedback input to CNS that causes alterations in proprioceptive and kinesthetic properties of joints, (5, 20, 24). it's seem to effect of hyperthermia plays a significant role in this reduction. Due to progressive hyperthermia, the elevations of the core temperature induce to more deteriorate voluntary muscle activation (20). Therefore, the effect of fatigue can be more affected by hyperthermia that supported by several investigators (9, 18, 20). Nybo and Nielsen,2001 compare the effect of exercise-induced fatigue between hot and thermoneutral environment (18). They stimulated fatigue by cycling at 60% VO_2max in hot environment increased the core temperature to 40 ^{o}C and exhausted the subjects about 50 min, whereas during control trial the core temperature about 38 ^{o}C and exercise was maintained for 1 h without exhausting the subject (8). They found that the subjects in hot environment trial were unable to sustain the same activation and the voluntary force production as well as the rectified integrated surface electromyogram (iEMG).

Effect of muscle fatigue on postural stability

The result showed that after exercise-induced fatigue in both groups produce higher dynamic postural stability scores than in before exercise but not significant. Our result was consistence with previous study. It has been proposed that muscle fatigue is a key factor to deteriorate the postural stability (16). Lundin et al,1993 also reported that exercise-induced fatigue can affect sensory inputs and motor output of the postural system (25). Although, the human body has the mechanism to compensate the deterioration of sensory input and motor output as soon as muscle fatigue is established, compensation for the decline of postural stability is no longer possible (16). Muscle fatigue affect postural stability by the quality of sensory information that involve alteration in muscle strength. Paillard T et al,2012 reported that the mean velocity of the center of pressure(COP) significantly increase when the strength loss reaches 30% of the maximal voluntary contraction (MVC) of a specific muscle group (16).

Effect of exercise-induced fatigue

This study confirms the effect of exercise-induced fatigue by measuring maximal EMG during exercise-induced fatigue. The current result showed that iEMG values at the last 10s of exercise protocol was significant lower than before exercise in both groups. This finding was supported by the previous study that used the same protocol to stimulate the effect of muscle fatigue with EMG assessment during exercise in 33°C, 50% RH. They found that maximal iEMG were significantly reduced at the last period of exercise protocol compared with initial values. Their study concluded that the reduction of maximal iEMG after exercise caused by the effect of muscle fatigue (8).

The relative contributions of central and peripheral factors development of muscle fatigue

The relative contributions to the development of muscle fatigue in hot environment relates mainly to change in the central-nervous system (CNS) that reduce voluntary activation lead to central fatigue (8). This study examined separately the contributions of muscle fatigue by comparing the change in iEMG and CMAP before and after exercise (iEMG/CMAP ratio). This study found that iEMG during post-exercise was significantly lower than pre-exercise but there were no significantly difference in CMAP in both groups. The decreasing in iEMG indicate that central activation was impaired that negatively affect in the central-nervous system(CNS). The previous study showed that decreased iEMG may be attributed to a decrease in motor neuronring rates rather than a reduction in the extent of motor unit recruitment (12) CMAP values indicated no failure of neuromuscular transmission.

Directional components of postural stability

The result of this study showed that the exercise-induced fatigue in hot environment had worse anterior-posterior stability index (APSI) than in thermoneutral environment. However, there were no significantly difference in Medial-lateral stability index (MLSI) and vertical stability index (VSI) between hot and thermoneutral environment. The result indicate that exercise-induced fatigue produced higher postural stability scores in the anterior/posterior, medial/lateral and vertical axis while completing a single-hop jump protocol. The results support the hypothesis that exercise-induced fatigue increased (worse) postural stability scores. The current finding is consistent with the result of previous study. Salavati M et al,2007 study the effect of muscle fatigue on postural stability of the lower extremities during transitioning movement in healthy young men. Similarly, they reported that anterior-posterior, medial-lateral deficits in individual after exercise-induced fatigue protocol (25).

The core temperature

The elevations of the core temperature induce to impair voluntary muscle activation (20). Previous study showed that prolonged exercise in hot environment can result in fatigue when the core temperature at exhaustion is over a range of 38–40°C (8, 20). That was consistent with the result of this study in both hot environment (39.35± 0.57°C) and thermoneutral environment trial (38.94 ± 0.58 °C). However, some studies reported that fatigue in untrained subjects occur during light exercise in hot environments at core temperatures of 38°C (20). The other factors that affect core temperatures at voluntary exhaustion both in trained and untrained subjects depends on the study designs, where low- to moderate-intensity exercise is combined with a large external heat stress (8).

