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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.

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.

Key words: thermography; decathlon; warm-up; thermal portrait
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, 2, 3]. For example, the decathlon begins with the 100m sprint run before which competitors typically warm-up for between 40 to 60 minutes. This warm-up needs to also contain elements which are specific for the rest of the competition because the preparation for the next event starts immediately following the previous event [1, 2, 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, 8, 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 individual’s 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, 15, 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, 20, 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 (\( \bar{x} = 4.4 \pm 2.6 \)). 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 60Hz; 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 (Tsk) 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 paracentrical clavicle (directed to the sternum) to the ankles, while on the back surface from the spinous process (C7) to ankles (Figure 1). These landmarks were marked with markers to ensure the analysis used the same surface for each thermogram. The mean (Tsk °C) from the examined ROI’s was used for subsequent statistical analyses.

Figure 1. Front and back infrared thermograms of athlete and the location of the measured ROI’s taken to mean temperature analysis.

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-minutes 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 analysing was done with the use of Researcher 2.9 Pro software designed for use with the thermal camera.

2.3. Statistical analysis

Descriptive statistics (\( \bar{x} \pm SD \)) were determined for each of the variables of interest. Changes in skin temperatures between skin temperatures at rest, following the GWU, and the SWU were analysed using one-way analysis of variances (ANOVA). If effects were observed, post-hoc analysis was undertaken using the Tukey’s honest significant difference test. Student
t-test has been done to examine $T_{sk}$ differences between subgroups. Dependences between the sports-level (the result in decathlon) of competitors and the changes of temperature were qualified by means of Pearson correlation coefficient. A $p$ value of $\leq 0.05$ was accepted as significant. Statistical analyses were conducted using STATISTICA for Windows XP – StatSoft, Inc. (2009) version 9.0.

3. Results

Analysis showed changes in global average temperatures between resting state and following measurements. Undertaking GWU caused significant ($p<0.001$) lowering of surface temperature by -1.1°C in Elite and -0.6°C in National subgroup, but there was no significant difference between subgroups ($p=0.16$) in that parameter. Subsequent exercise (SWU) showed further, crossed one Celsius degree, decrease of $T_{sk}$ in both subgroups (tab. 1). Differentiation between thermal reactions in Elite and National subgroups was observed only in HURDLES and LJ, but close to significant values were also noted in SPRINT and PV. Significant differences ($p=0.03$) also noticeable when analysing mean values of $T_{sk}$ changes after undertaking physical effort for all kind of activities (-1.8°C for Elite and -1.1°C for National subgroup).

Table 1. Skin temperature [$^\circ$C] changes ($\Delta T_{sk}$) following specific event warm-up (SWU) in relation to temperature after general warm-up (GWU)

<table>
<thead>
<tr>
<th>$\Delta T_{sk}$</th>
<th>SPRINT</th>
<th>HURDLES</th>
<th>LJ</th>
<th>HJ</th>
<th>PV</th>
<th>SP</th>
</tr>
</thead>
<tbody>
<tr>
<td>GWU vs SWU</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite</td>
<td>-1.7 ±1.1</td>
<td>-2.4 ±0.9</td>
<td>-2.1 ±1.2</td>
<td>-1.8 ±0.5</td>
<td>-1.6 ±0.6</td>
<td>-1.8 ±0.6</td>
</tr>
<tr>
<td>National</td>
<td>-0.9 ±0.8</td>
<td>-0.7 ±0.8</td>
<td>-0.9 ±0.8</td>
<td>-2.2 ±0.6</td>
<td>-1.8 ±0.6</td>
<td>-1.2 ±1.2</td>
</tr>
<tr>
<td>Difference</td>
<td>0.09</td>
<td>0.008</td>
<td>0.05</td>
<td>0.50</td>
<td>0.08</td>
<td>0.18</td>
</tr>
</tbody>
</table>

Considering the kinds of warm-up, the most homogeneous (i.e. lowest standard deviation) temperature change was obtained after the preparation for the SP.

Correlation analysis proved statistically essential dependence between the sports-level and the thermal reaction on the exercise ($r= -0.62$). The higher result in connected track and
field event was, the greater drop in temperatures after activity. Athletes with higher decathlon result seems to be characterized with the higher variability of temperatures depending on the activity (No. 1 & No. 5 – fig. 2).

The specific high jump warm-up (HJ) proved the only kind of activity which caused similar reaction of the organism expressed with the fall of skin temperature in all examined subjects (fig. 2).

![Graph](image)

Fig.2. Individual changes in Tsk from rest to post-GWU and post-SWU of different events.

