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The applications of thermal imaging in energy cost rating during Aerobic Circuit Training

by Teresa Kasprzyk*, Magdalena Wójcik*, Karolina Sieroń-Stołtny**, Tomasz Piętka** , Agata Stanek***, Zofia Drzazga* and Armand Cholewka*,

** A. Chełkowski Institute of Physics, Department of Medical Physics, University of Silesia, Uniwersytecka 4, 40-007 Katowice, Poland, ter.kasprzyk@gmail.com*
** Chair and Clinic of Internal Diseases and Physical Medicine,
Silesian Medical University, Batorego 15, 41-902 Bytom, Poland
**** School of Medicine with the Division of Dentistry in Zabrze, Department and Clinic of Internal Diseases, Angiology and Physical Medicine in Bytom, Medical University of Silesia, Batorego Street 15, 41-902 Bytom, Poland*

Abstract

The aim of the studies was to check the possibility of efficiency evaluation using thermal imaging during Aerobic Circuit Training. The studies were performed for group of amateurs and sportsmen and another goal of this work was to find the answer if it is possible to evaluate the fitness body level by using the thermovison. The absolute temperature change and the dynamics changes of skin surface as well as body core temperature due to ACT (Aerobic Circuit Training) were taken into consideration. All studies were performed by thermovision camera FLIR Systems E60. Results of the study showed thermoregulation mechanisms behavior during the short and dynamic training. Performed analysis showed clearly the differences between amateur and regular training group.

1. Introduction

It is known the biochemical and physiological processes in human body are very sensitive to temperature changes. Inner body temperature is nearly constant and maintained on basic level 37^{o}C with the typical daily changes about 0,7^{o}C. However the body surface temperature changes in quite wide range due to environmental temperature changes and other external physical factors impact. The thermal energy of human body is gain from the metabolic active tissues. From all energy produced by the organism only 15-25% is transformed into kinetic energy. The remaining part of energy is converted to the heat and distributed through blood supply to all parts of the body [1-3,7,9,11]. There are three main ways of heat loss from the body: conduction, convection and infrared radiation. However important mechanism of body thermoregulation is also water evaporation from body surface (sweat), from respiratory mucosa and from the oral cavity. In fact the exchange from water to steam is the endothermic process and in result the organism is cooled down during sweating. The evaporation of 1 gram of water is equal to remove about 0,6 kcal of heat [4].

The average temperature of human body surface Tsurf is calculated based on the empirical formula (1) [5]:

$$T_{surf} = 0.32 \cdot T_{tibia} + 0{,}18 \cdot T_{chest} + 0.14 \cdot T_{arms} + 0.07 \cdot T_{foot} + 0.07 \cdot T_{head} + 0.05 \cdot T_{hands} + 0.17 \cdot T_{back} \quad (1)$$

where: T_{tibia} - legs surface temperature; T_{chest} - chest surface temperature; T_{arms} - arms surface temperature; T_{foot} - foot surface temperature; T_{head} - head surface temperature; T_{hands} - hands surface temperature; T_{back} - back surface temperature.

Living organisms are characterized by the ability to transforming the matter and the energy. The food delivered to the organism is converting by the digestive processes, which are related to the metabolism [2]. The amount of the heat loss ΔQ is linked with the metabolism energy change ΔE_M and the work done by the muscles ΔW due to the first thermodynamics law for the biological processes are written as:

$$\Delta Q = \Delta E_M + \Delta W \quad (2)$$

When the organism is resting and work is not performing ($\Delta W = 0$) there is possibility to modification the equation (2) to the equation (3). Then the heat flux ϕ transferred to the environment can be calculated by using the equation (3), which is called the Basal Metabolism Rate BMR_0 and is presented below [6,7,8]:

$$\phi = \frac{\Delta E}{\Delta t} <=> BMR_0 = mM^{3/4} \quad (3)$$

where: M – body weight; m – the factor for mammals with the value 3,4 W*kg$^{-3/4}$.

The equation (3) can be used as approximation but it gives interesting data and may be useful in heat of the body production.

2. Material and methods

Whole studied group consisted of 13 women. The age of subjects was between 21 and 47 years old. All activities involved in ACT were performed always in the same place, at the same time (Wednesday, about 20 p.m. in The Energy Studio in Ruda Śląska, Poland) in the similar environment conditions. The measurements were performed in closed space where the temperature was nearly constant, (20 ± 1°C). There weren't any active radiation sources and measurements disrupting devices (e.g. air conditioner or air fan) in the test room. Thermal imaging was performing by using the thermal camera FLIR Systems E60, with the 0,05 K sensivity [10]. Participants had to exercise in short ACT (Aerobic Circuit Training), which took 5 min ± 1 min. In this research ACT was composed with exercises like: jumping jack (30 sec), squats on whole feet (12 repetitions), lunges – step backward (by turns, 10 repetitions by side), the alternate extension arm and leg in sup posted knee (10 repetitions by side), women's pump (12 repetitions), back bows (12 repetitions), mountain climbers (20 repetitions) and burpees (12 repetitions).

