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USE OF THE THERMOVISION METHOD IN SPORT TRAINING

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Abstract. *The article presents the infrared (IR) thermovision diagnostic method as one of the tools for monitoring changes in an athletes' loading conditions during their training. The advantage of the method lies in its quantitative approach, fast analysis and the comparative studies involving the application of this method. All of the basic mechanisms of heat transfer to the skin's surface are presented, enabling a comprehension of the experimental results. In this article the results are presented as a temperature field distribution on a selected segment of skin and they change with time, depending on the integral parameters of an athlete's loading. Also examined were the characteristic changes in the temperature field which depend on an athlete's physical loading. In addition to a quality evaluation of the topological structures of the temperature field, time-related changes in locally averaged temperatures in a selected window were evaluated, as well as the pertinent time-dependent local temperature variations in individual training loading regimes. The results of the study indicate the rationality of applying the IR method for monitoring various types of loading on an athlete's muscle segments. This method may also be used as a comparative tool for establishing the efficiency of different means and methods in the training process.*

Key words: *thermovision, diagnostics, muscle loading, training*

1. INTRODUCTION

Thermovision is a non-contact method for measuring heat radiation on the body's surface that is based on the infrared part of the electromagnetic specter. In medicine, it is commonly used as a non-invasive method for diagnosing cancerous growth in breasts, inflammations– rheumatism, traumas and soft-tissue diseases, inflammation of the tissue surrounding artificial implants, the vascular system of diabetics', blood circulation in the limbs of para and quadriplegics, skin temperature in newborns etc. In ecology, this method is used to identify disorders and diseases in the vegetation, to measure levels of

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certain types of environmental pollution and to detect objects buried in the ground. Thermovision is also applied in industry, namely for inspecting electrical equipment, machinery and other devices and facilities so as to establish their operating condition. This enables a preliminary detection of the overheating of parts of machinery, thereby preventing more serious damage in technological systems. Similar inspections are carried out in the construction industry. The increasing costs of heating, the desire to create the most comfortable and healthiest living environment possible and the growing awareness of the ecological use of energy products have also established new criteria and requirements in construction. The thermovision camera has become an indispensable tool for detecting heat bridges, construction flaws and draughty windows and doors. In the energy industry, thermovision inspections are carried out to identify flaws in the insulation of underground central heating networks.

In sports practice, this method was already in use thirty years ago (Keyl & Lenhart, 1975; Clark, Mullan, & Pugh, 1977; Wade & Veghte, 1977; Veghte, Adams, & Bernauer, 1979; Buckhout & Warner, 1980; Nakayama, Ohnuki, & Kanosue, 1981). The basic aim of the majority of these sports studies was to measure the fall or rise in skin temperature during a specific sport exercise, with a change in air temperature (running, cycling, swimming) and in the case of injuries and lesions. Clark, Mullan and Pugh (1977) were some of the first to use the infrared thermovision method in an analysis of changes in skin surface temperature. They measured skin temperature in two athletes standing and running on an athletic track (an outdoor environment) at an air temperature of 20 °C, and in a climatic chamber at 11 °C. They established that skin temperatures were higher over the active muscles than over other body segments and were considerably higher after exercise than prior to it. Moreover, they found that the temperature of the trunk was higher than that of the limbs, while the temperature of the skin over the muscles was 2-4 ºC higher than that over the bones. Keyl and Lenhart (1975) were among the first to use thermography in an investigation of changes in skin temperature in the area of injuries (tears, wounds, meniscus, tendinopathy and chrondropathy) to the locomotor system. The infrared camera recordings showed that wounds reveal themselves as local hyperthermia, but only if they are not located too deep inside the tissue. In combination with the medical history and clinical and radiological tests, infrared thermovision is one of the most efficient diagnostic methods, and is also used for the subsequent control of the healing process of an injury. Wade and Veghte (1977) delved into the regional changes of skin temperature in four swimmers. The swimmers had different body structures. The measurements were carried out before they jumped into the water, after five minutes in the water at 23.5 ºC, and after 500 m of swimming at a training pace. They established that, after swimming, the skin temperature was higher in those areas over the active muscles and that the temperature was independent of skin thickness. Skin temperature rose in the areas over m. deltoideus, m. trapezius, m. triceps and m. biceps. Veghte, Adams and Bernauer (1979) measured dynamic temperature changes in the conditions of different training loadings: a hand grip with 20%, 50% and 80% of maximum force caused a 1.7 ºC rise in temperature. Asymmetric leg ergometry showed that the temperature of the active leg was higher than that of the inactive leg, while running exercises reduced the skin temperature of both legs.

