ผลของการเมื่อยล้าจากการออกกำลังกายในที่ร้อนเปรียบเทียบกับการออกกำลังกายในอุณหภูมิปกติต่อความมั่นคงในการทรงตัวภายหลังจากการกระโดดขาเดียว

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บทคัดย่อ

การเมื่อยล้าจากการออกกำลังกายเป็นปัจจัยสำคัญที่ทำให้ความมั่นคงในการทรงตัวแบบไดนามิกลดลง ยิ่งไปกว่านั้น ผลของการเมื่อยล้าจะเพิ่มมากขึ้นเมื่ออยู่ในภาวะที่อุณหภูมิร่างกายสูงกว่าปกติหรือการออกกำลังกายในที่ร้อน อย่างไรก็ตาม ยังไม่มีงานวิจัยที่ศึกษาเปรียบเทียบความแตกต่างระหว่างผลของความเมื่อยล้าในที่ร้อนกับในอุณหภูมิปกติต่อความมั่นคงในการทรงตัวแบบไดนามิก

วัตถุประสงค์ เพื่อศึกษาผลของการเมื่อยล้าจากการออกกำลังกายในที่ร้อนเปรียบกับในอุณหภูมิปกติต่อความมั่นคงในการทรงตัวแบบไดนามิกและศึกษาลักษณะของการเมื่อยล้าระหว่างในที่ร้อนเปรียบเทียบกับในอุณหภูมิปกติ

วิธีดำเนินการวิจัย ในงานวิจัยนี้ทำการศึกษาในชายสุขภาพดีทั้งหมด 23 คน โดยผู้เข้าร่วมงานวิจัยทำการออกกำลังกายโดยการปั่นจักรยานเป็นระยะเวลา 20 นาทีทั้งในที่ร้อน (อุณหภูมิ 31-33 องศา ความชื้นสัมพันท์ 60%) และในที่อุณหภูมิปกติ (อุณหภูมิ 23-25 องศาความชื้นสัมพันท์ 50%) โดยใช้ตัวชี้วัด คือความมั่นคงในการทรงตัวภายหลังการกระโดดขาเดียว Dynamic postural stability (DPSI) ส่วนในการแยกลักษณะของการเมื่อยล้าจากการออกกำลังกายในที่ร้อนเปรียบเทียบกับในอุณหภูมิปกติจะใช้ตัวชี้วัด Integrated electromyography/ Compound muscle action potential (iEMG/CMAP) ในกล้ามเนื้อน่องส่วน lateral (lateral gastrocnemius) ก่อนและหลังการออกกำลังกาย

ผลการวิจัย ข้อมูลจากการวิจัย พบว่า DPSI ภายหลังจากการออกกำลังกายในที่ร้อน (0.99 ± 0.15) มีค่าสูงกว่าอย่างมีนัยสำคัญทางสถิติ ($P \leq 0.05$) เมื่อเปรียบเทียบกับการออกกำลังกายในอุณหภูมิปกติ (0.48 ± 0.10) และพบว่า iEMG ในที่ร้อนลดลงอย่างมีนัยสำคัญทางสถิติเมื่อเปรียบเทียบกับที่อุณหภูมิปกติ แต่ไม่พบความแตกต่างของ CMAP

สรุปผลการวิจัย ผลของการเมื่อยล้าจากการออกกำลังกายในที่ร้อนส่งผลเสียต่อความมั่นคงในการทรงตัวแบบไดนามิกมากกว่าในอุณหภูมิปกติ ในทิศทาง anterior-posterior และลักษณะของการเมื่อยล้าเป็นการเมื่อยล้าจากส่วนกลาง

คำสำคัญ: การออกกำลังกายที่ทำให้เกิดการเมื่อยล้า/ความมั่นคงในการทรงตัวแบบไดนามิก/สภาพแวดล้อมในที่ร้อน/การเมื่อยล้าจากส่วนกลาง/การเมื่อยล้าจากส่วนปลาย

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EFFECT OF EXERCISE-INDUCED FATIGUE IN HOT COMPARED WITH THERMONEUTRAL ENVIRONMENT ON POSTURAL STABILITY AFTER SINGLE-HOP JUMP

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Abstract

Effect of exercise-induced fatigue is considered to deteriorate the dynamic postural stability which is important for injury prevention. This effect was more pronounced when exercise performed in hot than thermoneutral environment. However, there is lack of evidence regarding the relationship between the effects of fatigue on dynamic postural stability in hot environment.

