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THE THERMOVISION METHOD IN SPORT TRAINING

1.0 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 spectre. 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 tissues surrounding artificial implants, diabetics' vascular system, 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 of vegetation, measuring levels of certain types of environmental pollution and detecting 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 healthy 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 changing air temperatures (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 structures and were considerably higher than prior to exercise. 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) on a locomotor system. The infrared camera recordings showed that wounds reveal themselves as local hyperthermia, but only if they are not too deep in the tissue. In combination with the medical history and clinical and radiological tests, infrared thermovision is one of the most efficient diagnostic methods and also used for the subsequent control of healing an injury.

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 sportspersons are exercising. The aim of the study is to evaluate significant changes in the temperature field measured on the skin's surface in specific body parts and correlate them with the integral exercise parameters. 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 athletes' abilities, which is why modern training modelling 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 hypothesise 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 visualisation method for monitoring athletes' loadings in various phases of the training process.

2.0 Methods

2.1 Experimental procedure

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). Focusing on an investigation of quality relations between the integral parameters of a track-and-field athlete's exercise and the reaction on the surface of a selected body segment, the experiment was divided into two parts. The first part related to 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 protocol of 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 spectre 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**.** The temperatures of a calibrated segment were measured by Pt100 probes. Even though the applied method enabled an accuracy of measured 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 the 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.

Table 1: *Integral loading of a track-and-field athlete*

Series	Loading description
1	unwarmed muscle
2	thigh muscle after 15 minutes of warming up
3	1 x 60-metre sprint (max. 70% intensity)
4	5-minute break
5	1 x 60-metre sprint (max. 90 % intensity)
6	5-minute break
7	4 x 50-metre sprint (90% intensity)
8	5-minute break
9	vertical jumps (30 sec)

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. variations were negligible). All other effects such as skin surface conditions, including humidity, were integrated in 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 pertaining 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.

3.0 Results and Discussion

Figure 1 shows the characteristic IR thermovision recordings with various degrees of loading during training. Each recorded shot shows the temperatures on the skin surface in equal conditions of taking IR shots 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 pertaining standard deviations.

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 1 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 characterised 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 homogenises 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.

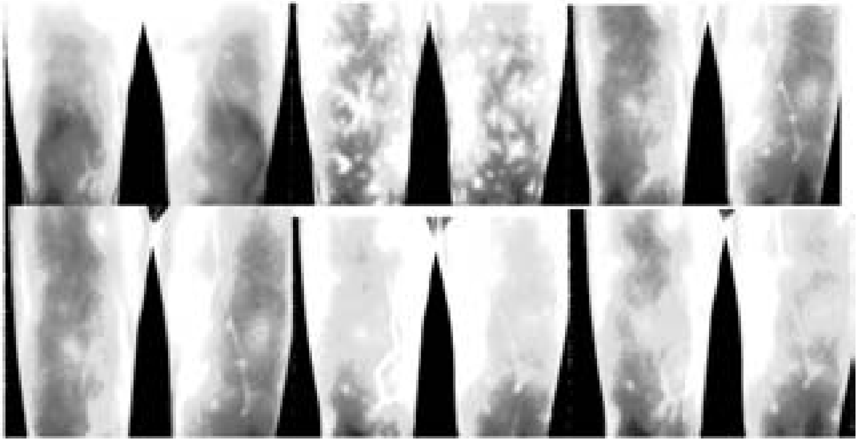

***Figure 1:** Impact of loading regimes on the temperature field structure in the IR recordings*

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 digitised IR shots, as shown in Figure 1. Figure 2 shows the curves of standardised temperature *T(-)* depending on time for different loading conditions. All curves are characterised 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 derives 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 organism.

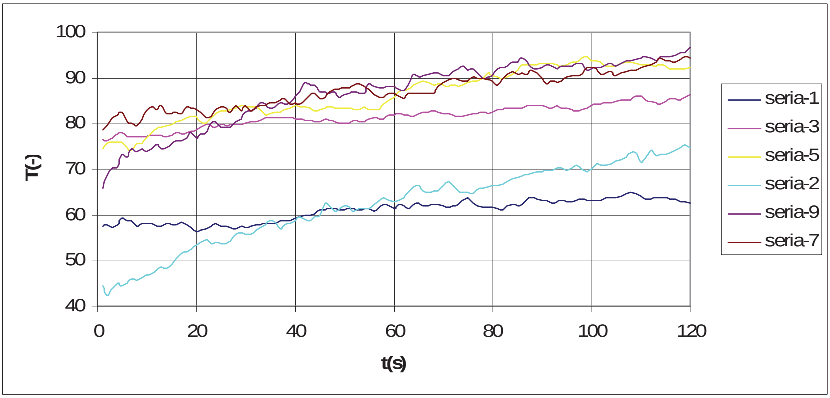

***Figure 2:** Spatially averaged temperature in a selected active window*

Analysis of the standard deviation of the temperature field in the observed window under different loading conditions, as shown in Figure 2 also shows one point in common. A monotonic decrease was noticed in the variable that describes the heterogeneity of the sample of images, which means that during relaxation of the organism after physical exercise the temperature field on the skin surface homogenises, thus indicating the 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 3 shows that the changing of the observed standardised temperature over time can be described by a 3rd degree polynomial, indicating the adaptive reaction of the organism during temperature relaxation after loading.