This article focuses on the application of the IR method as a diagnostic/monitoring method for observing the physical activity of muscle groups when track and field athletes and other athletes are exercising. The aim of the study is to evaluate significant changes in the temperature field measured on the surface of the skin over specific body parts and correlate them with the integral exercise parameters.

Heat transfer mechanisms

Humans are homeothermic, which means that their internal body temperature is kept nearly constant throughout their lives. Fluctuations in body temperature do not exceed 1.0 ºC. Only during prolonged heavy exercise, illness or extreme conditions of heat and cold do body temperatures deviate beyond the normal range of 36.1 to 37.8 ºC. Body temperature reflects a careful balance between heat production in the body and the heat transferred to the external environment which takes place on the body's surface. The primary mechanism for delivering heat from the core of the body to its surface is convection through blood circulation. Then, the following mechanisms transfer heat to the external environment through the skin: conduction, convection, radiation and evaporation.

The conduction mechanism is a molecular transfer of heat flow from an area with higher temperature to an area with lower temperature. This heat transfer is characteristic of solid materials or those featuring inter-molecular contact; in our case, this is the muscle tissue adjacent to the skin tissue on the body's surface. Where the external temperature is higher than the temperature of the body, the heat flow can be directed from the external surface, i.e. the skin, towards the muscle tissue.

Convection involves transferring heat from one place to another by the movement of fluid, either gas or liquid. Heat is mainly transferred throughout the body by blood circulation and by the movement of water in the skin from the inside of the skin to the surface. Heat is removed by convection directly from the external surface of the skin, i.e. by air passing over the surface of the skin.

Radiation is the primary method for discharging the body's excess heat into the external environment. At normal room temperature (typically 21 to 25 °C), the naked body loses about 60% of its excess heat by radiation. The heat is given off in the form of infrared rays. The intensity of the radiation flow per skin surface unit depends on the body's temperature on the skin surface and the temperature of the external environment.

Evaporation is the primary avenue for heat dissipation during exercise. It accounts for about 80% of the total heat loss during physical activity, but only about 20% of body heat loss at rest. The evaporation process involves the intensive transfer of heat to the external environment. This is referred to as the insensible/imposed transfer of water heat which intensifies during physical activity when body fluid is brought into contact with the external environment. During exercise, evaporation becomes the predominant avenue of heat loss, particularly as the environmental temperature approaches the body's skin temperature.

Physiological responses to exercise

The cardiovascular system conveys the heat produced by the muscles to the surface of the body where it can be discharged into the external environment. In this process, a major part of the cardiovascular capacity involves the muscles and the skin. Due to the limited volume of blood, physical activity is a complex response resulting in higher blood circulation in specific areas and a limited flow of blood to other parts of the body. The higher the intensity of physical exercise, the stronger the need for fresh blood and oxygen in the muscles. Metabolic heat production increases as well. This excess heat can only be dissipated by increasing blood circulation in the skin, whereby the heat is conveyed faster to the surface of the body. At a specific moment, due to the increasing loading imposed by physical activity, the body is no longer able to neutralize the excess heat. Neither the muscles nor the skin receive enough blood. At such a moment, any factor causing an overburdening of the cardiovascular system or interrupting the heat transport can reduce the necessary efficiency and cause the risk of overheating. A study by Buckhout and Warner (1980) showed that physical activity in heat not only increases the heart rate and body temperature but also oxygen absorption, which results in the active muscles consuming more glycogen and producing more lactic acid. In view of the presented heat transfer mechanisms and physiological limitations, this article focuses on measuring the temperature on the skin surface of an athlete participating in different phases of physical exercise. In accordance with the hypothesis regarding a significant correlation between skin surface temperature and the intensity of physical activity in constant measurement conditions of the ambient, our aim was to investigate the possibilities of identifying an athlete's loading with various degrees of loading.

