Infrared Physics & Technology 75 (2016) 180–186

Contents lists available at ScienceDirect

Infrared Physics & Technology

journal homepage: www.elsevier.com/locate/infrared

Definition of the thermographic regions of interest in cycling by using a factor analysis

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HIGHLIGHTS

- Factor analysis is a useful method to determine fewer number of large ROIs.
- Different ROIs groups were obtained depending on the skin temperature parameter.
- Differences between ROIs groups were related to their thermal characteristics.
- These findings could help future studies to define their ROIs.

ARTICLE INFO

Article history:
Received 12 November 2015
Available online 28 January 2016

Keywords:
Infrared thermography
Exercise
ROIs
Body
Principal components

ABSTRACT

Research in exercise physiology using infrared thermography has increased in the last years. However, the definition of the Regions of Interest (ROIs) varies strongly between studies. Therefore, the aim of this study was to use a factor analysis approach to define highly correlated groups of thermographic ROIs during a cycling test. Factor analyses were performed based on the moment of measurement and on the variation of skin temperatures as a result of the cycling exercise. 19 male participants cycled during 45 min at 50% of their individual peak power output with a cadence of 90 rpm. Infrared thermography was used to measure skin temperatures in sixteen ROIs of the trunk and lower limbs at three moments: before, immediately after and 10 min after the cycling test. Factor analyses were used to identify groups of ROIs based on the skin absolute temperatures at each moment of measurement as well as on skin temperature variations between moments. All the factor analyses performed for each moment and skin temperature variation explained more than the 80% of the variance. Different groups of ROIs were obtained when the analysis was based on the moment of measurement or on the effect of exercise on the skin temperature. Furthermore, some ROIs were grouped in the same way in both analyses (e.g. the ROIs of the trunk), whereas other regions (legs and their joints) were grouped differently in each analysis. Differences between groups of ROIs are related to their tissue composition, muscular activity and capacity of sweating. In conclusion, the resultant groups of ROIs were coherent and could help researchers to define the ROIs in future thermal studies.

1. Introduction

The use of infrared thermography as a technique to measure skin temperature during exercise has gained much attention in the research community in the last years. This increased interest can be observed when searching the keywords "thermography" and "exercise" in PubMed: while only 20 articles were published between 1990 and 2009, as many as 38 studies have been published in the last 5 years (2010–2015). Infrared thermography is becoming a popular technique since it

Abbreviations: ΔT, difference between temperature immediately after the cycling test and before; $\Delta T10$, difference between temperature 10 min after the cycling test and before; ΔTafter, difference between temperature 10 min after and immediately after the cycling test; A, abdomen; AA, anterior ankle; AB, abductor; AC, Achilles; BF, biceps femoris; C, chest; G, gastrocnemius; K, knee; LB, lower back; P, popliteus; POmax, peak power output; RF, rectus femoris; ROIs, Regions of Interest; SM, semitendinosus; TA, tibialis anterior; UB, upper back; VL, vastus lateralis; VM, vastus medialis.

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http://dx.doi.org/10.1016/j.infrared.2016.01.014
1350-4495/

is a safe, non-invasive, non-contact and cost-effective measurement system [10,12,15].

Although the number of studies using thermography in the field of sport physiology has increased, some methodological aspects remain unclear. One of the most controversial aspects is the definition of the Regions of Interest (ROIs) in the thermal images [12]. In this sense, *The Glamorgan Protocol* was published in 2008 and one of its main objectives was to standardize the ROIs for the thermographic studies [1]. However, researchers have developed their own criteria to define their ROIs, with different geometries and methodologies [12]. Depending on the purpose of research, some studies determine their ROIs from the analysis of a muscle or a muscle group [3,26,27], while other studies select specific body segments [7,23,25]. Furthermore, a recent study has observed higher temperatures in small compared to large ROIs after cycling, thereby showing that the determination of the ROIs influences strongly the results [28].

To address these issues, the identification of ROIs that are highly correlated could help researchers to decide how to select the ROIs. Depending on their thermal characteristics, a large number of ROIs can be grouped into a smaller number. Factor analysis could be used to group the ROIs according to their temperatures at different times of measurement. Moreover, if this analysis is performed on the temperature variations occurring as a result of physical exercise, it would enable researchers to observe the influence that exercise has on the temperatures of the different ROIs of the body. Therefore, the aims of this study were, by using a factor analysis, to determine the thermographic ROIs at different moments during cycling, as well as the effects that the cycling exercise has over these ROIs.