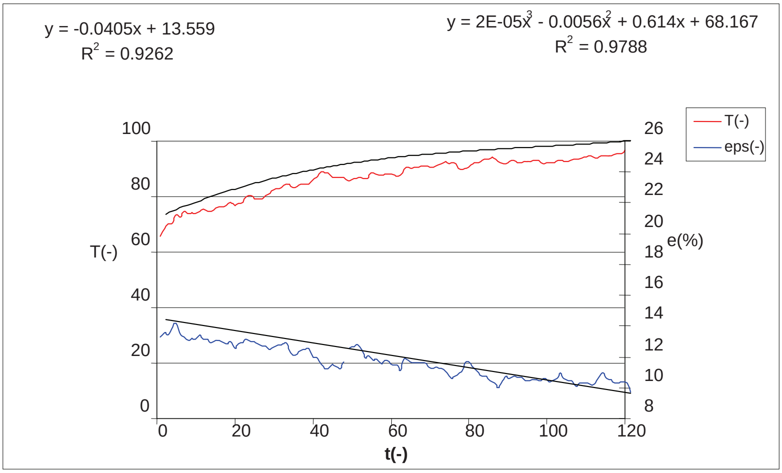

Figure 3: *Loading regime – series 9*

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.

4.0 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 analysing a temperature field in a selected window on the surface of the thigh muscle, where the locally averaged standardised temperature on the skin surface in a selected time interval was analysed. 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.

5.0 References

1. Clark, R.P., Mullan, B.J., & Pugh, L.G. (1977). Skin temperature during running – A studi using infrared colour thermography. *J. Physiol.*, 267, 53-62.
2. Buckhout, B.C., & Warner, M.A. (1980). Digital perfusion of handball players. Effects of repeated ball impact on structures of the hand. *American Journal of Sport Medicine*, 8(3), 206-207.
3. Keyl, W., & Lenhart, P. (1975). Thermography in sport injuries and lesions of the locomotor system due sport. *Fortschr. Med.*, 93(3), 124-126.
4. Nakayama, T., Ohnuki, Y., & Kanosue, K. (1981). Fall in skin temperature during exercise observed by thermography. *Jpn J Physiol.*, 31(5), 757-762.
5. Sherman R.A., Woerman, A.L., & Karstetter K.W. (1996). Comparative effectiveness of videothermography, contact thermography, and infrared beam thermography for scanning relative skin temperature. *J Rehabil Dev.*, 33(4), 377-386.
6. Veghte, J.H., Adams, W.C., & Bernauer, E.M. (1979). Temperature changes during exercise measured by thermography. *Aviat Space Environ Med.*, 50(7), 708-713.
7. Torii, M., Yamasaki, M., Sasaki, T., & Nakayama, H. (1992). Fall in skin temperature of exercising man. *Br J Sports Med.*, 26(1), 29-32.
8. Wade, C.E., & Veghte, J.H. (1977). Thermographic evaluation of the relative heat loss by area in man after swimming. *Aviat Space Environ Med.*, 48(1), 8-16.
9. Wilmore, J.H., & Costill, D.L. (1999). Thermoregulation and Exercise. *Physiology of Sport and Exercise. Human Kinetics, Champaign, IL. P.O. Box 5076*, 311-338.
10. Zaproudina, N., Ming, Z., & Hanninen, O. (2006). Plantar infrared thermography measurements and low back pain intensity. *J Manipulative Physiol Ther.*, 29(3), 219-223.
11. http://en.wikipedia.org/wiki/Thermography
12. http://www.metacafe.com/tags/thermal/
13. http://www.ncbi.nlm.nih.gov/pubmed/1173237

THE THERMOVISION METHOD IN SPORT TRAINING

The article presents the thermovision diagnostic method as one of the tools for monitoring changes in athletes' loading conditions during their training. The method's advantage lies in its quantitative approach, fast analysis and the comparative studies involving an application of this method. All 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 skin segment 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 temperature field's topological structures, time-related changes in locally averaged temperatures in a selected window were evaluated as well as the pertaining 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.

***Keywords**: thermovision, diagnostics, muscle loading, training.*

"Pobjeda", 30. septembar 2009.

ЦРНОГОРСКА СПОРТСКА АКАДЕМИЈА ОРГАНИЗОВАЋЕ ПРЕСТИЖНЕ СКУПОВЕ

Учествују научници из 20 држава

Никшић, 29.септембра - Почеле су припреме за научне скупове које организује Црногорска спортска академија.

Договорен је програм 7. Међународне научне конференције која ће обухватити 43 задате теме обрађене у четири сесије, а уједно ће бити одржан и 6. Конгрес Црногорске спортске академије под мотом „Трансформациони процеси у спорту".

ПРОФ.ДР ДУШКО БЈЕЛИЦА

Одређен је и приређивачки одбор који ће припремити те научне скупове и то су еминентна имена: **проф. др Милан Жван** (Љубљана), **проф. др Душко Бјелица** (Подгорица), **проф. др Изет Рађо** (Сарајево), **академик Никола И.Волков** (Москва), **проф. др Павле Опавски** (Београд), **проф. др Жарко Костовски** (Скопље) , **проф. др Бранимир Микић** (Тузла) , **проф. др Зоран Милошевић** (Нови Сад) и **проф. др Михаил Шестаков** (Москва).

Средином октобра биће одржан састанак Одбора, који ће усвојити коначан програм рада најпрестижнијих научних скупова у региону, за чију припрему треба најмање шест мјесеци. Скупови ће бити одржани на Црногорском приморју од 1. до 4. априла наредне године. Очекује се рекордан број учесника из најмање двадесет држава, каже предсједник Црногорске спортске академије проф. др Душко Бјелица.

Ра.П.