New technologies in sports training enable the application of ever more accurate methods for monitoring physical loading. In many sports, physical loading has already reached the peak of the athletes' abilities, which is why modern training modeling procedures underpinned by objective methods will enable the further development of sports results. One method for identifying physical loading is thermovision, which is based on the detection of temperature fields on the skin's surface. The method enables a time and position-related verification of temperature fields, depending on the type and intensity of an athlete's loading.

It is possible to hypothesize that, by increasing an athlete's loading, a significant change in the temperature field on the skin surface will occur. In addition to an integral rise in temperature, local temperature variations may also be expected, indicating the type and intensity of an athlete's loading. In the framework of this study, an experiment was conducted to identify the significant dependence of the measured temperature field on the surface of a selected segment (thigh muscle) with various types of loading. We thus tried to establish the appropriateness of the IR visualization method for monitoring athletes' loadings in various phases of the training process.

2. Methods

Participants

One subject participated in the experiment, namely a trained track-and-field athlete (aged 24, body weight 84.5 kg, body height 187.5 cm, personal record for the 400-metre run 49.65 sec).

Experimental procedure

Focusing on the study of the quality relations between the integral parameters of a track-and-field athlete's exercise and the reactions on the surface of a selected body segment, the experiment was divided into two parts. The first part had to do with the protocol of four types of loading. After each loading, the temperature was measured on the skin surface over the thigh muscle at defined time intervals. The temperature was measured by infrared thermography, enabling the time monitoring of the temperature on the entire surface of a selected segment of the thigh muscle. The protocols for measuring the motor tasks and implementing the thermography are presented in Table 1.

The temperature field was recorded by a fast Thermosensorik CMT384SM thermocamera. This IR camera operates in the infrared specter between 3 and 5 μm. It was calibrated against the environment which was used to simulate a black body with a constant temperature and with a proportionate temperature distribution on the surface (Figure 1). The temperatures of a calibrated segment were measured by Pt100 probes. Even though the applied method enabled accurate measurements of the absolute temperature of ±0.5 K– in view of our goal, namely to measure and evaluate a time- and locally-dependent temperature field – we could ensure a much greater accuracy of the measured relative temperatures in the observed segment. In the end, the relative accuracy of the measurement was ±0.02 K.

Fig. 1. Thermovision – applying the measurement procedure

Two parameters had to be considered when setting the thermocamera, which in turn affected the speed of recording. These are the size of the window and the integration time. The smaller these two are, the higher the speed of recording. The area of application was defined by the integration time τ = 100 ms, a window of 556 x 556 pixels and a camera frequency of 25 frames/sec. The active window is presented in Figure 2 where the index i is an integer with the value {1, 2, ... *N*} and the index j is an integer with the value {1, 2, ... *M*}.

The thermovision camera was used to record the temperature field on the skin surface over the thigh muscle. The same position of the camera, facing the selected skin surface, was maintained throughout the experiment. The ambient conditions (a tennis court at the Faculty of Sport), including the temperature of the environment, were constant (i.e. the variations were negligible). All other effects such as skin surface conditions, including humidity, were integrated into the measured skin temperature and yielded a direct result which depended on the integral loading parameters. An integral – quantitative variable is the mean temperature calculated for different loadings from thermovision recordings of a defined surface of the thigh muscle and the relevant standard deviation of temperature on the same surface. Both variables are given as time series calculated from a series of subsequent IR recordings in the observed time interval (Figure 2).

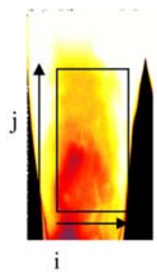

Fig. 2. Calculation area on the thigh muscle

The algorithms used for calculating the time series were as follows:

$$A(t) = \frac{1}{NM}\sum_{j=1}^{N}\sum_{i=1}^{M} E(t,i,j) \quad E(t) \in \{\Im\} \tag{1}$$

$$\sigma(t) = \frac{1}{NM}\sum_{j=1}^{N}\sum_{i=1}^{M}\sqrt{\left(E(t,i,j) - A(t)\right)^2} \tag{2}$$

where $E(t,i,j)$ is the integer value of the color scale in the (i,j) element of the IR digital recording at time t. $A(t)$ is the average value of the color scale in the selected window of time t, while $\sigma(t)$ is the relevant standard deviation evaluating the heterogeneity of the temperature field in a selected window. Given that the temperature is evaluated against a color scale, both variables $A(t)$ and $\sigma(t)$ were standardized to the maximum output of the color scale throughout the entire experiment:

$$T(t) = \frac{A(t)}{\max A(t)}[-] \tag{3}$$

$$\varepsilon(t) = \frac{\sigma(t)}{A(t)} 100\,[\%] \tag{4}$$

where max $A(t)$ is the maximum value achieved during the experiment in the observed field within the complete set of loadings. In the rest of this article, the variables $T(t)$ and $\varepsilon(t)$ were used as proportionate evaluators of the temperature field in the selected window with the observed integral loading parameters. They represent a starting point for forming phenomenological relations between the IR thermovision and the loading parameters.

3. Results and Discussion

Figure 3 shows the characteristic IR thermovision recordings with various degrees of loading during training. Each recorded shot shows the temperatures on the skin surface under identical conditions when the IR shots were made and, at the same time, regarding the starting time of recording the series of IR shots. Mean temperatures T_s were added to the IR thermovision recordings and the relevant standard deviations σ were calculated by Expressions 3 and 4.

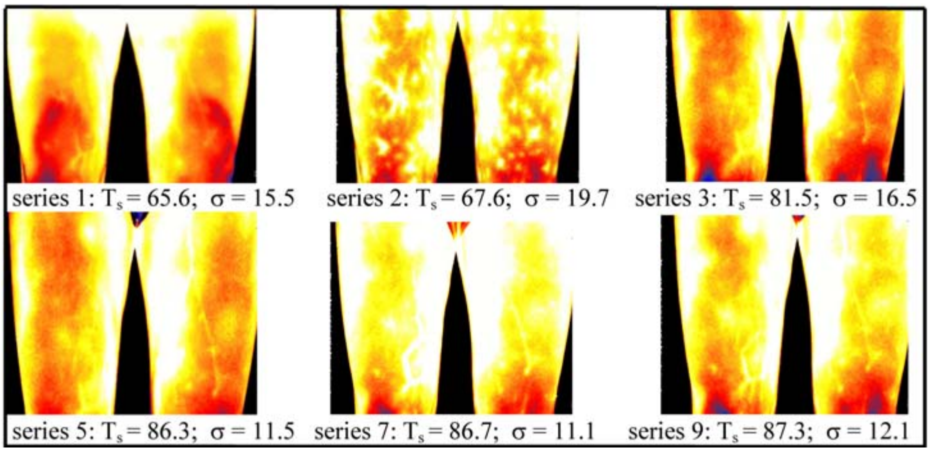

Fig. 3. Impact of loading regimes on the temperature field structure in the IR recordings

The aim of presenting different temperature distributions on the skin surface is to provide a qualitative evaluation of various topological structures which indicate characteristic variability, thus enabling an evaluation of the thigh muscle loading. It may be concluded from Figure 3 that different loading conditions are reflected in the measured skin surface temperature as well as on the texture, i.e. the structure, of the temperature distribution on the skin surface. An increased loading on the muscle significantly boosts the mean temperature. The texture, i.e. the temperature field distribution on the skin surface, is characterized by relatively high local temperature gradients in the transitory loading regimes that are related to the activation of mechanisms for transferring heat from the muscle core to the skin surface. With the increased loading, the temperature field homogenizes at a higher temperature level. Judging from the quality evaluation of temperature fields in Figure 3, it may be concluded that the characteristic temperature differences in the recorded IR shots occur with loading regimes under constant ambient conditions, enabling this method to be used in the diagnostics of loading conditions.

