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Relationship between skin temperature and muscle activation during incremental cycle exercise

Jose I. Priego Quesada [a,b,c,*], Felipe P. Carpes [c], Rodrigo R. Bini [d], Rosario Salvador Palmer [a], Pedro Pérez-Soriano [b], Rosa Mª Cibrián Ortiz de Anda [a]

[a] Biophysics and Medical Physics Group, Department of Physiology. Faculty of Medicine and Dentistry, University of Valencia, Valencia, Spain
[b] Research Group in Sport Biomechanics (GIBD), Department of Physical Education and Sports, University of Valencia, Valencia, Spain
[c] Applied Neuromechanics Group, Laboratory of Neuromechanics, Federal University of Pampa, Uruguaiana, RS, Brazil
[d] School of Physical Education of the Army, Brazilian Army Center for Physical Training, Rio de Janeiro, RJ, Brazil

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ABSTRACT

While different studies showed that better fitness level adds to the efficiency of the thermoregulatory system, the relationship between muscular effort and skin temperature is still unknown. Therefore, the present study assessed the relationship between neuromuscular activation and skin temperature during cycle exercise. Ten physically active participants performed an incremental workload cycling test to exhaustion while neuromuscular activations were recorded (via surface electromyography – EMG) from rectus femoris, vastus lateralis, biceps femoris and gastrocnemius medialis. Thermographic images were recorded before, immediately after and 10 min after finishing the cycling test, at four body regions of interest corresponding to the muscles where neuromuscular activations were monitored. Frequency band analysis was conducted to assess spectral properties of EMG signals in order to infer on priority in recruitment of motor units. Significant inverse relationship between changes in skin temperature and changes in overall neuromuscular activation for vastus lateralis was observed ($r < -0.5$ and $p < 0.04$). Significant positive relationship was observed between skin temperature and low frequency components of neuromuscular activation from vastus lateralis ($r > 0.7$ and $p < 0.01$). Participants with larger overall activation and reduced low frequency component for vastus lateralis activation presented a better adaptive response of their thermoregulatory system by showing fewer changes in skin temperature after incremental cycling test.

1. Introduction

When performing physical exercise, metabolic rate increases to satisfy the needs of the human body (Maughan, 2012; Merla et al., 2010). Approximately 30–70% of the energy produced during muscle contraction is dissipated as heat (Krustrup et al., 2003). Thermoregulation aims to reduce excessive heat from internal organs (Sherwood, 2011), permitting to sustain exercise longer (Tucker et al., 2004) and to minimize risks of medical problems (Nybo, 2010). Skin temperature varies depending on the heat exchange between the body and the environment, primarily mediated by enhanced transportation of blood to the skin surface (Taylor, 2000).

Skin temperature during exercise could be related to muscular work, which reflects the efficiency in dissipating the heat produced and in turn depends on activity of circulatory system recruiting level and sweating rate (Akimov et al., 2010; Chudecka and Lubkowska, 2010; Xu et al., 2013). A significant reduction in skin temperature is observed during or after an incremental workload or intense workload exercise (Chudecka and Lubkowska, 2010; Ferreira et al., 2008; Merla et al., 2010; Torii et al., 1992; Zontak et al., 1998), which can be related to sweat evaporation for heat dissipation during exercise (Chudecka and Lubkowska, 2010; Havenith, 2001).

Abbreviations: ΔT, Temperature variation 1. Difference between temperature (°C) before and immediately after the cycling test; ΔT_{10}, Temperature variation 2. Difference between temperature (°C) before and 10 min after the cycling test; ΔT_{after}, Temperature variation 3. Difference between temperature (°C) immediately after and 10 min after the cycling test; ΔHigh, Variation (90–10% of the total time of test) of the high frequency band of the muscle activation; ΔLow, Variation (90–10% of the total time of test) of the low frequency band of the muscle activation; ΔOverall, Variation (90–10% of the total time of test) of the overall muscle activation; BF, Biceps femoris; GM, Gastrocnemius medialis; RF, Rectus femoris; VL, Vastus lateralis

* Correspondence author at: GIBD. Facultat de Ciències de l'Activitat Física i l'Esport. C/ Gascó Oliag, 3. 46010. Valencia, Spain. Fax: +34 96 3864353.
E-mail address: j.priego.gibd@gmail.com (J.I. Priego Quesada).

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Differences in the kinetics of skin temperature during exercise were observed between trained and untrained subjects (Abate et al., 2013; Formenti et al., 2013), as well as a correlation between skin temperature and aerobic capacity was suggested (Akimov et al., 2009; Chudecka and Lubkowska, 2012, 2010). Recently it has been observed a reduced relationship between core and skin temperatures during exercise due to the effect of the evaporation of sweat (Xu et al., 2013). However, the relationship between muscular effort and skin temperature is still unknown.

Infrared thermography is a safe and non-invasive technique to record infrared radiation, which permits to estimate temperature from volume surfaces (Akimov et al., 2010; Hildebrandt et al., 2012). Recently, infrared thermography became more popular in exercise physiology to infer on heat production and dissipation (Abate et al., 2013; Akimov and Son'kin, 2011; De Andrade Fernandes et al., 2014; Formenti et al., 2013; Fournet et al., 2013). Nevertheless, some methodological aspects about the use of infrared thermography are still unclear. For example, it was suggested that sweat could affect emissivity of the skin (James et al., 2014). However, a water surface presents values as high as the skin (Niclòs et al., 2005) and a low potential for changes in skin surface emissivity could be expected as result of a wet skin. Ammer (2003) indicated that a water film covering the skin may be a filter for infrared radiation and could affect infrared measures. However, any study has shown the magnitude of the effect of sweat on skin emissivity when no water layers are allowed to form on the surface.

