Experimental Thermal and Fluid Science 77 (2016) 91–99

Contents lists available at ScienceDirect

Experimental Thermal and Fluid Science

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

Effects of the cycling workload on core and local skin temperatures

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A R T I C L E I N F O

Article history:
Received 26 January 2016
Received in revised form 6 April 2016
Accepted 7 April 2016
Available online 9 April 2016

Keywords:
Thermoregulation
Exercise
Intensity
Thermography

A B S T R A C T

Purpose: The aim of the study was to determine the influence of cycling workload on the variation of core and skin temperature of the different body regions, and the relationship between both temperature variables.
Method: Fourteen cyclists performed two 45-min cycling tests at 35% and 50% of peak power output on different days. The cadence was constant in both tests (90 rpm). Core temperature was measured continuously throughout the test and local skin temperature was recorded before, immediately after and 10 min after finishing the cycling test. Differences in variation of the core and skin temperature and in the effort perception and body mass loss due to different cycling workload were analyzed. Additionally, the relationship between core and skin temperature was assessed.
Results: Core temperature of the test at 50% was between 0.2 and 0.3 °C higher than at workload of 35%. The tibialis anterior region, the ankle anterior region and the Achilles region presented higher reductions in skin temperature due to exercise for test at 50% than 35%, and knee presented a lower increase ($p < 0.05$). Core and skin temperatures showed either weak or moderate inverse correlation for most of the body regions, but in others such as knee, ankle anterior and Achilles region, a positive weak relationship was observed.
Conclusions: The findings of the present study highlight the difficulty of linking skin temperature with cycling workload and core temperature due to the thermoregulatory system efficiency in the increase of the thermal gradient, alongside the multifactorial dependence of the skin temperature.

1. Introduction

An efficient thermoregulation activity is important in sports, especially during prolonged exercises, such as cycling, and in hot environments [33,24]. A high thermal stress limits performance and may increase the risk of heat exhaustion and heat stroke during cycling [33]. Furthermore, high core temperatures (~40 °C) are associated with fatigue and performance impairment [26,34].

In this regard, core temperature measurements during exercise allow us to assess internal thermal state with the aim to reduce the risk of thermal stress, heat exhaustion and heat stroke [34,6]. At rest, core temperature presents small variation, whilst during physical exercise, core temperature increases due to the higher metabolic activity and convective heat transfer in the bloodstream from the exercising limbs [25,24]. Such increases in core temperature is moderated by cutaneous vasodilation and sweating [20,22]. However, core temperature requires an invasive method, which usually presents practical limitations during sports activities.

Thermal balance between the human body and the environment has been studied through assessment of skin temperature [32,21]. During the initial stage of the exercise, skin temperature usually decreases due to the cutaneous vasoconstrictor response

Abbreviations: ΔT, difference between temperature immediately after and before the cycling test, expressed in °C; $\Delta T10$, difference between temperature 10 min after and before the cycling test, expressed in °C; ΔTafter, difference between temperature 10 min after and immediately after the cycling test, expressed in °C; POmax, peak power output; ROI, region of interest; RPE, Rating of Perceived Exertion.

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http://dx.doi.org/10.1016/j.expthermflusci.2016.04.008
0894-1777/

to exercise [47,44,45]. After that, the skin temperature at specific regions of the body may primarily increase when blood flow drifts from internal tissues to the skin surface for dissipating extra core and muscles located underneath heat production due to an increased metabolic activity [40,29]. On the other hand, in moderate environments skin temperature decreases due to convective and radiated heat loss [10]. However, sweat evaporation represents the main mechanism to reduce skin temperature during exercise [10,42]. Therefore, skin temperature in each region of the body results from the thermal balance between muscle activity, vasodilation and sweat evaporation rate [48,42,24].

During the last years, skin temperature monitoring with infrared thermography have gained attention in running and cycling for analyzing the effect of exercise [32,9,37,45]. In cycling, exercise workload produces greater power output [18] with higher muscle activation [31] resulting in an increased core temperature [16]. However, it is unclear how it affects skin temperature. A recent study showed that during incremental cycling exercise, some muscles showed an increment in the skin temperature (e.g., regions of the rectus femoris and vastus lateralis), whereas other regions temperature remained unchanged (e.g., regions of the biceps femoris and gastrocnemius medialis) [37]. Although the incremental maximal test performed in this study allowed some results in skin temperature during cycling, research about constant workloads is required. Research about how workload affects skin temperature in each body region is necessary to determine the potential use of the infrared thermography camera in the training assessment.

Due to the lack of information about how cycling workload affects the skin temperature of each body region and the relationship between core and skin temperature, the aim of the present study was therefore to determine the influence of cycling exercise on core and skin temperature at seventeen different specific body regions when exercising at two different intensities, and the relationship between both temperatures.