Algorithms 1 to 4 were used to carry out an analysis of the time variation of the temperature field in a selected window on subsequent digitized IR shots, as shown in Figure 2. Figure 4 shows the curves of standardized temperature T(-) depending on the time for different loading conditions. All of the curves are characterized by a monotonic increase in temperature from the moment the loading phase is completed and the IR recording starts, with a time interval of recording of τ = 120 secs. The observed phenomenon is derived from the heat flowing from the muscle core to the skin surface as a result of the need to reduce the temperature owing to the physical stress on the body.

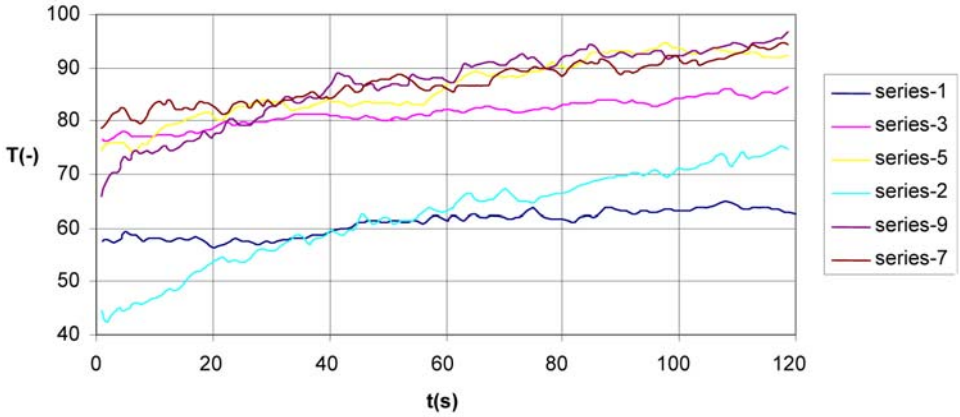

Fig. 4. Spatially averaged temperature in a selected active window

The analysis of the standard deviation of the temperature field in the observed window under different loading conditions, as shown in Figure 5, also shows one shared point. A monotonic decrease was noticed in the variable that describes the heterogeneity of the sample of images, which means that during the relaxation of the body after physical exercise, the temperature field on the skin surface homogenizes, thus indicating a higher intensity of a heat transfer from the surface to the external environment. Example 9 – loading condition (30-second vertical jumps) – was used to demonstrate the timeline of the temperature on the skin surface in a selected window as well as the related standard deviation of the temperature field in a selected window. The diagram in Figure 6 shows that the changes to the observed standardized temperature over time can be described by a 3rd degree polynomial, indicating the adaptive reaction of the body during temperature relaxation after loading. The curve ε(%), representing the standard deviation of the temperature field in a selected window, can be described as a linear monotonic decreasing function of time. Both findings are typical of all loading conditions, only varying in terms of the intensity of the time variation with regard to the loading conditions.