There were two subgroups specified:

- Trained group: 5 women, which were practising fitness regular.
- Amateur group: 8 women called amateurs, without a daily fitness schedule.

The face, palm, chest, arms, back and front and back side of legs were measured during researches. The thermal imaging were done from a distance 2,0 ± 0,1 m. Reserchers tried to set camera perpendicular to the measured part of the body. Also important was to kept eyes open by the studied woman, what was needed to investigate the body core temperature read from the eye corner. All measurements were performing in a similar way to *Glamorgan Protocol*, which introduced standards and rules in thermal imaging in medicine [7].
Each of the subjects had to pass the body surface temperature to environment temperature adaptation process, which took about 20 minutes. The adaptation process was based on uncovered the measured parts of the body. This operation purpose was to avoid the artifacts due to contact between skin and clothes. The measured parts of body had to stay uncovered till the end of researches.
Also the body mass and height each of subject were measured, which allowed to define the BMI parameter.

Obtained thermograms were elaborate using a ThermaCam Researcher Pro 2.10 program. Using STATISTICA Soft 12 and Microsoft Excel 2010 all statistics were done.

3. Results:

The representative thermograms from amateur group are presented in Figure 1.

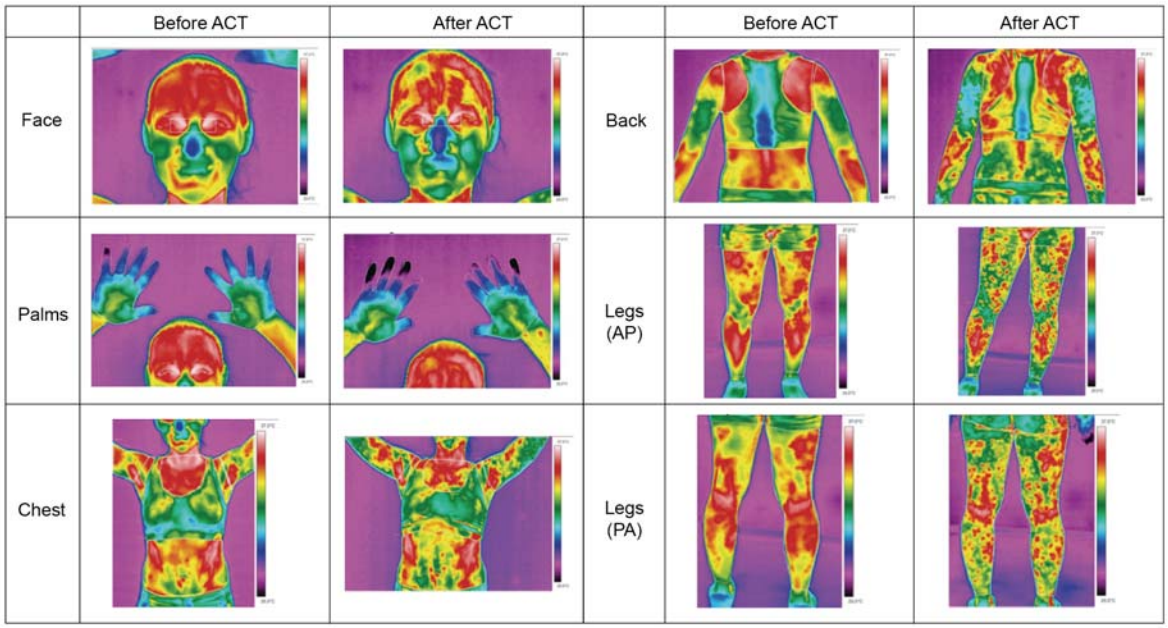

Fig. 1. *Represetative thermograms for measured body parts for one of subjects (women from amateur group). Comparision between thermal images before and after ACT.*

The differences in body surface temperature before and immediately after ACT are clearly visible. It is easily to see that just after short-term ACT the body surface temperature seems to be cooler than before. However it was necessary to perform detail temperature analysis as a function of time. That is why, based on Eq. (1), the average body surface temperature was calculated. Feet temperature was skipped in calculations due to unavailable of measure surface temperature for this body part. Moreover it should be noted that this region has a small contribution to the result. Also the training top covered part of the chest so it was possible to use the mean temperature from this part of the body.

