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THE USE OF THERMAL IMAGING TO EVALUATE BODY TEMPERATURE CHANGES OF ATHLETES DURING TRAINING AND A STUDY ON THE IMPACT OF PHYSIOLOGICAL AND MORPHOLOGICAL FACTORS ON SKIN TEMPERATURE

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ABSTRACT
Purpose. The aim of this study was to assess the temperature changes of selected body surfaces (the arm and forearm) as a response to 90-minute physical exercise as well as to analyze the impact of physiological and morphological factors on the dynamics of temperature change. **Methods.** A study group that consisted of 12 professional volleyball players was subjected to endurance training which lasted 90 minutes. Numerous physiological and morphological factors were measured, with mean temperatures registered from the body surface of the upper extremities before, immediately after, and ten min after physical effort by a thermal camera (SC500 ThermaCAM camera) at room temperature. **Results.** After physical exercise, a fall in skin temperature resulting from prolonged sweating during the dynamic exercise tests was observed. The temperature changes in volleyball players, recorded in a series of tests, were found to be larger on the front surfaces of their upper extremities when compared to the rear. In addition, statistically significant positive correlation between maximum oxygen uptake (VO_{2max}) and $\%HR_{max}$, calculated with the decrease in skin temperatures, was found. **Conclusions.** The strong and statistically significant influence of maximum oxygen uptake on the drop in surface temperature of the upper extremities (arm and forearm) immediately after the exercise indicates that thermography can be used as an additional, non-invasive method that provides information on a player's fitness level in comparison to other athletes.

Key words: thermography, thermoregulation, physical activity

Introduction

The human body can be separated into an always warm-blooded thermal core and a cold-blooded shell, where the average core body temperature is 37°C, while the body surface is commonly found to be 33°C. These temperatures depend on a number of variables and are a function of the internal organs' temperature as well as the thermal properties of the tissues that separate an organ from the surface of the body, including, among others, the muscle tissue and fat content, as well as blood flow, blood temperature, skin moisture and the amount of energy produced during regulated homeostatic metabolic processes [1–4].

The surface of the human body is a rich map of isotherms with a very wide temperature range that is influenced by endogenous and exogenous changes. Body surface temperature can be evaluated and analyzed thanks to thermal emission, which can be recorded using thermal imaging (an infrared camera) as a non-invasive and non-contact method that captures the heat emitted by human skin, allowing one to record the temperatures of selected areas of the body. Thermography has found a wide application in medicine, but in the area of sports no comprehensive study has been conducted on the possibility of its use.

Physical activity naturally increases muscle metabolism, which can lead to a rise in both muscle and body temperature by the generation of heat. In such circumstances, the body's surface temperatures changes as a consequence of thermoregulatory homeostatic mechanisms that attempt to prevent hyperthermia and release excess heat from the body. Although a small amount of the heat produced by the working skeletal muscles is passively conducted by surrounding tissues to the outer skin, the majority of this heat is transferred by convention through the venous blood flowing from these muscles which is then directed to superficial veins [5].

A trained body must have an efficient mechanism for eliminating heat. In the available literature on the subject, some studies reported that trained individuals had an overall smaller increase of rectal temperature [5–8]. One of the important physiological benefits of physical training is an increased ability to dissipate heat from the body (as an increase to reaction rate and sweating dynamics and a decrease in the allowance of internal temperature rise). Afanacewa et al. [9] stated that not only internal body temperature but also surface temperature indicates the thermal state of a human body. Changes in body surface temperature provide information on the efficiency of the endogenous heat removal systems generated during exercise as well as the metabolic changes associated with the body's return to homeostasis after exercise. On this basis, the possibility of using thermal imaging as way to monitor

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these changes and use it as a tool for sports trainers becomes increasingly apparent [10], as the efficiency of the thermoregulatory system is an important component of the body's adaptation to exercise.

Some studies also reported on drops in body surface temperature after exercise [11–14]. However, these studies were conducted on very small sample groups. Merla et al. [15] provided information on the surface temperature of the forearm, thigh and torso of 15 runners during a progressive treadmill exercise. The authors recorded drops in the surface temperature of those areas of the body after beginning exercise, with the largest decrease in the peripheral parts of the body, namely, the forearm, rather than the central parts of the body (torso). In addition, the rise in body temperature after exercise was observed to be faster in the isotherms of the peripheral parts of the body.