4. Discussion

The aim of the this study was to observe thermal adaptations for exercise of track and field athletes, in order to verify possibility of differ their warm-up for the various track and field events in decathlon and if there are important differences in thermal reactions depending on sports level of competitors. The findings suggest that the thermal responses to warm-up are highly individual and dependent on the subsequent event that the warm-up is being used to prepare for. Moreover, it appears that the higher the level of the athlete, the more likely they are to benefit from an event-specific warm-up.

However we know that during exercise internal temperature is rising, interestingly, the present results suggest skin temperature dropped after both GWU and SWU exercise. The explanation is therefore, the fact that the loss of warmth by the working muscle takes place
mostly as the result of transpiration and further evaporation of sweat from the skin surface. Other important mechanism in $T_{sk}$ drop is convection [10]. The more dynamic form of exercises we use, the higher fall of temperature we can expect [18, 24, 25]. The fact that not all competitors could lower the temperature of the body surface under the influence of every kind of the exercise, can be explained by the fact that the training causes the increase of thermoregulation efficiency, but doesn’t have result in causing the improvement of general or local improvement of heat transfer abilities [26].

Using thermovision, Adamczyk et al. [25] observed a relationship between the surface temperature of quadriceps and the height of a vertical jump, suggesting relationship between performance and $T_{sk}$. This finding supports previous thermovision research by, Ding et al. [27] who observed that thermographic diagnostics allow the estimation of metabolic reactions occurring in working muscles. Strong and statistically essential dependence between the maximum intake of oxygen ($VO_{2\text{max}}$) and the decrease of skin temperature, suggests that the thermography can be an interesting supplement of qualifying methods used to determine the efficiency of thermoregulatory mechanisms, intensity of the exercise and the efficiency of restitution [19, 28, 29]. The current results support this suggestion as a result of the more highly-ranked finishers in the present study were characterized by greater decreases of skin temperature. It means that high level competitors should have better thermal capacity which means possibility to lowering $T_{sk}$ during exercise to react to thermal stress to lose excess heat [30].

As observed by the size of the standard deviations in table 1, individual thermal responses of the decathletes to each type of exercise and type of warm-up were very diverse. Highest observed individual differences referred to long jump, where the difference in the thermal reaction between the examined persons (No. 1 vs No. 8 – fig. 2) exceeded 4.5°C. With the exception of one person, taking up the physical effort (GWU) caused the reduction of $T_{sk}$. Reactions of temperature rise were however rare. Six decathletes, independently from the kind of activity, reacted with the temperature fall (fig. 2).

The current finding of a large individual variation in skin temperature increases following both the GWU and specific WU, suggest the need for individual optimization of event preparation to maximize the subsequent performance and minimize the risk of injury [1]. This finding may have significance for team sports where coaches are often limited by organizational limitations with every athlete in the team often doing the same warm-up prior to competition [2]. The current results suggest the need for individual or position-specific warm-up may need to be undertaken to maximise subsequent competitive performance.
In summary, the present results suggest thermal imaging using a thermovision camera might enable the development of an individual athlete’s thermal profile following warm-up before an event in three ways [29, 31]. Firstly, thermography provides an athlete, coach and/or sport scientist with information to specifically target body segments needed to be warmed-up prior to the start of an event. Secondly, creating a thermal portrait for individual athletes prior to a specific event might enable an athlete, coach, and/or sport scientist to know whether the competitor is adequately prepared for that specific event, or if there are some muscle groups which need increased volume or intensity of warm-up [1]. Thus, the use of thermal imaging can assist in deciding what modifications may be required for the warm-up in order to meet the specific demands of that event and thus help optimize subsequent performance. Finally, thermal imaging may allow athletes, coaches and/or sport scientists to explore different methods of warm-up and thus assist in choosing the most effective warm-up for that individual athlete [17, 28, 29, 31].

The present study was based on the foundation that results of thermal imaging validly measure the metabolic reactions which occur in exercising muscles (Ding et al., 2001). Based on this premise, the present findings can help inform athletes, coaches and sport scientists about the warm-up preparation for events associated with the decathlon.

5. Conclusions
In decathlon events characterized by the need for specificity of warm-up prior different specific events, the present results suggest the thermal response to warm-up is both specific to the nature of the warm-up and highly individualised. Moreover, the present findings suggest that thermography can be a valuable method of monitoring sports-training in individual athletes. However, further research is warranted with larger samples and among athletes of different performance levels in order to evaluate the value of thermal imaging in monitoring athletic training.

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7. References:


