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Possible uses of infrared thermography in sport

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Abstract
The authors discuss the physiological bases of thermographic research and review its current applications in sport performance diagnostics on the basis of available professional literature. The methodology of thermographic studies involves the proper preparation of the workstation, thermographic equipment, and the athlete. The authors also refer to the results of their own research conducted during real training sessions. Factors influencing the obtained outcomes are discussed.

KEYWORDS: sport performance, thermography, influence factors, skin temperature.

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What is already known on this topic?
While carrying out thermographic research in sport it must be taken into consideration that many factors can influence the outcome of the measurement. These are technical, environmental and individual factors connected with investigated subjects. For the purpose of repeatability of the research, standardization and following proper procedures are very important.

Introduction

In the last decades new possibilities of infrared thermography (IRT) use in sport have emerged [1]. IRT is a non-invasive and non-contact method used to visualize invisible infrared radiation emitted by the human body. It reflects human body temperature changes in response to physiological processes or pathological reactions [2]. The amount of heat emission depends on a number of internal factors, e.g. skin vascularity, cellular metabolism, or body insulation; and external factors, e.g. environmental humidity and temperature [3].
The human body is homeothermic. Regardless of external factors, the internal body temperature (i.e. 36.8 ± 1.5°C) is stable and optimal for the body's functioning [4]. Temperature constancy is maintained thanks to the thermoregulatory control of the blood flow in the skin [5]. Skin blood circulation is regulated by the sympathetic neural control of the adrenergic vasoconstrictor and cholinergic vasodilator systems [5]. Kenney and Johnson [6] suggested that the skin blood flow reflects thermoregulation processes inside the body. The skin surface temperature is poikilothermic [4].
During intensive or long-lasting exercise, skin blood vessels become constricted and the blood flows mainly to the working muscles [7, 8]. Simultaneously, blood circulation in other tissues becomes limited [5]. In this situation, the core temperature rises up to about 38 degrees reaching the vasodilation threshold. After that, the peripheral skin blood flow increases linearly [9], which is necessary to eliminate excess body heat. The degree of blood circulation in the skin is reflected in the skin surface temperature. Vasoconstriction and reduction

in skin blood circulation leads to a temperature decrease [4], and inversely, vasodilation and enhancement in blood circulation may lead to a temperature increase.
Skin temperature regulation is influenced by such factors as blood flow rate, activity of the sympathetic nervous system, and local structures, especially the content of the subcutaneous tissue [10]. There are numerous factors which can modify the thermoregulation of skin blood flow, e.g. age, reproductive hormones, illnesses, body hydration, or physical effort [5]. Thus there is a constant need of new research into the mechanism of thermoregulatory adaptation to exercise. Thermography is a commonly used tool in this kind of research.
Thermal imaging permits assessment of temperature and its layout on the body (passive thermography). It also helps monitor stimulated thermal processes (active thermography) [11], including physiological thermoregulatory responses to body cooling [12] and heating [13].

Uses of thermography in sport

IRT is used both for post-traumatic states and sports performance diagnostics [1, 10, 11]. Numerous studies have been published on monitoring skin temperature changes induced by constant endurance exercise at various work intensities [14], prolonged continuous exercise with incremental intensity [7, 8, 15, 16, 17], or resistance exercise [4].
Studies were conducted mainly on untrained participants [4, 14, 15, 16], or semiprofessional trained individuals [7, 8, 16, 17, 18]. Presumably, our own last study has been the first one conducted on elite athletes [19].
Foregoing studies were conducted mainly in laboratory conditions with the use of bicycle ergometers or treadmills [4, 8, 14, 15, 17]. Our last, yet unpublished, study discussed the possible uses of thermographic cameras for outdoor training at sport stadiums [19].
Some researchers assessed skin temperature distribution during and after physical exercise not only above working muscles [4, 8, 16]. They measured temperature above the parts of the body which were not directly involved in exercise. For example, they measured temperature on the forehead [17], upper body [14], upper limbs [15], during a bicycle ergometer exercise; or in the anterior body regions during a treadmill test [7].

Factors affecting thermographic research

Results of thermographic research are affected by multiple factors: technical, environmental, and individual [20]. Among technical factors, Fernandez-Cuevas et al. [20] indicated, e.g. research protocol, camera features, calibration, camera position, software and image analysis technique.
While carrying out thermographic research it is recommended to use a standardised protocol to minimise or even eliminate the potential influence of technical factors. Many international thermographic associations publish recommendations for this kind of research. One of the latest is the Glamorgan Protocol which determines the positioning of subjects during experiments and techniques of image analysis [21]. A thermographic camera selected for research should be of the possibly highest resolution to ensure the best image quality and more reliable outcomes [20].
Environmental factors include room size, ambient temperature and relative humidity. Atmospheric pressure and other radiation sources should also be taken into consideration [20]. Fernandez-Cuevas et al. [20] stipulate that experiments can be performed in standardized conditions after considering environmental factors mentioned above. Unfortunately, they also point out that controlling all individual factors is almost impossible.
Many individual factors can also influence the research outcome. Fernandez-Cuevas et al. [20] divided them into "intrinsic factors", e.g. age, sex, body height, and body weight – especially subcutaneous fat, circadian rhythm, hair density, skin emissivity, metabolic rate, skin blood flow, medical history (diseases), genetics and emotions; and "extrinsic factors" which depend on personal habits or daily activities, such as intake of drugs, medicaments, alcohol, tobacco and food, applications (ointments and cosmetics, water, sunlight), therapies (physiotherapy) and physical activity (recent activity, sweating, fitness level, dominance of asymmetries, sport specialization).

Thermographic research methodology

As far as experiment repeatability is concerned, reliability and proper outcome interpretation following certain rules in thermographic research is of prime importance. Selection of thermographic cameras and the emplacement of the device and the subjects are crucial for the experiment [2]. The main recommendations are shown in Table 1.

Preparation of the research room

It is very important to keep stable temperature inside the research room during the measurements. Ring and Ammer [22] suggest that the optimal temperature range for taking pictures is 18-25ºC. It has been observed that shivering can occur below, and sweating above this temperature range. What is more, exposing an undressed person to low temperature can cause discomfort and induce reflex vasoconstriction.

Table 1. Main recommendations for IRT research on the human body

Infrared Camera	− device selection with short or long IR waves [11, 24]; − periodical calibration required [11, 25].
Research emplacement	− conduct the experiment at the same time of the day because of the circadian rhythm of thermoregulation [2, 20, 22]; − research room size min. 2 × 3 m [22, 24]; − insulate other infrared radiators [24]; − ambient temperature of 18-25ºC [22, 24]; − perpendicular angle of view [20]; − minimal distance between the subject and the IR camera: 1-1.2 m [24].
Subject	− first measurement after at least 10-15 min of acclimatization [22, 24]; − during acclimatization the investigated body part should be unclothed [24]; − avoid folding and crossing limbs, and contact with hot/cold surface [22]; − any touching and contact with other objects is forbidden [24]; − any cosmetics, ointments or cream applications on skin are forbidden [20, 22, 24]; − any hot beverages or meals are forbidden [24]; − drugs influencing body temperature are forbidden [20, 22]; − no excessive physical exertion before examination [22, 24]; − do not use physiotherapy before the test (e.g. massage, electrotherapy, ultrasound, heat treatment, cryotherapy, hydrotherapy) [20,22]; − pictures should be always taken in the same subject position (standing position, sitting or lying) [22].
Researcher	− experience in taking thermographic images is desirable [10, 22]; − knowledge of anatomy and human physiology is desirable.

On the other hand, in the case of inflammatory lesions, thermal images should be taken in a lower ambient temperature (about 20ºC) to be more clearly visualized. Temperatures of 22-24ºC are recommended for limbs evaluation [22]. Some authors believe that the optimal ambient temperature is 21ºC, because the greatest infrared emission in humans occurs in this temperature [3].
Some other authors highlight the necessity of considering the relative humidity of the environment. IRT research is usually conducted at 40-70% of humidity; however, so far no established norms exist [20].