However performed thermal imaging and possibility to study other important parts of the body surface had significant influence to mean of total body surface (Eq. 1) temperature allowed to perform the temperature plot that is shown in Fig 2. .

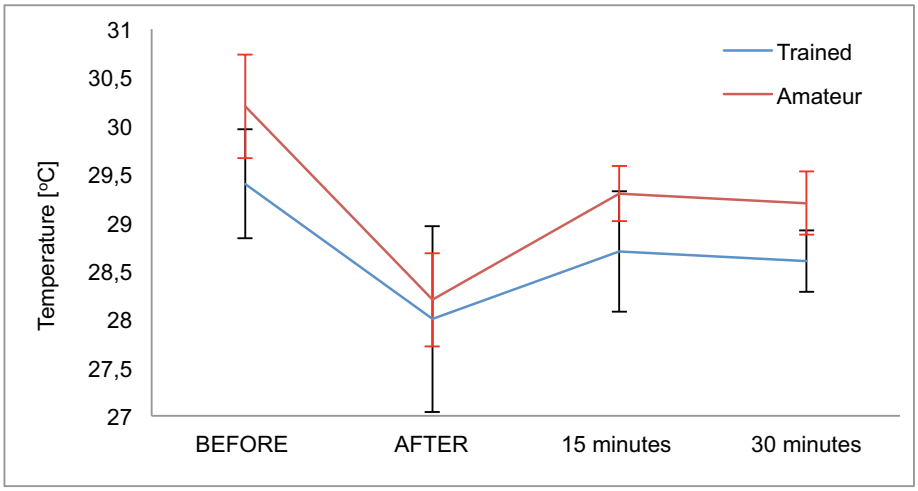

Fig. 2. *The relationship between average body surface temperature and the point of training for the amateur women group and trained group (after 1 month of regular exercising).*

The average body surface temperature changes during activities and till 30 minutes after are shown in Figure 2. Both plots have similar shape. However for the women who did their training regular through the 1 month the surface temperature is lower than body surface temperature of amateur group. The smallest temperature difference (0,2 °C) is directly after the ACT and it is the minimal point of average body surface temperature. The biggest differences (more than 0,5 °C) were observed after 15 and 30 minutes after ACT. Also the body core temperature was measured from the eye corner (face thermal images). The changes of average body core temperature during the ACT are showed in Figure 3.

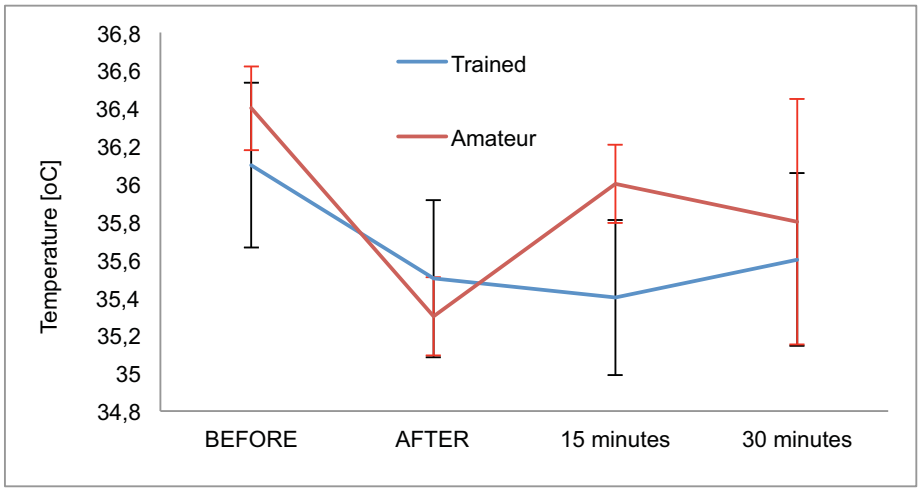

Fig. 3. *The relationship between average body core temperature and the point of training for the amateur women group and trained group (after 1 month of regular exercising).*

Based on the Figure 3 it can be easily see that shape of body core temperature curve is more varied than for the body surface temperature (Fig. 2). For women with training plan the minimal point of temperature is achieved 15 minutes after the end of ACT. The minimal value of body core temperature is noted directly after the ACT for amateur gorup of women. It is possible that people who work out regular and have better condition are getting tired later. Therefore the themoregulation mechanisms are more effective and they are activated later than for amateur subjects.

We might supposed that organism of woman with training plan has got more effective thermoregulation mechanisms. It seems that trained organism expel heat to environment better than amateur because the temperature of trained women is lower in most cases. It seems that the body of trained person is being protected from hyperthermia better. Moreover calculations of the temperature changes between proposed intervals may give us possibilities to determine the training level of subject.