Purpose The purpose of this study was to investigate the effect of exercise-induced fatigue on the dynamic postural stability in hot environment compared with thermoneutral environment and differentiate the relative contributions of central and peripheral factors to the exercise-induced fatigue.

Methods The design of this study was randomized crossover trial. Twenty-three healthy males were divided into two groups to perform exercise-induced fatigue both in hot environment (31-33°C 60% relative humidity) and thermoneutral environment (23-25°C, 50% relative humidity). Dynamic postural stability index (DPSI) scores were identified by dynamic postural stability scores. In addition, the contributions of muscle fatigue were examined by comparing the change in integrated electromyography (iEMG) and Compound muscle action potential (CMAP) in lateral gastrocnemius muscle before and after exercise-induced fatigue.

Results The result showed that DPSI scores in hot environment (0.99 ± 0.15) was significantly ($P < 0.05$) higher than in thermoneutral environment (0.48 ± 0.10). Exercise-induced fatigue in hot environment had worsen postural stability than that in thermoneutral environment. That iEMG of lateral gastrocnemius muscle was significantly lower after exercise with no significant difference observed in CMAP in both groups.

Conclusion Exercise-induced fatigue in hot environment elicits greater negative effects on the dynamic postural stability than that in thermo-neutral environment counterpart. In addition, the contribution factors of exercise-induced muscle fatigue is possibly related to central-fatigue component.

Keywords: Exercise-induced fatigue/Dynamic postural stability/ Hot environment/ Central fatigue/ Peripheral fatigue

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Introduction

It is well-known that postural stability is an essential requirement for the performance of daily tasks and sporting activities (1,2). Postural stability deficit induced to the incidence of lower extremity injuries (3) that have been found in populations with musculoskeletal injury such as ankle injury (1,4,5). 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). Dynamic postural stability can be defined as an ability to maintain balance while transitioning from dynamic to static state (1). 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.

It has been proposed that muscle fatigue is a key factor to deteriorate the postural stability (3,4). Muscle fatigue has the effect on postural stability by the quality of sensory information that involve alteration in muscle strength. Lundin et al. (1993) also reported that exercise-induced fatigue can affect sensory inputs and motor output of the postural system (7). 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. Several studies investigate the disturbing effects of fatigue on the postural stability. Most of the studies showed that a muscular exercise on a short duration induce a reduction of postural control when the MVC loss is more or equal to 30 % (6).

In addition to, the previous studies indicated that effect of fatigue can be more stimulated by hyperthermia (8). The hyperthermia-induced fatigue occurs during core temperature at exhaustion over a range of 38-40°C and to be independent of exercise intensity (9). 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. 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 (9).

Most studies have examined the effects of muscle fatigue on static postural stability (6). However, dynamic postural stability is more closely related to exercise and sport activity than static postural stability, there were only few studies that investigate the effect of muscle fatigue on dynamic postural stability (10). The dynamic postural stability can be mostly quantified by dynamic postural stability index (DPSI) which is an objective measure that is used in together with a jump protocol such as single-hop jump. Therefore, 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 in hot environment compared with thermoneutral environment

Objectives

1) To study and compare the effect of exercise-induced fatigue on the dynamic postural stability in hot environment and thermoneutral environment

2) To determine the relative contributions of central and peripheral factors development of muscle fatigue.

Research hypothesis

1) Exercise-induced fatigue in a hot environment had a greater deteriorate effect on postural stability after single-hop jump than in thermoneutral environment.

2) The relative contribution of exercise-induced fatigue in hot environment was related to change in the central nervous system more than in thermoneutral environment.