However, no comprehensive knowledge exists on temperature change dynamics, which could be recorded by thermal camera, of the body's surface when subjected to physical activity (and which changes are the consequence of thermoregulation) or the dependency of these changes on physiological parameters, body composition and morphological features. One of the facets considered in this study was the assumption that thermoregulatory mechanisms may be dependent on the training level (endurance) of the tested subjects. It was also presumed that body composition (especially fat content) and the skin-fold thickness of the analyzed areas of the body could act as an endogenous insulator of heat and may therefore impede heat dispersal.

In addition, this study attempted to assess a thermographic method at analyzing the efficiency of the thermoregulation system. This study is a continuation of a research project on the dynamics of body surface temperature changes when subjected to physical activity (recorded by infrared camera), as well as the dependencies of these changes on the physiological parameters, body composition, and morphological features of various sports groups in relation to their different training environments. Thus far, research has been conducted on handball players [16], water polo players [17] and basketball players [18].

Therefore, the aim of this study was to assess the changes of specific body surfaces (the arms and forearms) on a group of volleyball players before 90 minutes of physical exercise (as a training session performed in a sports gym), immediately after exercise, and 10 min after its completion, as well as assess what influence physiological and morphological parameters have on temperature change.

Material and methods

This study was conducted on 12 athletes (all men) who professionally played volleyball in a second-league team (the Morze Bałtyk Szczecin Sports Club). The study took place during the beginning of the 2008 season. The physical exercise component of the study included speed-endurance training with certain game elements (aerobic exercise, running with changes in pace and as a race; games such as a paced attack/block exercise) which lasted for 1.5 h.

Each of the test subjects were measured with three thermograms taken in a standing position of the front (PP) and rear (PT) upper limbs (KG), specifically the right (P) and left (L) arms and forearm in three series:

Series 1 (S.1) – Before training (in this case the subjects remained in a room for 20 min at 25°C in athletic wear that was all made of the same material before the thermal images were taken)

Series 2 (S.2) – Immediately after the 90-minute long training session

Series 3 (S.3) – 10 min after the end of the training session

The players started and finished their training in turn in order to ensure that each player performed the same amount of exercise and had their temperature measurement taken at identical intervals.

Digital thermal images (thermograms) were recorded in each of the sessions for the front and rear surfaces of the upper limbs (the arm and forearm). Both of these areas were continuously exposed during exercise. The study used a TMSC500 ThermaCAM thermal camera (Flir, USA), with measurements analyzed by AGEMA computer software (AGEMA, Poland). The mean temperature of the selected areas of the body were recorded and retained for later analysis. The study was performed in accordance with the standards set forth by the European Society of Thermography. The skin's emissivity was assumed to be 0.98. All thermograms were taken in a room with a humidity of 60%, at 25°C and at a distance of 3 m.

In addition, anthropometric measurements were taken of the studied group of players, including: height, body mass, skin-fold thickness of the right (P) and left (L) arm. The players' BMI (Body Mass Index) was also calculated. In addition, all of the players taking part in the study were found to be right-handed. Bioelectrical impedance analysis (Bodystat 1500 analyzer, AKEM, Turkey) was used to find the basic body composition of the players, namely: the percentage of Lean Body Mass and water and fat content. The surface area of the players' bodies was calculated using the Dubois method, whereas the surface area of the upper limbs was calculated using Wallace's rule of nines.

Evaluation of the athlete's aerobic capacity (taken one week prior to the study) was performed by measuring VO_{2max}, the maximum oxygen uptake, using the direct method. The subjects were subjected to a progressively increasing amount of resistance (until maximum) on a Monark ergometer (Monark, Sweden). During the test, respiratory rates were recorded using an Oxycon Alpha analyzer (Jaeger, Germany). Heart rate

Table. 1. Physical characteristics of the studied volleyball team ($N = 12$)

Characteristics	Min–max	M	± SD
Chronological age (years)	19–24	21.7	1.23
Player seniority (years)	4–12	8.7	2.54
Body height (cm)	186–203	192.5	4.642
Body mass (kg)	75–92	81.83	5.132
Average skin-fold fat thickness of the right and left arm (mm)	6–15	9.25	2.221
BMI (kg/m^2)	20.61–23.95	22.07	0.794
Surface area of the right and left upper limbs (m^2)	0.07–0.08	0.07	0.003
LBM% (the percentage of lean body mass)	85.2–92.6	90.02	1.908
FAT% (the percentage of fat body mass)	7.4–14.8	9.98	1.908
Water % (the percentage of body water content)	56.3–63.9	61.10	2.185
Maximum oxygen uptake (VO_{2max}) (mL/kg/min)	41.7–53	47.46	3.514
HR_t (%HR_{max})	73.44–78.15	75.80	2.750
Energy expenditure (kcal)	750–820	790.67	25.520

measurements taken during both rest and restitution after exercise were made by using a sport-tester (Polar, Poland) that established maximum heart rate values (HR_{max}).