Conclusion

In summary, exercise-induced fatigue performed in hot environment is more deteriorate the postural stability after single-hop jump than in thermoneutral environment. The relative contributions of factors development of muscle fatigue mainly involve to change in the central-nervous system (CNS) that reduce voluntary activation lead to central fatigue. On the directional component of postural stability, the exercise-induced fatigue in hot environment had worse anterior-posterior stability index (APSI) than in thermoneutral environment. However, there were no significantly difference in Medial-lateral stability index (MLSI) and vertical stability index (VSI) between hot and thermoneutral environment. To address the comparative effect of exercise-induced fatigue on postural stability after single-hop jump between hot and thermoneutral environment and relative contribution of central and peripheral factors development of muscle fatigue. This ground information may provide important insight onto future research regarding exercise intervention in hot environment for specific population.

APPENDICES

APPENDIX A Screening Questionnaire (แบบสอบถามเพื่อการคัดกรอง)

ลำดับที่ .... วันที่.............เดือน............................พ.ศ. ....

ตอนที่ 1 ข้อมูลเกี่ยวกับผู้ตอบแบบสอบถาม

1. วัน/เดือน/ปีเกิด.. อายุ.................ปี..................เดือนเชื้อชาติ........................สัญชาติ........................อาชีพ..

2. น้ำหนัก.......................... กิโลกรัม ส่วนสูง.........................เมตร BMI………………. kg/m2

ตอนที่ 2 ข้อมูลเกี่ยวกับสุขภาพ

โปรดตอบคำถามต่อไปนี้ตามความเป็นจริง โดยทำเครื่องหมาย ☐ลงใน ☐ หรือเติมข้อความลงในช่องว่างที่เว้นไว้

1) ท่านมีโรคประจำตัวหรือไม่

☐ ไม่มี ☐ มี โปรดระบุ...

2) ท่านตรวจร่างกายครั้งล่าสุด โดยมีผลของระดับไขมัน,น้ำตาลในเลือดและ คลื่นไฟฟ้าหัวใจ (EKG)เมื่อไร

☐น้อยกว่า 6 เดือน ☐มากกว่า 6 เดือน ☐ไม่เคยได้รับการตรวจมาก่อน

3) ท่านรับประทานยา/ วิตามิน หรืออาหารเสริมอยู่หรือไม่

☐ไม่ ☐รับประทานโปรดระบุ...

4) ท่านออกกำลังกายหรือไม่

☐ไม่ ☐ ใช่

5) ท่านออกกำลังกายชนิดใด

☐ เดิน ☐ วิ่ง ☐ว่ายน้ำ ☐ ปั่นจักรยาน ☐ อื่นๆ...

6) ท่านออกกำลังกายกี่ครั้งต่อสัปดาห์

☐ <3ครั้งต่อสัปดาห์ ☐≥3ครั้งต่อสัปดาห์

7) ท่านออกกำลังกายเป็นระยะเวลาเท่าไรต่อครั้ง

☐ <30 นาที ☐≥30 นาที

8) ขณะนี้ท่านมีปัญหาสุขภาพ และ/หรือมีภาวะเครียดหรือไม่

☐ ไม่มี ☐ มี

9) ท่านสูบบุหรี่หรือไม่

☐ ไม่เคยสูบ ☐ สูบ.................มวน/วัน เป็นระยะเวลา.......................ปี ☐ เลิกสูบมาแล้ว .... ปี ☐อื่นๆ โปรดระบุ...

10) ท่านดื่มเครื่องดื่มที่ผสมแอลกอฮอล์หรือไม่

☐ ไม่เคยดื่ม ☐นานๆครั้งโปรดระบุ.. ☐ ดื่มเป็นประจำ

11) ท่านได้รับการบาดเจ็บบริเวณรยางค์ช่วงล่างและศีรษะ ภายในระยะเวลา 3 เดือนหรือไม่

☐ ได้รับ ☐ ไม่ได้รับ

12) ท่านมีปัญหาเกี่ยวกับการทรงตัว ภายในระยะเวลา 6 เดือนหรือไม่

☐ มีปัญหา ☐ ไม่มีปัญหา

13) ท่านมีปัญหาเกี่ยวกับอาการข้อต่อไม่มั่นคงหรือไม่

☐ มีปัญหา ☐ ไม่มีปัญหา

14) ท่านมีแผลเปิดหรือปัญหากล้ามเนื้ออักเสบหรือไม่

☐ มีปัญหา ☐ ไม่มีปัญหา

แบบบันทึกข้อมูล

ตารางที่ 1 แสดง อายุ น้ำหนัก ส่วนสูง ดัชนีมวลกาย การเต้นของหัวใจต่ำสุดขณะพัก มวลกล้ามเนื้อ มวลไขมัน ของอาสาสมัครชาย