Methods

Subjects

Twenty-three healthy males (age: 21.8 ± 1.2 yrs.; body height: 1.73 ± 0.05 m; body mass: 66.21 ± 8.18 kg; body fat: 14.07 ± 5.39 %) volunteered to participate in the study. Participants were examined by questionnaire and screening testing to determine their qualification. Participants were free from lower extremity and head injury, self-reported no vestibular disorders or in the previous 6 months. The study approval was approved by the Institutional Review Board of the Faculty of Medicine, Chulalongkorn University. All the subjects included in the study followed standard guidelines for exercise testing and prescription.

Inclusion criteria

1. Aged between 20-25 years
2. Had normal blood pressure (BP = 120 ± 10/80 ± 10 mmHg.)
3. Had normal weight status, body mass index (BMI) (18.5-24.9 kg/m^2)
4. Had physical activity less than 30 minutes at a time and less than 3 times per week.
5. Free from lower extremity and head injury for 3 months
6. Self-reported vestibular disorders or in the previous 6 months

Exclusion criteria

1. Had contraindications to exercise
2. Had an open wounded or muscle tendinitis that will be restricted to performance and measurement

3. Had ankle instability and abnormal proprioceptive sense

4. Were at high risk or had exercise limitation

5. Incomplete participation of all experimental conditions

Research methodology

The study was a randomized crossover trial composed of 3 visits. In the first visit, questionnaire and screening testing were determined according to inclusion criteria. For the second visit, subjects were randomized to perform exercise-induced fatigue in hot or thermoneutral environment. Then, subjects were required to avoid the vigorous activity or the activity that would affect the intervention for 4-6 days before taking the third visit. In the third visit, subject were asked to perform exercise-induced fatigue in another environment as shown in figure1. (Fig. 1 page 5)

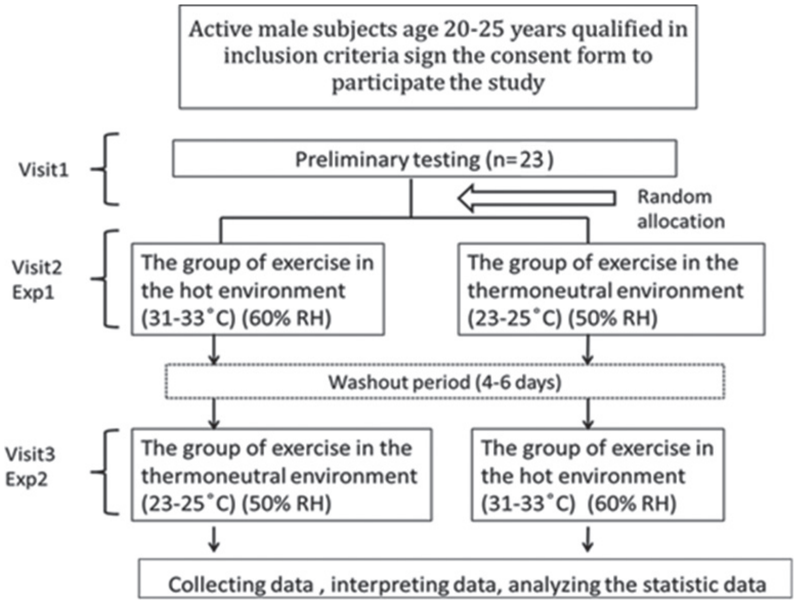

Figure 1 The study design: a randomized cross-over trial. All subjects were randomized to undergo exercise-induced fatigue in either hot or thermoneutral environment and required to perform exercise-induced fatigue again in other environment after washout period (4-6 days).