Preparation of the subject

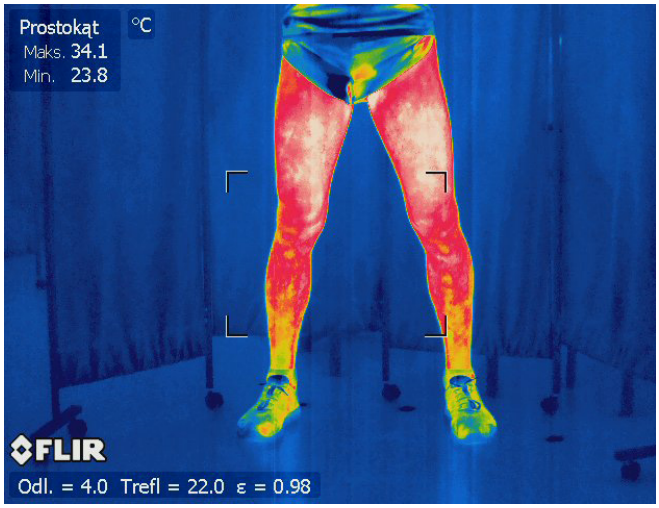
The subject should be introduced to the experimental procedure before the measurement. It is suggested that medical anamnesis about injuries, diseases and medical surgeries should be obtained prior to thermographic examination. This information might be helpful in case of noticing any anomalies in the images e.g. asymmetry. Moreover, drug treatment or medicaments intake should be noted; however, no drug list which could influence the skin temperature evaluation has been published as yet [20]. Every subject should be instructed how to behave during the measurement. On the day of the measurement, consuming alcohol, tea and stimulants present in coffee is forbidden [20]. Presumably, a hot drink intake can also have an impact on the research outcome [23]. However, there is still no clear data on how food intake can influence skin temperature [22].

Some authors indicate that nicotine can reduce skin temperature. For that reason, non smoking is highly recommended on the day of the research [20]. Subjects should avoid ointments and cosmetics applied on examined body part, because they can affect the skin emissivity factor [20]. Some authors suggest that taking a shower or a bath before experiment should be avoided because of the risk of skin hydration [20]. Subjects should not wear tight fitting clothing before and during the time of the research [22]. They should be also informed to minimize physical exertion before the first measurement because muscle activity strongly influences skin temperature. It is advised that a subject should sit still and rest 15 minutes (minimum 10 minutes) before the measurements to stabilize blood pressure and skin temperature [22].

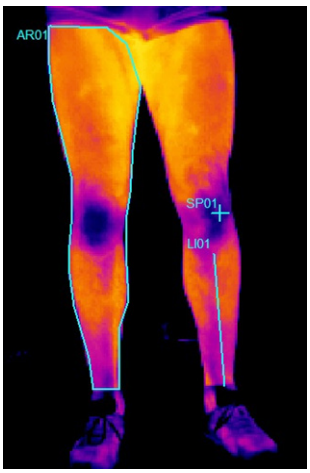
Taking pictures and data interpretation

Pictures should always be taken in the same subject position (standing, sitting or lying) [22]. The optimal distance between the camera and the subject has not been defined yet. Bauer and Dereń [24] suggest a minimal distance of about 1-1.2 m. Recently, a short distance to the fixed body area has been recommended to increase the number of pixels. For more accurate images, a perpendicular angle of view is suggested [20]. After taking an image, the researcher needs to conduct thermal analysis. There are three common techniques of thermal analysis. The first one is the establishment of

the Region of Interest (ROI – marked as AR01 in Figure 1). It means that the researcher has to outline the area of tissue to assess its mean temperature. The second is to draw a line (marked as LI01 in Figure 1) to assess temperature distribution along this line. The last one is to mark a dot (marked as SP01 in Figure 1) on an established temperature point at the selected location [10].



