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Analysing visual pattern of skin temperature during submaximal and maximal exercises

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HIGHLIGHTS

- We examined skin temperature changes in similar body surface area cohort.
- A structural relation was observed in skin temperature variations among participants.
- Temperature pattern of skin was different between maximal and submaximal exercise.
- Thermal kinetic analysing may be useful tool for monitoring thermoregulations.
- New method was examined for determining skin temperature by infrared thermography.

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ABSTRACT

Aims of this study were to examine our hypotheses assuming that (a) skin temperature patterns would differ between submaximal exercise (SE) and graded maximal exercise test (GXT) and (b) thermal kinetics of T_{skin} occurring in SE and GXT might be similar in a homogenous cohort. Core temperature (T_{core}) also observed in order to evaluate thermoregulatory responses to SE and GXT. Eleven moderately to well-trained male athletes were volunteered for the study (age: 22.2 ± 3.7 years; body mass: 73.8 ± 6.9 kg; height: 181 ± 6.3 cm; body surface area 1.93 ± 0.1 m^2; body fat: 12.6% ± 4.2%; $\dot{V}O_{2max}$: 54 ± 9.9 mL min^{-1} kg^{-1}). Under stabilized environmental conditions in climatic chamber, GXT to volitional exhaustion and 20-min SE at 60% of VO_{2max} were performed on cycle ergometer. Thermal analyses were conducted in 2-min intervals throughout exercise tests. T_{skin} was monitored by a thermal camera, while T_{core} was recorded via an ingestible telemetric temperature sensor. Thermal kinetic analyses showed that T_{skin} gradually decreased till the 7.58 ± 1.03th minutes, and then initiated to increase till the end of SE (Rsqr = 0.97), while T_{skin} gradually decreased throughout the GXT (Rsqr = 0.89). Decrease in the level of T_{skin} during the GXT was significantly below from the SE [F (4, 40) = 2.67, $p = 0.07$, $\eta_p^2 = 0.211$]. In the meantime, T_{core} continuously increased throughout the SE and GXT ($p < 0.05$). Both GXT and SE were terminated at very close final T_{core} values (37.8 ± 0.3 °C and 38.0 ± 0.3 °C, respectively; $p > 0.05$). However, total heat energies were calculated as 261.5 kJ/m^2 and 416 kJ/m^2 for GXT and SE, respectively ($p < 0.05$). Thus, it seems that SE may be more advantageous than GXT in thermoregulation. In conclusion, T_{core} gradually increased throughout maximal and submaximal exercises as expected. T_{skin} curves patterns found to be associated amongst participants at both GXT and SE. Therefore, T_{skin} kinetics may ensure an important data for monitoring thermoregulation in exercise.

1. Introduction

Chemical energy is converted to mechanical energy approximately 20% depending on type of exercise and athletic status. Remaining part is released into the environment as heat. Thus, human body is not very efficient [1]. Air temperature, radiant temperature, relative humidity and air flow velocity are four main factors affecting the heat transfer mechanism of the human body [2]. Brain is a thermoregulatory centre of human body. Core temperature (T_{core}) can be smoothly raised in the range of 36–39 °C with motor activities and chemical reactions. T_{core} value greater than 39 °C is critical for human body [3,4]. For this reason, maintenance of T_{core} in optimal range is crucial for human thermal comfort. During exercise, the blood flow is directed to active skeletal

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muscles and myocard in order to supply their metabolic needs. When heat stress increases, warmed blood is passed to the skin for exchanging the heat thus causing an increment in skin temperature.[5]. During a prolonged exercise, heat loss is limited in an attempt to maintain venous return and cardiac output [6]. Therefore, it can be interpreted that the skin blood flow has a dominant role in thermoregulation, and thus athletic performance [5].

Contact thermistors have been widely used to evaluate T_{skin} by using different body parts [7]. However, these contact thermistors cause technical complications by preventing the heat loss from the skin. Moreover, the thermistors can analyse only a limited part of the surface on the body. In addition to using thermistors, thermal imaging is more advantageous for analysing skin temperature owing to its ability to analyse larger areas without contacting the skin [8,9]. In limited literature, the infrared thermography have been used to analyse T_{skin} by multiple plot analysis, averaging around hottest pixels area, averaging total body segment temperatures and averaging geometric areas with or without markers [10–17].

Jay et al. emphasized that T_{core} and sweating rate is not affected by fitness level while the same workload is used with participants having similar body surface area (BSA) [18]. If so, the total amount of heat exchange would be similar with the participants who have the same BSA.

The aim of this study was therefore to examine the changes in T_{skin} during graded maximal exercise test (GXT) and submaximal cycling exercise (SE) at 60% of maximal oxygen consumption level (VO_{2max}) in a homogeneous BSA cohort by using a thermal camera. It was hypothesized that (a) T_{skin} pattern in response to GXT differs from those of SE and (b) thermal kinetics of T_{skin} occurring in both SE and GXT are similar amongst participants with similar BSA.