Procedures

For the first visit (Preliminary testing), general data such as age, weight, height and body mass index (BMI) were collected from all subjects by (Bioelectrical Impedance Analysis Inbody 230 Biospace co., ltd., Korea). Maximal oxygen uptake (VO_2max) is predicted by a submaximal YMCA test protocol to determine the intensity of the exercise protocol by using constant-load cycle ergometer (Monarkergomedic 839E). The submaximal YMCA test protocol composed of three or four consecutive 3-minute sets. The initial work load was 25 Watts and then progressively increased due to their heart rate response. The subjects were asked to maintain the cadence of 50 rev/min for every sets. The heart rate response during the last 15 seconds was used to determine targeted workloads. The heart rate was then is plotted against work load (Watts) on a graph to estimate VO_2max. Jump height was measured by asking each subject to take a maximum jump and recored the data.

After resting for 4-6 days (Visit2), all subjects were randomly assigned to perform either cycling exercise in hot or thermoneutral environment. On the day of experiment, subjects were required to arrive about 60 min before testing. Subjects emptied their bladder, wearing cycling clothes and perform the pre-jump protocol test. Thereafter, subjects were rested on a chair for 30 min in a thermoneutral environment (23-25 C 50% relative humidity) and 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 (EMG), 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 inserting a 10-12 cm thermistor inside the rectum. After instrumentation, subjects were required to move to the cycle ergometer to perform cycling exercise at the individual targeted workload. After completion of each exercise intervention, subjects were weighed, exited the climate room and repeated the post-jump protocol.

After resting for another 4-6 days (Visit3), subjects performed the same exercise protocol as the visit2 but in another environment.

The dynamic postural stability index (DPSI) protocol

Subjects stood in front of the center of the force plate and jumped with both legs to touch an overhead marker placed at a position equivalent to 50% of subject's maximum height before landing on one leg on the same force plate (11). Each subject was asked to jump vertically with and hands in position to touch the designated marker and land on the dominant leg, stabilized as quickly as possible and balanced for 10s with two hands on the hips while looking straight ahead. If the subjects lose their balance and touched the floor with a contralateral limb, the trial was discarded and repeated.

A Bertectriaxial force plate (Bertec Force plate FP4060-08) was used to measure jump-landing ground reaction force (GRF) data (reported in Newtons at 120 Hz). Ground reaction force was recored as described by Wikstrom et al (11). The average GRF values were calculated from the 3 successful trials. The formulas used to calculate the dynamic postural stability index (DPSI) were described below

$$\text{DPSI} = \sqrt{\left\{\sum(0-x)^2 + \sum(0-y)^2 + \sum.(bodyweight\ equivalent - z)^2 \ / \ number\ of\ datapoints\right\}}$$

where x, y and z are the ground reaction force values during the jump-landing sequence (11).

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

The Medial-Lateral Stability Index (MLSI) and Anterior-Posterior Stability Index (APSI) were evaluated by the oscillation from 0 along the sagittal and frontal axes of the force plate, respectively. The Vertical Stability Index (VSI) was evaluated by the oscillation from the subject's body weight to standardize the vertical GRF along the vertical axis of the force plate.

$$\text{MLSI} = \sqrt{\left\{\sum(0-x)^2 \ / \ number\ of\ data\ points\right\}}$$

$$\text{APSI} = \sqrt{\left\{\sum(0-y)^2 \ / \ number\ of\ data\ points\right\}}$$

$$\text{VSI} = \sqrt{\left\{(body\ weight\ equivalent - z)^2 \ / \ number\ of\ data\ points\right\}}$$

where 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 (11)

Exercise-induced fatigue protocol

The exercise-induced fatigue was composed of 10 sets of 2-min periods, 10 s of passive rest, a 5-s maximal sprint on a stationary cycle ergometer start against a resistance of 7.5% body mass, followed by 105 s of active recovery (12). The active recovery intensity of the exercise protocol was equivalent to 35% of predicted VO_2max, calculated from estimated maximal power (Watts) at VO_2max (12). Before starting exercise protocol, subjects were required to warm-up on cycling ergometer (Monarkergomedic 839E) at 80 rpm at a power output of 95 W for 5 min. Rate of perceived exertion (RPE) was measured by using the Borg category scale and thermal comfort was evaluated using Thermal Comfort Scale. The exercise-induced fatigue protocol was terminated if subjects had the followings 1) a physical disorder, 2) core temperature more than 40°C, 3) RPE more than 17, and 4) when power output could no longer be maintained at a determined cadence and ask to stop exercise.

