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Is it possible to create a thermal model of warm-up? Monitoring of the training process in athletic decathlon

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HIGHLIGHTS

- The use of thermography is an effective tool in verification of efficiency of warm-up.
- Thermal response for physical effort is highly individualised.
- Typical thermal response to the exertion is a fall of T_{sk}.
- High level competitors have better thermal capacity to react to thermal stress to lose excess heat.

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ABSTRACT

The aim of the present study was to define if the athletes may vary their warm-up according to the specific demands of event they are preparing for and that higher-level athletes may differ in their thermal responses than lower-level athletes. Ten top level Polish male decathletes (19.9 ± 3.0 yr, 187.9 ± 4.7 cm, 82.7 ± 6.7 kg) who participated in the study were examined with a thermographic camera. Thermal imaging of each athlete was undertaken three times: at rest before the warm-up began, immediately after the general warm-up, and immediately after the specific warm-up.

As significant changes in skin surface temperatures were observed between rest and both general and specific warm-ups ($p < 0.001$) it seems that athletes are able to vary their warm-up according to the decathlon event. Moving from rest to the general warm-up was characterized by decrease of the body surface temperature within the decathletes as a cohort. Interestingly, correlation was found between decathlon result measured by points and decrease of temperatures after commencing the general or specific warm-up exercises ($r = 0.62$; $p < 0.05$). However, the higher-performing competitors were characterized by a higher variability of skin temperatures depending on the event being prepared for.

The present findings suggest that in sporting competitions characterized by the need for specificity of warm-up of different muscular segments, thermal imaging can be useful observe thermoregulatory responses. Due to these observed individual thermal reactions to the physical effort of warm-up, the present findings suggest it is possible to individually adapt the warm-up to the needs of both the event being prepared for and the level of athlete.

1. Introduction

The decathlon consists of 10 separate track and field events completed in sequence over two consecutive days. Apart from the complexities of the organization of training and technique development, an equally important challenge for both the athlete and coach is the structure of the competition warm-up given the different movement patterns and energetics of each event [1–3]. For example, the decathlon begins with the 100 m sprint run before which competitors typically warm-up for between 40 and 60 min. This warm-up needs to also contain elements which are specific for the rest of the competition because the preparation

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for the next event starts immediately following the previous event [1–3].

The warm-up is an important element of athlete preparation for an intense bout of exercise for a number of reasons [4]. Firstly, one of the major goals of a warm-up is to increase the temperature of the blood and consequently the core body temperature. Secondly, the increased core temperature and increased blood supply to the specific muscles used in the warm-up enhances the excitability and efficiency of muscles, leading to enhanced subsequent performance. Thirdly, the increased muscle temperature of the specific muscles also improves the elasticity of muscles and increases the range of motion around the joints used in the warm-up. Finally, warmed-up muscles are less susceptible to injuries [4].

During an effective warm-up there is an increase in energy metabolism of the muscles engaged in the exercise. The conversion of this energy metabolism to work is comparatively small (∼20–25%) with approximately 75% of the metabolic energy released as heat [5]. During exercise a muscle's temperature increases from a resting value of 37 °C to 38–42 °C depending on the ambient environmental conditions, duration and intensity of the warm-up exercise being undertaken [6].

Accompanying increases in muscle and core body temperature are changes in skin temperatures due to blood redistribution to the skin to offload excess core body heat [7–9]. Although there are differences between the core temperature and skin temperature, changes of the internal core temperature are inversely correlated with changes in skin temperature. Raise of internal and lowering of skin temperature at the same time can be observed [10,11].

Both at rest and during exercise, the human thermoregulatory system attempts to maintain thermal balance by generating or losing heat in cold or hot ambient conditions, respectively [9]. However, an individuals reaction to any bout of given exercise differs [7,8]. For example, the thermoregulatory response of well-trained trained athletes is significantly greater than in untrained individuals [12].

Regardless of the individual response to any particular bout of exercise, changes in skin temperature are commonly observed to offload generated heat from muscular activity [13]. Thus, the monitoring of skin temperature is seen as a valid method to monitor the body's thermal response to exercise and efficiency of an individual's thermoregulation ability [14–16] as well as effectiveness of post-exercise recovery [10,17].