A



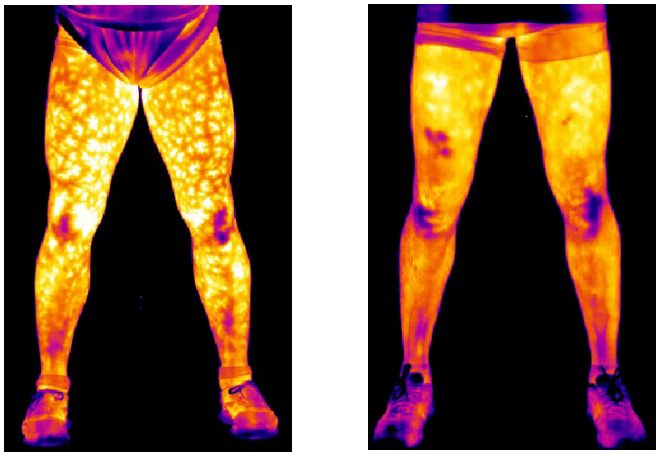
B

Figure 1. A – thermographic image; B – thermographic image with analysis; AR01 – region of interest; SP01 – thermal point; LI01 – thermal line

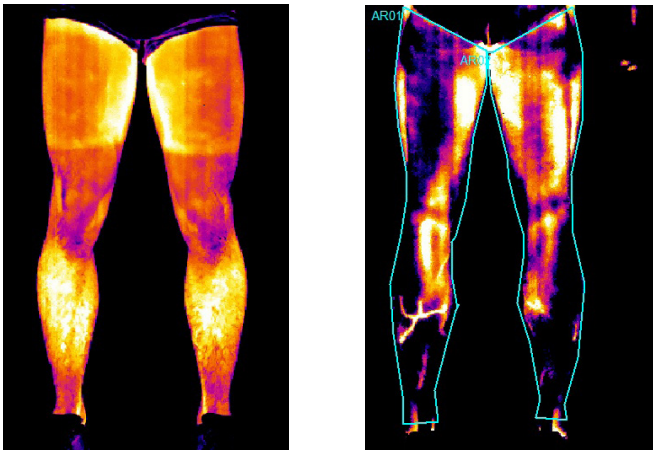
Many factors may affect the presented results. However, there is no scientific evidence to prove it [20]. One of the factors that may have an influence on skin temperature is subcutaneous fat tissue. Because of its thermal insulating property it may affect the skin temperature and the dissipation of body heat [10, 18, 26]. Many authors highlight that sweating cools the skin. However, Smith and Havenith [27] did not show any significant correlation between regional sweat rates and regional skin temperature. Local surface blood circulation, which has an impact on skin temperature dissipation, may be affected by mechanical factors such as skin hand contact or tight fitting clothing [22]. Tissue emissivity may be altered by dermatological lesions such as wounded skin [28], tattoos, and scars [24].

It should be mentioned that visible subcutaneous vessels can also affect thermographic images. These are the reasons why investigators should be experienced, and their anatomical and physiological knowledge is desirable.

Most of the thermographic research is conducted in laboratory conditions. Nevertheless, in some cases, exposure of the subject to direct sunlight should not be ignored [23]. Thermograms below (Figure 2) present some of the described cases.



A B



C D

Figure 2. Thermograms with errors and anatomical abnormalities: A – sweaty skin; B – touch mark; C – tight shorts; D – visible blood vessel

Symmetry in skin temperature should also be taken into consideration. Healthy subjects should have similar temperatures in symmetric body parts, and any changes may indicate pathology. However, there is no clear opinion on that matter, Some authors point to the possibility of small temperature differences such as 0.25 ± 0.2ºC [29], or 0.5ºC [30]. Bouzas Marins et al. [31] claim that such small differences (< 0.2ºC) may be connected with the domination of one of the limbs. In case of any asymmetry or temperature abnormality, the examination should be repeated in few days to verify the result.

Conclusion

Thermal imaging seems to have great potential in sports. However, environmental, individual anatomical and physiological factors as well as researcher's experience should be taken into consideration in thermographic research.

What this study adds?

The researcher's experience and knowledge of human anatomy and physiology play a crucial role in thermographic experiments on human body. Thermoghraphy in sport is still a promising method for monitoring sport activity.

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