Electromyography during exercise (Central fatigue measurement)

The surface EMG (SEMG) was recorded continuously during exercise by BIOPAC (EMG100C, Biopac Systems MP100A, Inc Santa Barbara, California, U.S.A). The data was transmitted to the electromyogram amplifier module (EMG100C), from which data were converted into digital form at a rate of 2000 Hz. The SEMG signals were amplified (gainx1000), sampled at 500 Hz and bandwidth filtered (10 Hz to 500 Hz). The signals was then rectified and down sampled at 120 Hz. After which the data was integrated to the iEMG which was calculated from a 500-ms. The iEMG values from the first 10 s compared with the last 10s of exercise were used to indicate the muscle fatigue iEMG during MVIC (Central fatigue measurement). SEMG signals were recorded from lateral gastrocnemius (GC) muscle using sliver-sliver chloride (Ag-AgCl) electrodes with an interelectrode distance of 10mm (EL258 series), which were connected to robust and pliable lead wires (1 mm OD). Subjects were laid down on the adjustable bed in order 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.

Compound muscle action potential (Peripheral fatigue measurement)

Compound muscle action potential (CMAP) was stimulated by a built-in electrical stimulator (Neuropack Electromyography; MEM-3202) and recorded using Biopac MP100 System (EMG100C, BIOPAC Systems MP100A, Inc Santa Barbara, California, U.S.A). The signals were further analyze 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 was 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 was showed in millisecond (ms).

Core temperature

Core temperature was measured in the rectum by using a Biopac MP100 system with a 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. 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 was collected every 5 minutes throughout the experiment.

Data 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. 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).

Results

All twenty-three subjects completed the submaximal YMCA test and jump height measurement. The results were presented in Table1.

Table 1 Basic characteristics of subjects

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)	137.63 ± 2.13
Body fat mass (kg)	8.78 ± 3.7
Fat free mass (kg)	57.41 ± 4.88

Dynamic postural stability index (DPSI)

Dynamic postural stability index (DPSI) in hot environment group (31 ± 2°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 thermoneutral environment group (23-25°C 50% relative humidity) was higher than pre exercise (0.44 ± 0.18), although was not significant as shown in figure 2. By comparing DPSI after exercise between hot and thermoneutral environment group, the results revealed that DPSI after exercise in hot environement (0.99 ± 0.15) was significantly ($P < 0.05$) higher than that of thermoneutral environment group (0.48 ± 0.1).