During the physical exercise component of the study, the athletes' heart rates were monitored (using the Polar sport-testers) to determine individual average heart rate during training (HR_t), which was used to calculate what percentage of maximum heart rate was obtained during training as a marker of training load [HR_t (%HR_{max})]. In addition, the energy expenditure during exercise was measured, in the number of burned calories, using a Caltrac accelerator (Muscle Dynamics Fitness Network, USA).

In Table 1 the physiological characteristics of the studied athletes are presented. In addition, the following statistical procedures were applied to the collected data:

1. The arithmetic mean and standard deviation were calculated for the studied traits.
2. The Shapiro-Wilk's test was used to examine the distribution of the studied traits (in all cases normal distribution was found).
3. The significance of the temperature T_{mean} changes of the front and rear upper limbs (the right and left limbs were analyzed both separately and together) by using the non-parametric Friedman test post-hoc Nemeny.
4. Multiple linear stepwise regression analysis (post-hoc last significance differences – LSD) were performed between the series of body surface temperatures readings and the obtained morphological and physiological parameters.

Results

Figure 1 presents the individual temperature drops (T_{mean}) immediately after completing the 90-minute training session with respect to the stasis temperature (T_{mean}) of the separate right and left upper limbs at rest. The difference in the drop in temperature between the right and left limbs (both arm and forearm) did not exceed more than 0.5°C in any of the tested subjects. Larger differences were expected due to the greater functional asymmetry of the right and upper limb during training. In Table 2–4 the minimum and maximum values as well as mean temperature changes (T_{mean}) during the test series are presented.

The largest body surface temperature decreases of the analyzed body areas were recorded in Series 2, immediately after the completion of the physical training session, when compared to the pre-exercise values. The average temperature T_{mean} drop was similar for both right and left upper limbs. Larger drops in average temperatures T_{mean} were recorded at the front of the upper extremities than at their rear (Tab. 2). The average temperature T_{mean} rise of the analyzed isotherms in Series 3, when analyzed in relation to Series 2, were also found to be higher for the front rather than at the rear (Tab. 3).

The significance of the temperature T_{mean} changes of the front and rear surfaces of the upper limbs were analyzed separately as well as together by the non-parametric Friedman test, with Nemeny post-hoc analysis (Tab. 5). The results found that the changes in temperature of the upper limbs' surface in the three series of tests were all statistically significant.

In order to search for the relationships between the changes in surface temperature of the front and rear upper limbs in the series of tests and the analyzed morphological and physiological factors, multiple stepwise regression analysis (post-hoc LSD) was performed. The results of the regression analysis (Tab. 6) found that two factors had a statistically significant effect on the temperature changes in the series of tests: maximal oxygen uptake and HR_t (%HR_{max}). The results found no relationships between the isotherms' temperature changes and the morphological features of the study participants.