Over recent years, observing thermoregulatory responses by means of thermal imaging of the body have been used to both evaluate the level of physical fitness [18] and the effectiveness of a warm-up in a number of sports [19–21]. However, there is a need to undertake further studies using thermal imaging in order to provide feedback to athletes, coaches and sport scientists as to the effectiveness of warm-up specific sport disciplines [21]. Thus, the aim of the present study was to characterize track and field athletes' thermal imaging portrait following warm-up for the various track and field events in decathlon. We hypothesised that athletes may vary their warm-up according to the specific demands of event they are preparing for and that higher-level athletes may differ in their thermal responses than lower-level athletes.

2. Material and methods

2.1. Participants

Ten male national level decathletes (19.9 ± 3.0 yr; 82.7 ± 6.7 kg; 187.9 ± 4.7 cm) took part in the study. The competitors were of diverse training duration in decathlon with training age varying from 2 to 9 years ($\bar{x}$=4.4 ± 2.6). For further analysis athlete's were divided into two subgroups according to their sport level. In "Elite" subgroup were five athlete's with personal best result in decathlon above 6700 points. Those with result below 6700 points were referred to "National" subgroup. Subjects were instructed to avoid consuming alcohol and any energizing supplements (e.g. caffeine). Care was taken to ensure 24 h interval between training sessions where measurements were undertaken.

2.2. Methods

A thermal imaging camera (FLIR A325, FLIR Systems, Sweden) was used for all measures. The camera has a measurement range from −20 to +350 °C, an accuracy of ±2 °C or ±2%, a sensitivity below 0.05 °C, an infrared spectral band 7.5–13 μm, a refresh rate of 60 Hz; and a resolution of 320–240 pixels Focal Plane Array.

Each subject was thermal imaged three times: at rest before warm-up following adaptation to ambient temperature, immediately following the general warm-up, and immediately following the specific warm-up.

Thermograms were taken for each subject while standing on both the front and back of the body. With each recorded thermograms we subsequently analysed the skin temperature (T_{sk}) in five body regions of interest (ROI's) in anterior and posterior view: calf, thigh, trunk, arm, and forearm. Scanning of the temperature on the forepart of lower limbs was done from the end of the clavicle (directed to the sternum) to the ankles, while on the back surface from the spinous process (C_7) to ankles (Fig. 1). These landmarks were marked with markers to ensure the analysis used the same surface for each thermogram. The mean (T_{sk} °C) from the examined ROI's was used for subsequent statistical analyses.

As recommended for thermovision testing in biomedical sciences [22,23], the temperature of the laboratory where the thermal imaging took place was 22 °C ± 0.5 °C, while the relative humidity 50% ± 4.1%. The thermal imaging took place three times for each athlete. The first measurement was taken at resting state following 10-min of adaptation to the ambient conditions in the indoor track and adjacent laboratory where the thermal imaging took place. The second measurement was performed directly after the general warm-up (GWU) and the third measurement immediately after the specific warm-up (SWU). GWU was undertaken before each event after which each athlete then completed their individual SWU. Because there were no significant differences between body temperature after adaptation to ambient temperature and in GWU on consecutive days, mean values from four measurements were calculated. Further measures were then carried out for the following activities:

- general warm-up (GWU),
- 60 m run specific warm-up (SPRINT),
- 60 m hurdles run specific warm-up (HURDLES),
- long jump specific warm-up (LJ),
- high jump specific warm-up (HJ),
- pole vault specific warm-up (PV),
- shot-put specific warm-up (SP).

Due to conducting research at indoor condition we excluded some decathlon events normally played during decathlon (e.g. long throws, 1500 m run). For 100 and 400 m run we took sprinting 60 warm-up as representative.

In accordance with the manufacturer's instructions, care was taken to ensure that the thermal imaging camera was perpendicular to the scanned surface and the distance between the camera and the subject set at 3 m to allowed for diminution of movement artefacts associated with respiration but to also capture the whole analysed body surface. In the analysis of individual thermal reactions, mean temperatures for the whole body were used. The