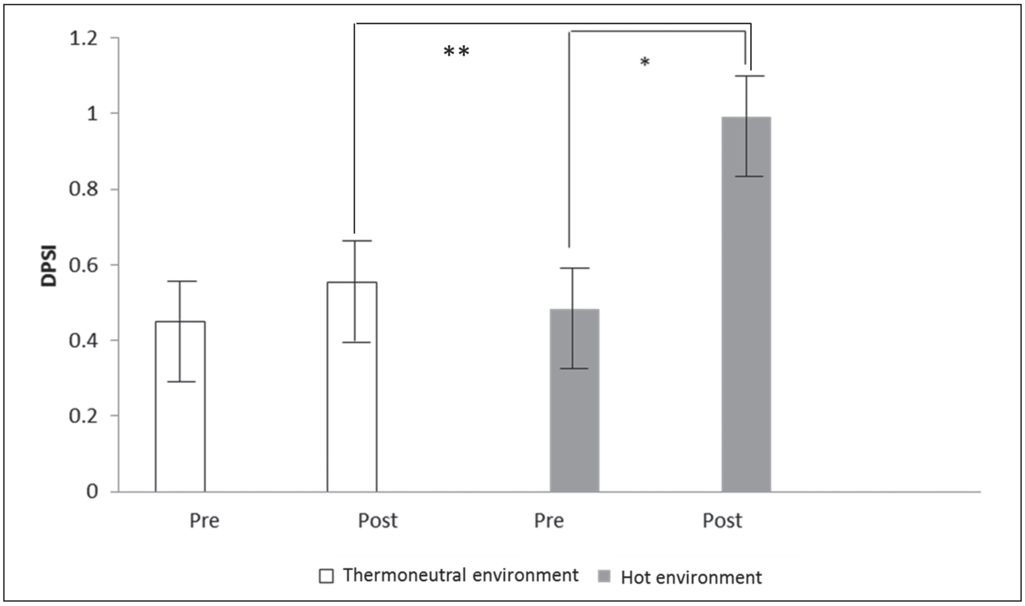

Figure 2 Dynamic postural stability index (DPSI) between thermoneutral and hot environment (n=23).

* Indicated significant between Pre and Post. ** Indicated significant between Post and Post

Directional components of postural stability

The directional component of DPSI in hot and thermoneutral environment were presented in Table 2. The results showed that anterior-posterior stability index (APSI) after exercise-induced fatigue in hot environment (0.18±0.05) was significantly higher than in thermoneutral environment (0.09±0.04). However, there were no significant difference in medial-lateral stability index (MLSI) and vertical stability index (VSI) between hot and thermoneutral environment.

Table 2 Dynamic postural stability index (DPSI) and its directional components between thermoneutral and hot environment *Indicated significant between thermoneutral and hot environment.

	Thermoneutral environment		Hot environment	
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

Fatigue

The iEMG in hot compared with thermoneutral environment were presented in every 2 minutes. The iEMG in both hot and thermoneutral environment progressively decrease 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) respectively. These results confirm the effect of exercise-induced fatigue in both hot and thermoneutral environment.

Central fatigue (iEMG during MVIC)

The maximal iEMG during sustained maximal voluntary isometric contraction (MVIC) of 23 healthy males showed a significant decrease in the iEMG from Pre-MVIC (before exercise-induced fatigue) in hot (725.89 ± 401.12 μV) and thermoneutral environment (809.26 ± 429.27 μV) to the Post-MVIC (after exercise-induced fatigue) in hot (328.1 ± 193.3 μV) and thermoneutral environment (374.91 ± 202.5 μV) respectively.

Peripheral fatigue (CMAP)

The CMAP data in hot and thermoneutral environment were presented in mean ± SD. There were no significant ($P > 0.05$) difference in CMAP between hot environment and thermoneutral environment and no significant ($P > 0.05$) difference within group.

Core temperature

The core temperature in hot compared with thermoneutral environment were presented in figure 3. The core temperature in hot environment was significantly higher than in thermoneutral environment at 5, 10, 15, and 20 minutes during exercise. But, no significant difference was observed between hot and thermoneutral environment at rest and warm-up.

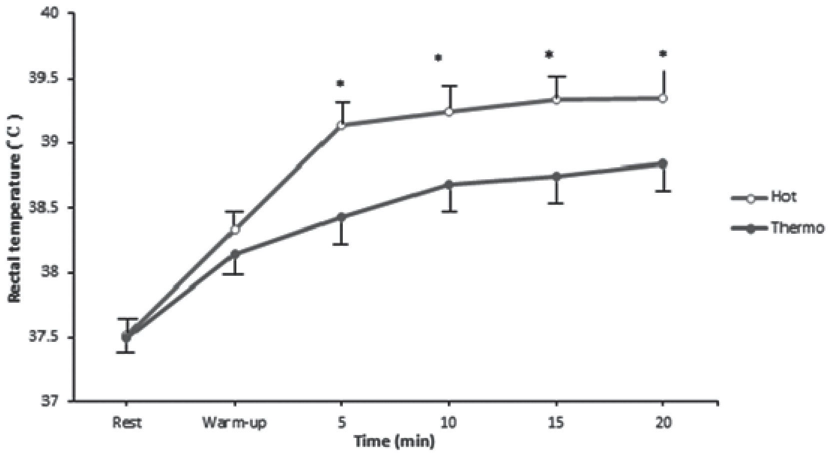

Figure 3 Changes in core temperature at rest and every 5 minutes during exercise in hot (n=23) and thermoneutral environment (n=23). *Indicated significant between hot and thermoneutral environment.