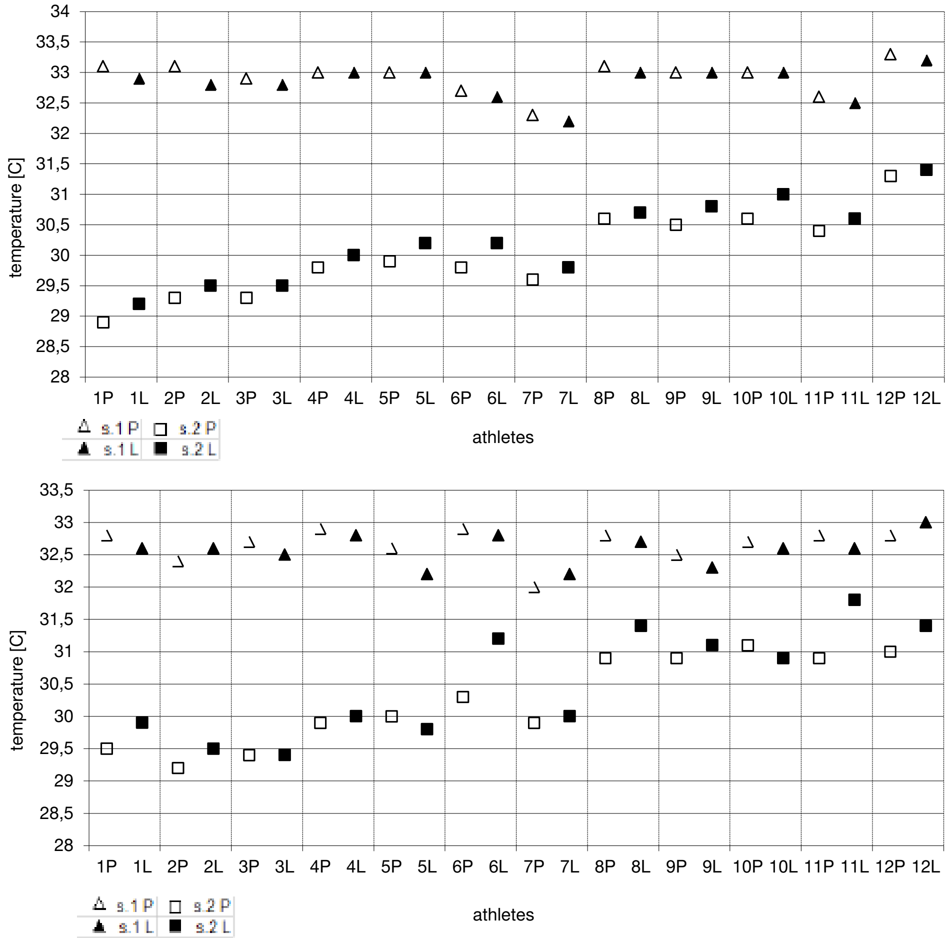

Figure 1. A graphical presentation of the individual temperature T_{mean} drops immediately after the training session (90 min) in relation to the temperature T_{mean} at rest for the right and left upper limbs (P – right, L – left)

Table 2. Minimum and maximum values (min, max) and the arithmetic mean (M) of temperature (°C) change of the selected areas of the body: the front and rear surface of the upper limbs (arms and forearms) before training and immediately after completing the training session (Series 1 – Series 2)

Front surface	min–max(P)	M(P)	± SD	min–max(L)	M(L)	± SD	min–max(LiP)	M(PiL)	± SD
	2–4.2	2.92***	0.676	1.8–3.7	2.59***	0.619	1.9–3.95	2.76***	0.645
Rear surface	min–max(P)	M(P)	± SD	min–max(L)	M(L)	± SD	min–max(LiP)	M(PiL)	± SD
	1.6–3.3	2.41***	0.669	0.8–3.1	2.04***	0.781	1.35–3.2	2.23***	0.701

*** Significant difference of temperature change in the series of tests at $p = 0.0001$, according to Friedman (post hoc LSD)
P – the right upper limb; L – the left upper limb; PiL – the right and left limbs together

Table 3. Minimum and maximum values (min, max) and the arithmetic mean (M) of temperature (°C) change of the selected areas of the body: the front and rear surface of the upper limbs (arms and forearms) immediately after completing the training session and 10 min after completing the training session (Series 2 – Series 3)

Front surface	min–max(P)	M(P)	± SD	min–max(L)	M(L)	± SD	min–max(LiP)	M(PiL)	± SD
	1.2–2.7	1.99***	0.494	1.4–2.7	1.92***	0.456	1.35–2.7	1.96***	0.462
Rear surface	min–max(P)	M(P)	± SD	min–max(L)	M(L)	± SD	min–max(LiP)	M(PiL)	± SD
	0.8–2.5	1.67***	0.547	0.2–2.3	1.39***	0.687	0.7–2.3	1.53***	0.586

*** Significant difference of temperature change in the series of tests at $p = 0.0001$, according to Friedman (post hoc LSD)
P – the right upper limb; L – the left upper limb; PiL – the right and left limbs together

Table 4. Minimum and maximum values (min, max) and the arithmetic mean (M) of temperature (°C) change of the selected areas of the body: the front and rear surface of the upper limbs (arms and forearms) before the training session and 10 min after completing the training session (Series 1 – Series 3)