2. Material and methods

2.1. Participants

19 male cyclists were involved in the present study: age [29.5 ± 9.8 years], body mass [76.6 ± 9.2 kg], height [179.2 ± 6.6 cm], average cycling training volume [229 ± 150 km/week], peak power output (POmax) [274 ± 52 W]. They all gave their written informed consent before participation. The study procedures complied with the Declaration of Helsinki and were approved by the University's ethics committee.

Participants followed some instructions in order to control some of the factors affecting skin temperature. They were asked to (a) not smoke, drink alcohol, coffee, or another stimulant beverage at least 12 h before the test; (b) avoid sunbathing or being exposed to UV rays and refrain from using sunscreen; (c) avoid high-intensity or exhaustive exercise at least 24 h before the test; and (d) refrain from having heavy meals before the test.

2.2. Protocol

Each participant visited the laboratory for a preliminary session in order to determine their individual POmax. In this session, participants carried out an incremental cycling trial to exhaustion on a stationary cycle ergometer (Cardgirus Medical, Bikemarc, Sabadell, Spain). This test consisted of a 5-min warm-up at an initial workload of 50 W followed by workload increments of 25 W each minute until exhaustion [26]. The pedalling cadence was controlled at 90 ± 3 rpm, and exhaustion was defined as the moment when the cyclist was no longer able to maintain a pedalling cadence of 87 rpm. POmax was defined as the workload of the last stage completed.

One week later, cyclist came back to the laboratory to carry out the cycling tests. These tests consisted of a 3-min warm up at 50 W at 90 ± 2 rpm, followed by 45 min at 50% POmax at 90 ± 2 rpm while maintaining a specific cycling posture. This posture was controlled using a 2D motion analysis system (Kinescan, IBV, Valencia, Spain) and consisted of a maximum knee extension angle of 25–30°, the saddle placed horizontally as defined by the plummet method [32], a trunk flexion angle of 40–45° related to the transverse plane, and an arm extension angle of 75–90° related to the trunk. The 19 participants repeated the main session three times, resulting in a total of 57 main tests for analysis. Five of these sessions were discarded as participants did not follow the instructions given 24 h prior to the study. Sample size was determined before the experimental phase with the aim to obtain a ratio of 3:1 (cases/variables), which is a ratio commonly used in principal component analysis studies [9]. Furthermore, after finishing the experimental phase and analysing the data, the minimum value of 0.94 of Tucker's coefficient of congruence in the absolute temperatures corroborated that the sample size was adequate [31]. Temperature and relative humidity of the 52 remaining tests was 23.7 ± 1.4 °C and 45.1 ± 12.0%, respectively.

2.3. Thermographic measurements and analyses

Skin temperature was determined using an infrared thermography camera with infrared resolution of 320 × 240 pixels and thermal sensitivity <0.05 °C (FLIR E-60, Flir Systems Inc., Wilsonville, Oregon, USA). Prior to each cycling test, a black body (BX-500 IR Infrared Calibrator, CEM, Shenzhen, China) was used to ensure a correct calibration of the camera. Skin temperature was measured three times: (1) before the cycling test, after participants had adapted for 10 min to the laboratory room temperature [22]; (2) immediately after the cycling test; and (3) 10 min after the cycling test. The thermal images were taken by the same trained thermography technician (Level I thermographer accredited by the Infrared Training Center) while the participant was standing up wearing underpants. The camera was located 1 m away from the participant and the thermal images were taken perpendicular to the ROIs. The camera was turned on 10 min before each measurement in order to ensure the electronic stabilization of the camera. This time was determined as a result of a previous experiment, where the thermographic camera recorded water at constant temperature measured with a platinum thermometer. Since the camera measurements became stable after 5 min of turning on the camera, a 10-min stabilization period was allowed to ensure this process.

Different environmental conditions were controlled to ensure the proper acquisition of the thermal images: (a) thermal images were taken with the lights off; (b) only the thermography technician and the participant were in the measurement space; (c) no electronic equipment was located within a 5 m range of the measurement space; (d) an antireflective panel was placed behind the participant to avoid the effects from radiation reflected by the wall [18]; and (e) for all measurements, air temperature, relative humidity and reflected temperature were measured and were set in the camera settings.

Sixteen ROIs were defined (see ROIs in Fig. 1): chest (C), abdomen (A), upper back (UB), lower back (LB), vastus lateralis (VL), rectus femoris (RF), abductor (AB), vastus medialis (VM), biceps femoris (BF), semitendinosus (SM), knee (K), popliteus (P), tibialis anterior (TA), gastrocnemius (G), anterior ankle (AA), and Achilles (AC). The area of each ROI was consistent for all participants and it was defined and analysed by the same evaluator. Mean temperature of each ROI was obtained using a thermography software (Thermacam Researcher Pro 2.10 software, FLIR, Wilsonville,