Discussion

The purpose of this study was to compare the effect of exercise-induced fatigue on dynamic postural stability between hot and thermoneutral environment. The results 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. Although exercise-induced fatigue in both conditions produce significantly higher dynamic postural stability scores than before exercise, this did not reach statistic significant. This suggest that exercise-induced fatigue tended to decrease dynamic postural stability in both groups. Consistent with this finding Lundin et al (1993) reported that exercise-induced fatigue can affect sensory inputs and motor output of the postural system (7).

The result of this study also showed that the exercise-induced fatigue in hot environment had worse anterior-posterior stability index (APSI) than in thermoneutral environment. However, there were no significant difference in Medial-lateral stability index (MLSI) and vertical stability index (VSI) between hot and thermoneutral environment. The results 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 (worsen) postural stability scores. The current finding is consistent with the result of previous study. Salavati M et al (2007) studied 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 (13).

The present study clearly demonstrates that hyperthermia leads to a marked reduction on dynamic postural stability during jump-landing protocol. Although dynamic postural stability was negatively affected by muscle fatigue which in turn disrupts the afferent feedback input to CNS that causes alterations in proprioceptive and kinesthetic properties of joints (6). It seems that 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. Therefore, the effect of fatigue can be more affected by hyperthermia. This notion was supported by several investigators (9). Nybo and Nielsen., 2001 compared the effect of exercise-induced fatigue between hot and thermoneutral environment (8). They induced fatigue by cycling at 60% VO2max in hot environment (core temperature to 40°C) the subjects were exhausted about 50 min, whereas during control trial (core temperature at 38°C) exercise was maintained for 1 h without exhaustion the subject. 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).

This study confirms the effect of exercise on muscle fatigue by measuring maximal EMG during MVIC before and after exercise-induced fatigue. The current result showed that iEMG values during MVIC after exercise-induced fatigue was significantly lower than before exercise in both groups. The reduction in iEMG after exercise was associated with a reduction in the nerve-based motor command of central-nervous system (CNS) that mainly lead to muscle fatigue. This finding was supported by the previous study that used the same protocol to stimulate the effect of muscle fatigue with EMG assessment immediately before and after exercise in 33°C, 50% RH. They found that maximal IEMG were significantly reduced after CISP protocol. Their study concluded that the reduction of maximal iEMG after exercise caused by the effect of muscle fatigue (9).

It is well-known that the development of muscle fatigue in hot environment was attributed mainly to change in the central-nervous system (CNS) which in turn reduce voluntary activation, leading to central fatigue. This study examined the relative contributions of muscle fatigue by comparing the changes in iEMG and CMAP before and after exercise (iEMG/CMAP ratio) (14). It was found that iEMG during post-exercise was significantly lower than pre-exercise but there were no significant 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). In line with their finding, the previous study also showed that decreased iEMG may be attributed to a decrease in motor neuron firing rates rather than a reduction in the extent of motor unit recruitment (15) CMAP values indicated no failure of neuromuscular transmission.

Previous study also 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 (9). This 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). Nevertheless, some studies reported that fatigue occurred during even a light exercise in hot environments at core temperatures of 38°C in untrained subjects (9). Other factors may that affect core temperatures at voluntary exhaustion both in trained and untrained subjects. Therefore, It should be noted that especially the study designs, where low–to moderate-intensity exercise is combined with a large external heat stress.

Conclusion

Exercise-induced fatigue performed in hot environment is more deteriorate the dynamic postural stability than in thermoneutral environment. Moreover, the hyperthermia-induced fatigue mainly involve a change in the central-nervous system (CNS) that reduce voluntary activation lead to central fatigue. Therefore, people who perform exercise in hot climate should be aware and prepare to prevent impairment of balance.

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