Front surface	min–max(P)	M(P)	± SD	min–max(L)	M(L)	± SD	min–max(LiP)	M(PiL)	± SD
	0.3–1.9	0.93***	0.51	0.1–1.2	0.67***	0.387	0.2–1.55	0.8***	0.433
Rear surface	min–max(P)	M(P)	± SD	min–max(L)	M(L)	± SD	min–max(LiP)	M(PiL)	± SD
	0.1–1.3	0.74***	0.345	0.1–1.4	0.65***	0.442	0.1–1.05	0.7***	0.345

*** Significant difference of temperature change in the series of tests at $p = 0.0001$, according to Friedman (post hoc LSD)
P – the right upper limb; L – the left upper limb; PiL – the right and left limbs together

Table 5. The results of the Friedman test (with post hoc LSD performed on the temperature changes in the series of tests)

	p	Critical difference: 0.9773			
kgpLiP	0.0001		S.1	S.2	S.3
		S.1	0	2.000	1.000
		S.2	–2.000	0	–1.000
		S.3	–1.000	1.000	0
kgtLiP	0.0001		S.1	S.2	S.3
		S.1	0	2.000	1.000
		S.2	–2.000	0	–1.000
		S.3	–1.000	1.000	0
kgpL	0.0001		S.1	S.2	S.3
		S.1	0	2.000	1.000
		S.2	–2.000	0	–1.000
		S.3	–1.000	1.000	0
kgpP	0.0001		S.1	S.2	S.3
		S.1	0	2.000	1.000
		S.2	–2.000	0	–1.000
		S.3	–1.000	1.000	0
kgtL	0.0001		S.1	S.2	S.3
		S.1	0	2.000	1.000
		S.2	–2.000	0	–1.000
		S.3	–1.000	1.000	0
kgtP	0.0001		S.1	S.2	S.3
		S.1	0	2.000	1.000
		S.2	–2.000	0	–1.000
		S.3	–1.000	1.000	0

kgpP – right upper limb, front surface
kgpL – left upper limb, front surface
kgtP – right upper limb, back surface
kgtL – left upper limb, back surface
kgpLiP – both upper limbs, front surface
kgtLiP – both upper limbs, back surface

Table 6. A summary of the results after progressive stepwise regression analysis (only the significant correlations are shown at $p < 0.05$)

Variable	R2%	Variable $p < 0.05$
kgp s.1-s.2(LiP)	91.84	VO_{2max} (+) $p = 0.003364$ HR_t ($\%HR_{max}$) (+) 0.040761
kgp s.2-s.3(LiP)	47.67	HR_t ($\%HR_{max}$) (+) $p = 0.012940$
kgp s.1-s.3(LiP)	69.64	VO_{2max} (+) $p = 0.003168$
kgt s.1-s.2(LiP)	96.22	HR_t ($\%HR_{max}$) (+) $p = 0.004587$. VO_{2max} (+) $p = 0.041781$
kgt s.2-s.3(LiP)	72.46	VO_{2max} (+) $p = 0.001583$
kgt s.1-s.3(LiP)	43.52	VO_{2max} (+) $p = 0.00871$

kgpLiP – both upper limbs, front surface
kgtLiP – both upper limbs, rear surface
s.1 – the series of thermal images taken before the training session
s.2 – the series of thermal images taken immediately after the training session
s.3 – the series of thermal images taken 10 min after the end of the training session

Discussion

The decrease in skin temperature after physical exercise is due to the prolonged act of sweating that takes place during dynamic exercise. It is known that shortly after physical exertion, one of the responses of the vascular system is the redistribution of blood flow and a reduction of blood flow to the skin [19]. During prolonged exercise an increase in core body temperature is due to metabolic heat production, which is dependent on its intensity and effort.

Trained individuals, as a result of the body's adaptive changes to physical exercise, are found with a lower internal temperature rise with an increased intensity of perspiration, which is able to better cool the body. At the same time, the body surface temperature decreases [20], as was confirmed by the research presented in this study on volleyball players.

The most effective mechanism for the elimination of heat produced by muscles is sweating and evaporation of sweat from the body surface, with the evaporation rate depending on the humidity level and ambient air temperature. In the study, the 90-min training session resulted in sweating, which eliminated endogenous heat and, consequently, led to the observed decrease in skin surface temperature. Therefore, it can be indirectly concluded that the efficiency of the thermoregulatory mechanisms of trained individuals allows them to continue physical exertion without a rise in internal temperature, which could be a factor limiting the physical performance of athletes. What is more, the recorded temperature changes in the series of tests were found to be greater on the front surface of the upper limbs. This can be attributed to the fact that the front surface of the arms and forearms has smaller body fat distribution than on the rear.