2. Material and methods

2.1. Participants

Fourteen cyclists, categorized as club level following criteria defined by Ansley and Cangley [3], participated in the study (mean ± standard-deviation age 29.9 ± 8.3 years, body mass 72.8 ± 10.6 kg, height 1.75 ± 0.08 m, average cycling training 162 ± 77 km/week, peak power output 281.7 ± 38.3 W, and power-mass ratio of 3.83 ± 0.67 W/kg). All participants signed an Informed Consent Term in agreement with the Committee of Ethics in Research with Humans, and in agreement with the Declaration of Helsinki.

To ensure similar conditions for skin temperature measurements, all participants were requested to refrain from drinking alcohol, coffee or other stimulants or smoking at least 12 h before the test. They were asked to refrain from sunbathing, to avoid exposure to UV rays and not to wear any jewelry or use sunscreen/sun blockers. They were recommended to eat at least two hours before the test and avoiding heavy meals. Finally, they should avoid high-intensity or exhaustive exercise at least 24 h before the laboratory trials.

2.2. Protocol

Participants completed one pre-test and two main tests with different workloads of 35% and 50% peak power output (POmax) on different days on a stationary cycle ergometer with electromagnetic brake (Cardgirus Medical, Bikemarc, Sabadell, Spain). The pre-test aimed at determining the cycling posture and the POmax. Cycling posture was determined for each participant using a sagittal plane kinematic 2D model by Kinescan/IBV system (IBV, Valencia, Spain) and a high-definition video camera (Sony Handycam HDR-FX1, Sony Corp., Tokyo, Japan) with a sampling rate of 50 Hz. Reflective markers were attached to the lateral malleolus, the lateral femoral condyle, the greater trochanter of the left lower limb, the left acromion and the olecranon tuberosity. The posture was defined by knee flexion angle between 25° and 30° when the pedal crank was at 180°, horizontal saddle position defined by the plummet method, trunk flexion between 40° and 45°, and elbow extension between 75° and 90°. POmax was determined by an incremental cycling test. It consisted of a 5-min warm-up stage at initial workload of 50 W followed by increments of 25 W every 1-min until exhaustion [8]. Pedaling cadence was controlled at 90 ± 3 rpm by visual feedback from cycle ergometer head unit. Exhaustion was defined as the moment when cyclists were no longer capable of maintaining the requested pedaling frequency. POmax was defined by the workload of the last stage completed.

The two main tests were performed on different days separated by one week. In these tests, participants warmed up during 3 min at 50 W before cycling for 45 min at 50% or 35% POmax with pedaling cadence 90 ± 3 rpm at the cycling posture determined in the pre-test. Cycling workloads (35% and 50% of the POmax) were randomized. Average cycling workload was 98.6 ± 14.0 W and 140.8 ± 19.8 W for 35% and 50% POmax test, respectively. Environmental conditions during the tests were 21.8 ± 0.7 °C and 39.4 ± 4.5% for 35% POmax test and 21.2 ± 0.8 °C ambient temperature and 39.0 ± 4.9% relative humidity for 50% POmax test (no statistically significant differences in room environmental conditions between both tests). Participants were wearing their own cycling short pants and cycling shoes (same in the both tests) while upper body was undressed. Drinking during the test was not allowed for the participants as this could influence the core and skin temperature. Core temperature was measured continuously throughout the test by using an ingestible thermometer. Skin temperature was determined before and after exercise by recording thermography images. Effort perception was measured using 20-point Borg RPE scale [4] one minute before finishing exercise. Whole body sweat rate was estimated with the changes in body mass between before and after cycling test and their values were reported in milligrams per square centimetre per minute ($mg\,cm^{-2}\,min^{-1}$). Body mass was measured before cycling and at the end of the cooling down phase using a digital scale (Edge YB02, Tecnovita by BH, Vitoria-Gasteiz, Spain) and body surface area was calculated with the height and body mass of the participant with the Du Bois and Du Bois formula [17]. Participants were not towelled down prior to body mass measurements in order to ensure that mass changes better reflected the quantity of sweat that evaporated [13].

2.3. Core temperature

Core temperature was registered at intestine-site using a core body thermometer enclosed in an ingestible pill (CorTemp, HQ Inc., Palmetto, Florida, USA) that transmits a continuous low-frequency radio wave signal in which wavelength varies according to the temperature to an external data logger. Participants ingested the pill between 6 and 8 h before coming to the laboratory, to ensure the pill would be located at the intestine during the cycling test.

Absolute core temperature values were recorded every 10 s and averaged for each minute during the test. Similarly as observed in previous studies [30,46], at the beginning of exercise, most of the participants responded with a latency period of approximately 5 min consisting of an initial slight decrease in the core temperature after which, it started to increase. With the aim of properly