Surface electromyography (EMG) permits to estimate the magnitude of electrical neuromuscular activity during exercise (Blake and Wakeling, 2013; De Luca, 1997). A link between muscle activation and skin temperature could be valuable to ascertain on the efficiency of thermoregulatory system to dissipate muscle heat production. In this issue, only one study observed an inverse relationship between biceps brachii activation and skin temperature during fatigue isometric contractions (Bartuzi et al., 2012). Along these lines, an increase in temperature of biceps brachii during loading was associated to a decrease in median power frequency of the EMG signal, suggesting increased muscle fatigue (Bartuzi et al., 2012). Therefore, it is unclear if subjects performing aerobic exercise (rather than isometric contractions) with larger neuromuscular activation could optimally dissipate heat.

The present study assessed the relationship between neuromuscular activation (measured using surface electromyography) and skin temperature (measured using infrared thermography) during cycling exercise. It was hypothesized that participants showing larger increases in neuromuscular activation during an incremented load exercise should present lower increases in skin temperature, which could highlight a better adaptive response of their thermoregulatory system (i.e. better heat dissipation). Along with that, this study aimed at detecting if individual muscles or body regions of interest could better represent the association between changes in EMG and surface temperature during aerobic exercise.

2. Material and methods

2.1. Participants

Ten physically active participants volunteered to participate in this study. Sample size was defined using the model of Hopkins (2002) (change in mean in a crossover study) looking for effect sizes greater than 0.8. All participants signed an Informed Consent Term in agreement with the local Committee of Ethics in Research with Humans (approval number *H13843445155519*), and in agreement with the Declaration of Helsinki. They were asked to avoid high-intensity or exhaustive exercise at least 24 h before the laboratory trials. The mean and standard-deviation values for age, body mass, height, and peak power output of the participants were: 25 ± 4.0 years, 77 ± 8.9 kg, 177 ± 6.1 cm, and 252 ± 36 W, respectively. All participants presented right footedness according to Waterloo inventory (Elias et al., 1998). To ensure similar conditions to measure skin temperature, all participants were informed that they should not have drinking alcohol or smoke at least 12 h before the test, as well as avoiding drinking coffee or other stimulants before the test, refrain from taking sunbathe or being exposed to UV rays, refraining from using sunscreen/sun blockers, avoid wearing any jewelry, eat at least two hours before the test and refrain from having heavy meals.

2.2. Testing

When the participants arrived to the laboratory, skinfolds were measured using a caliper (Innovare–Cescorf, Cescorf, Porto Alegre, Brazil) at two locations (anterior thigh and mid-calf) following ISAK protocols (Stewart et al., 2011). Afterwards, participants underwent an incremental cycling test to exhaustion using a stationary cycle ergometer (CG4, Inbrasport Co., Porto Alegre, Brazil). The incremental cycling test started with initial workload of 50 W during 3 min and was followed by increments of 25 W/min until exhaustion as described elsewhere (Carpes et al., 2011). Pedaling cadence was controlled at 90 ± 3 rpm by visual feedback from cycle ergometer head unit. Exhaustion was defined when the participant was no longer capable of maintaining pedaling cadence of 87 rpm. Peak power output was defined as the workload of the last completed stage. All participants performed the test with a similar position on the bike, having a maximum knee extension during cycling between 25° and 30°, horizontal saddle position defined by the plummet method (Zani, 2010), flexion of the trunk in relation with the transverse plane of about 55°, and an arm extension in relation to the trunk, defined by an angle between 75° and 90°.

2.3. Thermography data collection and analysis

Three thermographic measurements from the front and back surfaces of each participant's legs were acquired while they were in a standing upright resting position (Chudecka and Lubkowska, 2010), (1) before the cycling test [after resting for 10 min in a room temperature between 18° and 26 °C (Ammer, 2008; Marins et al., 2014)], (2) immediately after the cycling test and (3) 10 min after finishing the cycling test. Environmental conditions during the tests were 19.5 ± 1.3 °C and 62.9 ± 3.2% relative humidity during all trials.

All thermographic images were recorded digitally by a thermography camera with an infrared resolution of 320×240 pixels, thermal sensitivity < 0.05 °C, and accuracy of ± 2 °C (FLIR E60, FLIR, Wilsonville, Oregon, USA). A black body (BX-500 IR Infrared Calibrator, CEM, Shenzhen, China) was used before the study to ensure a correct calibration of the camera. The camera was positioned 1 m far from the subjects and kept perpendicular to body areas of interest. Images were recorded in a controlled environment (e.g. light and temperature controlled room) with no person (apart from the infrared operator and the participant) or equipment in a range of 5 m that could disturbed in the measure. An anti-reflective panel was used behind the participant to minimize effects from infrared radiation reflected by the participant in the wall (Hildebrandt et al., 2012). Images were stored for offline analysis using a commercial software (Thermacam Researcher Pro 2.10 software, FLIR, Wilsonville, Oregon, USA). All images were processed using an emissivity factor of 0.98 to obtain skin temperatures, and for all measures, air temperature, humidity and reflected temperature were informed in the camera setup using a weather station (Digital thermo-hygrometer, TFA Dostmann, Wertheim-Reicholzheim, Germany).

Skin temperature was monitored at four body regions of interest corresponding to the muscles where EMG activity was