In addition, the temperature changes in the series of tests on the symmetrical right and left surfaces of the upper limbs did not differ from each other by more than 0.5°C, even though all of the studied players were right-handed (which led to this limb being more frequently used in training). Similar results were also obtained in other studies [10]. Conducting original research, this group of scientists directed a stress test on an ergometer in which all of the tested subjects were found to demonstrate significant changes of not only the surface temperature of their lower limbs but also in the less-involved upper limbs.

It was found that physical exercise does not only cause local changes of the working muscles' temperatures but also affects the temperature of areas not directly involved in physical effort. During an intense physical workout, the amount of heat dissipated by the body can increase five to six times, that is, an adult of average body weight, with a resting value of 290 kJ/h can produce up to 2000–3000 kJ/h during intense physical activity [21].

Regression analysis found that the variable that had the largest statistically significant effect on temperature change in the series of tests was maximal oxygen uptake. An important aspect of the body's adaptation to physical effort is possessing an efficient thermoregulatory system and is known, from literature on the subject, that trained individuals have a greater ability to remove excess heat from the body. Thanks to these adaptive changes, a trained individual would have lower core temperature and an increased intensity of perspiration, which allows the body to better cool itself down as well as decrease the surface area temperature of the body [5, 22].

Heat loss, generated through the excretion and evaporation of sweat, is necessary to maintain thermal equilibrium during physical exercise, where the heart is used to transport heat to the skin and sweat glands [8, 22]. Therefore, the overall better efficiency and physical tolerance of the tested subjects should be a factor that improves this process, which allows for better heat transfer during the production of excess heat and would allow the body to return to homeotermia during restitution. There is, therefore, the possibility of using thermal imaging as a tool for coaches as a fast, non-invasive assessment of the dynamics of players' body surface temperature changes, which can provide indirect information on the efficiency of the mechanisms responsible for heat removal, enabling athletes to continue performing at their highest level.

Additionally, the decrease in temperature of the analyzed isotherms was also influenced by the percentage of maximum heart rate during training HR_t ($\%HR_{max}$), which was calculated individually for each player. This was also confirmed by literature, where a larger decrease in surface temperature, along with the body's "activation of the cooling process", depends on the fitness level and training intensity of an individual. Coh and Sirok [23] analyzed the surface temperature of the thighs before and during physical effort of varying intensity. The authors found that temperatures changes are adequate in their response of the "inflicted effort", that is, the greater amount of physical effort, the greater the change of the body's surface temperature.

This proves, first of all, the dependence between the intensity of the thermoregulatory processes and the stress load on an individual (dependent on $\%HR_{max}$ during physical exercise) and the overall efficiency of the body, estimated by maximum oxygen uptake. It seems that athletes with higher VO_{2max} are characterized by having a better thermoregulatory response by their circulatory system, which would result in a more intensive elimination of heat and, consequently, a greater decrease in skin surface temperature after 1.5 h of exercise.

The presented results are derived from pilot studies as part of a program studying the dynamics of body surface temperature and its interdependencies with various physiological and morphological factors, all taking place during physical activity by athletes of different sports disciplines. These studies, which take advantage of thermal imaging, may provide a deeper understanding of the body's thermoregulatory processes as well as its effects in specific training programs (as such, no information was found on this subject in available literature).

Conclusion

1. The strong, statistically significant correlation found between maximum oxygen uptake and a decrease in the surface temperature of the upper limbs (arm and forearm) immediately after physical training suggests that thermography can be used as an additional, non-invasive method of informing the efficiency of an athlete's thermoregulatory processes (being a component of gauging fitness level) against other athletes.

2. The front surface of the arms and forearms, rather than the rear, seems to be more suitable in assessing the dynamics of temperature changes. This is due to the decreased fat distribution of these areas, which can act as an insulator to the heat generated by the body. There-

fore, using the front surface of the forearms could allow one to more precisely capture temperature changes.