2. Materials and methods

2.1. Participants

The study was designed according to the rules and the principals of the Helsinki Declaration protocol and was approved by the university ethics committee (EGE.ETK.2009.09-3/18). Written informed consent was obtained after explanation of the nature of the study and risks involved in participating in the experiment. 11 moderately to well-trained male cyclists, track and field athletes and soccer players volunteered to take part in the study (age: 22.2 ± 3.7 years; body mass: 73.8 ± 6.9 kg; height: 181 ± 6.3 cm; BSA: 1.93 ± 0.1 m^2; body fat: 12.6% ± 4.2%; $\dot{V}O_{2max}$: 54 ± 9.9 $mL\,min^{-1}\,kg^{-1}$). The participants were involved in 5.8 ± 2.3 training sessions per week. Their mean athletic experience was 9.9 ± 2.8 years. Study protocol was completed within the period of six-days after the end of the competition season to minimize training effects. The volunteers consumed approximately 300 mL of natural water 1 h before their experiments. In addition, the testing time of day was replicated to minimize any effect of circadian variance for each volunteer. Participants were requested not to take part in any exhaustive exercise during the course of the study. None of the participants suffered from any injuries or were under any specific medication. Volunteers were also asked not to exercise for 24-h prior to the experimentation. Since their anatomical differences may limit surface area subjected to thermography, female athletes did not take part in the study.

2.2. Experimental design

A cross-sectional study design was used for this controlled laboratory experiment. Before performance test, subjects visited laboratory to have their body mass and height measurements. Then, a familiarization session was conducted to adapt volunteers to experimental study. A series of pilot studies were conducted before main experiments. The purpose of the pilot studies was to find out T_{skin} variances of different body surfaces, to ensure which body regions were accurate to measure T_{skin}. After pilot studies, a submaximal graded exercise test was applied to evaluate workloads corresponding to their individual ventilatory threshold. After a 45-min rest, a GXT was performed to reveal their VO_{2max}. A subsequent day, constant-load SE was conducted at %60 of VO_{2max} level. During the GXT and SE, thermal images and core temperature data were taken by a thermal camera and an ingestible telemetric temperature sensor, respectively.

2.3. Procedures

2.3.1. Anthropometrics and physiological analyses

$\dot{V}O_2$ and CO_2 production ($\dot{V}CO_2$) were measured breath by breath by a Quark b^2 gas analyser (COSMED, Rome, Italy). Heart rate (HR) was measured continuously by an integrated part of the gas analyser and an external hearth rate monitor (Polar RS400; Polar Electro Oy, Kempele, Finland). Device calibrations were undertaken according to the manufacturer's instructions. The determination of body surface areas calculated by DuBois formula [19] and body fat percentage was calculated by using Jackson and Pollock 7-site equation [20]. Metabolic rate and DuBois body surface area were calculated by using (E.1) and (E.2), respectively [21]. Mechanical work values were subtracted from determined metabolic heat production values given in E.1. All procedures were performed using standard condition of 21.3 ± 0.4 °C temperature and 64.5 ± 2.5% relative humidity in a climatic chamber equipped with the ability to control the temperature and relative humidity, as well as having an integrated heat recovery system by fresh air supplement.

2.3.2. Thermal data analyses

T_{skin} measurements were carried out by infrared thermal camera (Testo 875-1 ThermaCAM, Germany). Participants rested in a seated position in the climatic chamber for a period of 15-min for stabilizing thermal balance before each tests [22]. Clothing was standardized at ~0.1 Clo (clothing insulation for shorts, socks and sports shoes; 1 Clo = 0.155 $K\,m^2/W$) in order to obtain the thermographic imaging from larger body surface. Since there is limited information about the norms of T_{skin} measurements in literature, a pilot study was organized to find out T_{skin} variances of body parts during vary exercise intensities. During pilot studies, monitored thermal image were analysed using an area consisted of at least two reference points. Each area was evaluated with 160 × 120 pixel resolution and <80 mK (0.08 °C) thermal sensitivity. Emissivity value was set at 0.98 [23]. Thermal images were analysed by using the same software of the thermal camera system. Thermal camera was relocated in every two minutes from 1.5 m front and then 1.5 m back of participants in both GXT and SE with 90° angles to obtain thermal image. Lines were drawn on front and back of upper arms and head by using two reference markers. In the sequel, average temperatures on the lines were received. On the other hand, since they have larger skin surfaces, oval and ellipse areas were drawn by using four references points on chest and back, respectively. For the chest, the first reference was placed on second costae of anterior medialis, second reference was placed on fourth costae of arteculatios sternocostalis, third reference was placed on sixth costae of anterior medialis, and fourth reference was placed on a contralateral point to form an oval area. For the back, the first reference was placed on T2 processus spinalis, second reference was placed on T6 processus spinalis, third and fourth references were placed on a horizontal line between right and left scapula on T4s′ when the participant's arm to 90 degrees forward flexion. In the sequel and then average temperature on