AI-supported Thermography in Performance Physiology

Sports medicine performance diagnostics with the VarioCAM® HD head 880

Scientists from the Department of Sports Medicine, Prevention and Rehabilitation at the Institute of Sports Science of Johannes Gutenberg University (JGU) Mainz have demonstrated in their latest research how infrared thermography and artificial intelligence (AI) can help to better understand physiological responses to physical stress. Using methods such as StereoThermoLegs and ThermoNet, thermal images can be evaluated automatically to precisely record temperature changes in the legs during running or cycling.

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Thermal imaging camera:
VarioCAM® HD head 880

In sports medicine, thermography is becoming increasingly important as a non-invasive measurement method. As part of a study, scientists from JGU Mainz investigated the potential and applicability of the method for dynamic measurements in performance physiology. In their analysis, the research group under Dr. Barlo Hillen found skin temperature patterns across the entire body surface that resemble subcutaneous vessels with their tree-like branching structure. Previous scientific studies have also identified these “hyperthermal spots” or “thermal kinetic patterns” under physical stress; however, due to the small number of subjects, different camera systems, and varying experimental parameters, the results have been difficult to compare.

Fig. 1: Load-induced temperature patterns on legs at rest - (© Dr. Hillen, B. et al., JGU Mainz)

Precise thermography: Regional Temperature Curves Recorded in Detail for the First Time

The team led by Dr. Hillen conducted their own experiments confirming previous findings. In addition, the sports medicine researchers describe dynamic changes in skin temperature and patterns and show how they relate to physiological adaptations during exercise. Distortions caused by individual factors (e.g., skin blood flow) or environmental factors were minimized. For the temperature measurements on the skin, the researchers used a VarioCAM® HD head 880, enabling examination of different “regions of interest” (ROI) — torso, back and front side, but especially the lower and upper extremities — under various stress scenarios. For the first time, the fine structure of the skin temperature patterns could be visualized and analyzed using AI methods.

During endurance training with **constant load**, an initial drop in skin temperature was observed — as in other studies — which was particularly strong in the upper limbs. After some time, the temperature stabilized and then increased

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slightly again. Only after exercise did the skin become significantly warmer. This rise in temperature can be linked to the development of skin temperature patterns observed across the body during different types of endurance exercise.

With increasing exertion until exhaustion (**incremental exercise tests**), previously reported results have sometimes been contradictory. In their own trials, Dr. Hillen and colleagues demonstrated that temperature changes depend on the ROI being analyzed. The initial drop in temperature was greater than during steady-state endurance exercise and showed a clear relationship to exercise intensity. At the end of the trials, the typical skin temperature patterns were again visible.

Fig. 2: Load-induced temperature patterns on legs during movement - (© Dr. Hillen, B. et al., JGU Mainz)

Thermographically Detected Physical Responses During Strength Training and their Explanation

Differences are even more pronounced during resistance training than in incremental exercise tests. In these tests, which last less than 10 minutes and follow a standard protocol, some studies show that the skin temperature of stressed muscles rises, while others show that it falls. In this context, both the ROI and the participants' training level play a role. Specific skin temperature patterns during resistance training have not yet been reported in the literature. The research group conducted two of their own trials but could not draw clear conclusions regarding differences in exercise intensity. However, skin temperature patterns that differed from those in endurance or incremental exercise were observed here as well.

The skin temperature decrease during endurance and incremental exercise is attributed by the researchers to the constriction of blood vessels in the skin controlled by the sympathetic nervous system. This causes blood to be redistributed from the skin to organs that must work harder during exercise. It is assumed that thermographic measurement of skin temperature primarily reflects vasomotor adjustments (changes in vessel dilation and constriction), rather than cooling effects caused by sweating (evaporation). This is because the body considers regulating temperature via vessel dilation or constriction to be more efficient than sweating immediately.

Therefore, thermography is particularly well suited to identify changes in vascular regulation at the beginning of physical exertion and with increasing exercise intensity — without being strongly affected by sweating. The

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emergence of a distinct, increasingly visible vascular pattern with increasing exercise intensity supports this assumption.

As core body temperature rises, the body increasingly releases heat to the environment to cool itself. The **"tree-like" structure** visualized by infrared thermography is believed by the researchers to be caused by increasing vasodilation and reperfusion (restoration of blood flow) of cutaneous arterial **perforator vessels***.

** Perforator vessels are branches of deeper blood vessels that penetrate the fascia to supply the skin and subcutaneous tissue.*

Novel Insights into Temporal and Regional Heat Dissipation under Physical Stress

The results suggest that the body delays the vascular response during exercise, increasing heat dissipation only once core temperature exceeds a certain threshold. In the exercise tests, this delay was especially noticeable over active muscles (e.g., thigh), while non-active areas (e.g., forearm, chest) showed a rapid temperature increase.

In resistance training, the team led by Dr. Hillen showed for the first time that thermography can detect three different heat dissipation pathways during this type of exercise. Heat is primarily dissipated over the surface of larger muscle groups (venous radiation pattern), over the surface of smaller muscle groups (homogeneous radiation pattern), or over the surface of perforasomes (areas of skin supplied by one or more perforator vessels).

The researchers were additionally able to automatically capture, evaluate, and analyze the different vessel-associated heat distribution patterns during movement using deep neural networks as time-series data. This results in time-efficient, reproducible, and objective measurement of relevant temperatures in different skin areas.

Insights through Thermography and AI – An Advancement for Diagnostics and Monitoring

With these experiments, the researchers in Mainz gained deeper insights into the body's temperature regulation. The analyses show that skin temperature behaves differently during exercise depending on the stress level and body region. Particularly interesting are the comparisons between treadmill and cycle ergometry as well as the analysis of typical heat patterns and temperature curves related to cardiovascular parameters. Thermography – especially in combination with algorithmic pattern recognition – also provides the potential to quantify internal and external exercise load on participants. These findings open new possibilities for diagnostics and monitoring in sports science and medicine.

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