References

1. Aarts N.J., Presidential address: First European Congress on Thermography. *Bibl Radiol*, 1975, 6, 9–14.
2. Broniarczyk-Dyla G., Several remarks on skin thermometry [in Polish]. *Przegl Dermatol*, 1974, 61, 89–93.
3. Kuzański W., The application of thermography as an imaging diagnostic, method in medicine [in Polish]. *Przegl Pediatr*, 1993, 1, 135–141.
4. Davidovits P., Physics in Biology and Medicine. Academic Press, New York 2001.
5. Smorawiński J., Adaptation of human thermoregulatory mechanisms to physical effort in the course of endurance training [in Polish]. *Monografie Akademii Wychowania Fizycznego w Poznaniu*, 1991, 293.
6. Piwonka R., Robinson S., Gay V., Manlis R., Preacclimatization of men to heat by training. *J Appl Physiol*, 1965, 20, 379–384.
7. Shvartz E., Magazanik A., Glick Z., Saar E., Meverstein M., Benor D., Thermal responses during training in a temperate climate. *J Appl Physiol*, 1974, 36, 572–577.
8. Smorawiński J., Grucza R., Kozlowski S., Thermoregulatory adaptation to exercise in the course of endurance training. In: Nazar et al. (eds.) International Perspectives in Exercise Physiology. Human Kinetics, Champaign 1990, 188–191.
9. Afanacewa R., Basargina L., Załugujewa O., Estimation average temperature of human body during physical effort. *Gig i Sanitaria*, 1985, 9, 32–35.
10. Kempińska A., Chudecka M., Thermal presentation of physical effort of the third year students at the University of Szczecin (the Physical Education Institute) during the scheduled swimming classes [in Polish]. In: Bulicz E. (ed.), Potęgowanie Zdrowia. Politechnika Radomska, Radom 2003, 331–336.
11. Lund D., Gisolfi C., Estimation of mean skin temperature during exercise. *J Appl Physiol*, 1974, 36 (5), 625–628.
12. Hunold S., Mietzsch E., Werner J., Thermographic studies on patterns of skin temperature after exercise. *Eur J Appl Physiol Occup Physiol*, 1992, 65 (6), 550–554, doi: 10.1007/BF00602364.
13. Veghte J.H., Adams W.C., Bernauer E.M., Temperature changes during exercise measured by thermovision. *Aviat Space Environ Med*, 1979, 50 (7), 708–713.
14. Zontak A., Sideman S., Verbitsky O., Beyar R., Dynamic Thermography: Analysis of hand temperature during exercise. *Ann Biomed Eng*, 1998, 26 (6), 998–993, doi: 10.1114/1.33.
15. Merla A., Mattei P., Di Donato L., Romani G., Thermal imaging of cutaneous temperature modifications in runners during graded exercise. *Ann Biomed Eng*, 2010, 38 (1), 158–163, doi: 10.1007/s10439-009-9809-8.
16. Chudecka M., Lubkowska A., Temperature changes of selected body's surfaces of handball players in the course of training estimated by thermovision, and the study of the impact of physiological and morphological factors on the skin temperature. *J Thermal Biol*, 2010, 35 (8), 379–385.
17. Chudecka M., Lubkowska A., Kempińska-Podhorodecka A., Evaluation of temperature changes in upper extremities of waterpolo players by thermovision [in Polish]. *Inżynieria Biomedyczna. Acta Bio-Optica et Informatica Medica*, 2010, 4 (16), 334–338.
18. Chudecka M., Lubkowska A., Evaluation of the body surface temperature changes in the basketball players' after training. [in Polish]. *Inżynieria Biomedyczna. Acta Bio-Optica et Informatica Medica*, 2011, 17 (4), 271–275.
19. Torii M., Yamasaki M., Sasaki T., Nakayama H., Fall in skin temperature of exercising man. *Br J Sp Med*, 1992, 26 (1), 29–32, doi: 10.1136/bjsm.26.1.29.
20. Schlader Z.J., Stannard S.R., Mündel T., Human thermoregulatory behavior during rest and exercise – a prospective review. *Physiol Behav*, 2010, 99 (3), 269–275, doi: 10.1016/j.physbeh.2009.12.003.
21. Antoszewski Z., Gwóźdź B., Skalski J., Hypothermia and hyperthermia in clinical application [in Polish]. Śląsk, Katowice 2000.
22. Kozłowski S., Domaniecki J., Thermoregulation in the course of physical effort in people of different endurance capacity [in Polish]. *Acta Physiol Pol*, 1972, 23 (5), 761–772.
23. Coh M., Sirok B., Use of the thermovision method in sport training. *Facta Universitatis. Physical Education and Sport*, 2007, 5 (1), 85–94.

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