อายุ (ปี)	
น้ำหนัก (กิโลกรัม)	
ส่วนสูง (เซนติเมตร)	
ดัชนีมวลกาย (กิโลกรัม / ลูกบาศก์เมตร)	
หัวใจต่ำสุดขณะพัก (ครั้ง / นาที)	
มวลกล้ามเนื้อ (กิโลกรัม)	
มวลไขมัน (กิโลกรัม)	

ตารางการออกกำลังกายโดยการปั่นจักรยาน

อุณหภูมิ....................(°C)   ความชื้นสัมพันธ์.......................%

Time (min)	Range of Heart rate (bpm)	Rating of Perceived Exertion(RPE)	Thermal Comfort	Core temperature(°C)

Jump protocol

Maximal jump height…………..cm

Ground reaction force (GRF)	mean of ground reaction force(X)	mean of ground reaction force (Y)	mean of ground reaction force (Z)
Trial 1			
Trial2			
Trial3			
Mean			
SD			

YMCA cycle ergometer test

Stage	Workload (Watt)	Workload (kg-m/min)	HR (bpm)		BP (mmHg)	RPE
Warm up						
1						
2						
3						
4						

APPENDIX B

Basic characteristics of 23 subjects presented in mean ± SD

Variable	Subjects (n=23)
Age (years)	21.8 ± 1.2
Height (cm)	173.65 ± 5.38
BMI (kg/m^2)	21.8 ± 2.43
Predicted VO$_2$ max (ml/kg/min)	46.35 ± 6.56
Percent body fat (%)	14.07 ± 5.39
Maximal jump height (cm)	275.26 ± 4.27
Targeted jump marker (cm)	266.63 ± 2.13
Body fat mass (kg)	8.78 ± 3.7
Fat free mass (kg)	57.41 ± 4.88

Dynamic postural stability index (DPSI) and its directional components between thermoneutral and hot environment (Mean ± SD) *Indicate significant between thermoneutral and hot environment

	Thermoneutral environment		Hot environement	
Directional Components	Pre	Post	Pre	Post
Medial-lateral stability index	0.16±0.02	0.16±0.02	0.15±0.03	0.17±0.04
Anterior-posterior stability index	0.07±0.16	0.09±0.04*	0.09±0.25	0.18±0.05*
Vertical stability index	0.6±0.50	0.70±0.42	0.68±0.38	0.71±0.59
Dynamic postural stability index	0.44± 0.18	0.55± 0.1	0.48± 0.11	0.99± 0.15

The core temperature of healthy males at rest and every 5 minutes in hot (n=23) and thermoneutral environment (n= 23) during exercise intervention.

	Rest	Warm-up	5	10	15	20
Hot environment	37.52±0.62	38.33±0.53	39.13±0.67	39.23±0.63	39.33±0.57	39.35±0.54
Thermoneutral environment	37.49±0.65	38.14±0.59	38.42±0.66	38.68±0.67	38.74±0.63	38.84±0.62

Integrated electromyography (iEMG) of healthy males during maximal sustained isometric contraction in hot environment (n=23) and thermoneutral environment (n=23)

	Hot environment		Thermoneutral environment	
	Pre (µV)	Post (µV)	Pre (µV)	Post (µV)
Mean	725.89	328.1	809.26	374.91
SD	401.12	193.3	429.27	202.5

Compound muscle action potential (CMAP) of healthy males in hot environment (n=23) and in thermoneutral environment (n=23)

	Hot environment		Thermoneutral environment	
	Pre (mV)	Post (mV)	Pre (mV)	Post (mV)
Mean	11.08	9.65	10.17	8.76
SD	7.73	8.03	8.78	6.06

Maximal IEMG during cycling exercise presented in every 2 minutes of healthy males in hot (n=23) and in thermoneutral environment (n=23)

	iEMG (μV)	iEMG (μV)
Minute (Mins)	Hot environment	Thermoneutral environment
2	672.5 ± 223.51	642.5 ± 170.36
4	615 ± 190.17	585 ± 185.74
6	562.5 ± 186.25	530 ± 165.12
8	477.5 ± 131.24	475 ± 134.28
10	445 ± 98.82	437.5 ± 133.51
12	402.5 ± 76.32	385 ± 114.74
14	357.5 ± 74.10	347.5 ± 119.26
16	315 ± 82.25	315 ± 111.20
18	282.5 ± 66.01	277.5 ± 92.15
20	250 ± 35.59	258.5 ± 82.19

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APPENDIX

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