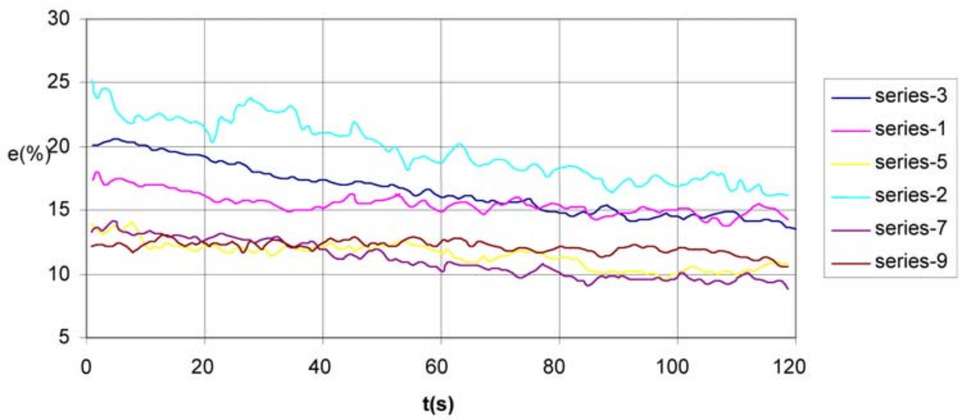

Fig. 5. Temperature fluctuation in a selected active window

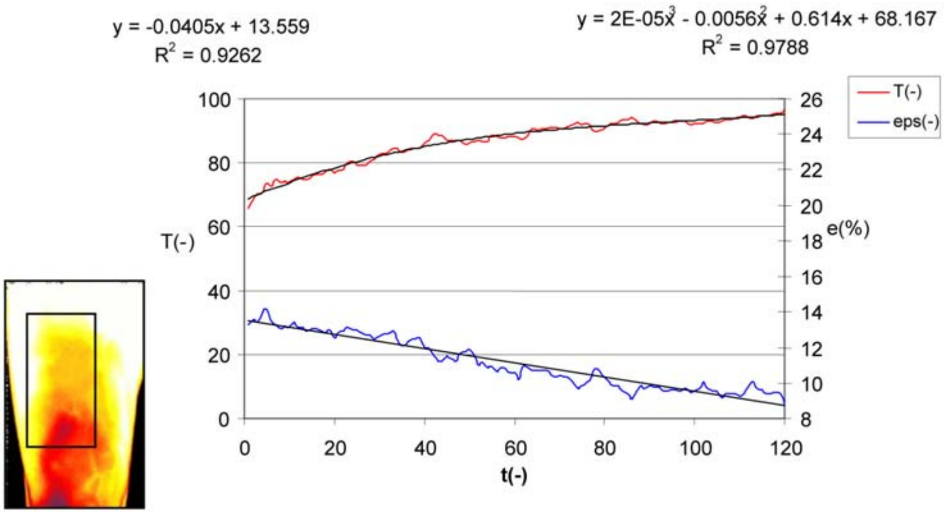

Fig. 6. Loading regime – series 9

4. CONCLUSION

The infrared thermovision method is a non-contact procedure for measuring heat radiation on the body's surface and can be effectively used in sports practice. The method is based on a registration of the change in the temperature field as a result of increased physical loading. Within the framework of this study, an experiment was conducted to establish the dependence of the measured temperature field on the surface of a selected segment (thigh muscle) with various types of loading. We presented the methodology for analyzing a temperature field in a selected window on the surface of the thigh muscle, where the locally averaged standardized temperature on the skin surface in a selected time interval was analyzed. The time change in the texture of the temperature field was also observed in the same selected window. The results obtained show a characteristic qualitatively and quantitatively different temperature distribution, which depends on the type of loading. These results lead us to conclude that the IR thermovision method is an important expert tool for monitoring loading conditions resulting from different training means and methods.

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UPOTREBA TERMOVIZIJSKIH METODA U SPORTSKOM TRENINGU

Milan Čoh, Brane Širok

Članak predstavlja infracrveni (IR) thermovision metod za dijagnostifikovanje kao jedno od sredstava za praćenje promena uslova opterećenja tokom treninga sportista. Prednost ovog metoda je u kvantitativnom pristupu, brzoj analizi i uporednim studijama koje učestvuju u primeni ovog metoda. Svi osnovni mehanizmi transfera vrućine na površini kože su predstavljeni, omogućavajući razumevanje eksperimentalnog rezultatata. U ovom članku rezultati su prezentovani kao distribucija temperaturnog polja na izabrani segment kože i njihove promene koje nastupaju sa vremenom, zaviseći od integralnih parametara opterećenja sportista. Takođe su istraživane karakteristične promene temperaturnog polja koje zavise od fizičkog opterećenja sportiste. U dodatku evaluacija kvaliteta topoloških struktura temperaturnih polja, promene koje se vezuju za vreme kod prosečnih temperatura u selektovanom okviru bili su procenjeni, kao i varijacije koje se odnose na vremenski zavisne lokalne temperature kod individualih trenažnih programa opterećenja. Rezultati ove studije pokazuju racionalnost u primeni IR metoda za praćenje različitih tipova opterećenja na mišični segment sportista. Ovaj metod takođe može da bude upotrebljen kao sredstvo za upoređenje u cilju utvrđenja efikasnosti različitih sredstava i metoda u procesu treninga.

Ključne reči: *termovizija, dijagnostifikovanje, mišićno opterećenje, trening*