Changes of the average core and surface temperature after the ACT for both groups of subjects were calculated. The results are presented in Table 1.

Table 1. *The changes of average body core and surface temperature before and after ACT for amateur and trained group.*

	Amateur group		**Trained group**	
	T_{BEFORE} [^oC]	**T_{AFTER} [^oC]**	**T_{BEFORE} [^oC]**	**T_{AFTER} [^oC]**
Average surface temperature	30,2	28,2	28,7	27,7
Temp. change	2,0		1,0	

Analyzing the Table 1 one can see that the decrease of the average body surface temperature due to the short and dynamic training is observed. The mean change of body surface temperature is 2,0 ^oC for amateur group and 1,0 ^oC for trained group. It may be assumed that increased sweating causes the higher change of surface temperature in amateur group. The thermoregulation mechanisms are less effective for amateurs. In consequence the sweating is increased and the body surface temperature is lower directly after the training.
Also the statistical significant of the average body surface temperature changes (before and after the ACT) was checked. The Student t-test for dependent attempt ($p<0,05$) was made for the data from Table 1. The result of the Student t-test indicates the statistically significant of the average body surface temperature decreasing after the ACT ($p << 0,5$).

To find out how the 1-month of regular training influenced on the body temperature the change of average body surface temperature ΔT between before T_{BEFORE} and after T_{AFTER} the training was calculated. Calculations were done for the group of women with training plan and the results are showed in Table 2 and Figure 4.

Table 2. *Change of average body surface temperature ΔT between before T_{BEFORE} and after T_{AFTER} the training. Calculations were done for measured before and after the 1 month of regular training.*

	Before 1 one month regular exercising			**After the 1 month regular exercising**		
Subject	**T_{BEFORE} [^oC]**	**T_{AFTER} [^oC]**	**ΔT_I [^oC]**	**T_{BEFORE} [^oC]**	**T_{AFTER} [^oC]**	**ΔT_{II} [^oC]**
P1	29,0	27,7	1,3	29,4	27,5	1,9
P2	28,3	27,0	1,3	29,1	27,3	1,8
P3	28,5	27,0	1,5	29,5	28,0	1,5
P4	28,3	27,2	1,1	28,7	27,2	1,5
P5	29,6	29,6	0,0	30,4	29,8	0,6
Average	28,7	27,7	1,0	29,4	27,9	1,5
Stdev	0,6	1,1	0,6	0,4	0,4	0,5

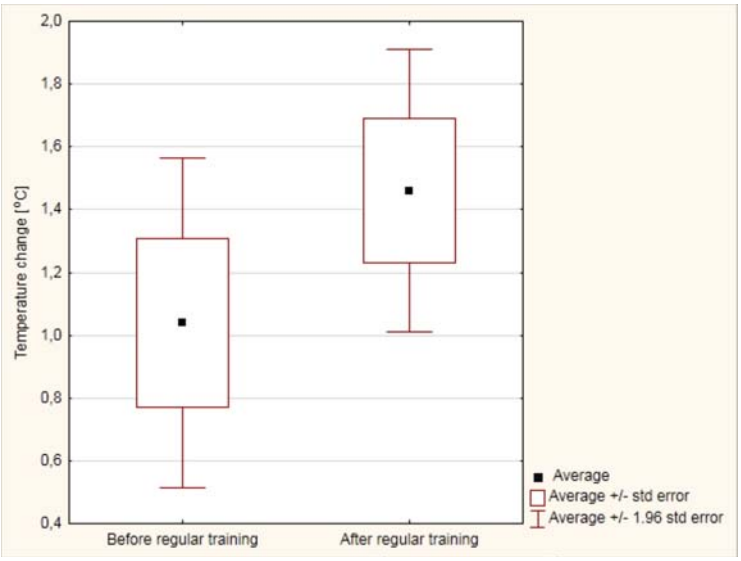

Fig. 4. *Change of average body surface temperature ΔT for women with training plan before and after 1 month of regular training.*

Furthermore the Student t-test was done to check if the change of average body surface temperature before and after 1 month of regular training is statistically significant. The level of significance was set with p factor less than 0,5 value. Analysis shows the value of p factor 0,02.
The difference between surface temperature before and after 1-month of regular training can be easily seen. Also important of this change is confirmed due to statistical analysis. Probably the thermoregulation mechanisms are reinforced due to the 1-month of regular training.

4. Discusion:

From the thermograms showed in Figure 1 we can observe the temperature distribution changes for different parts of the body caused by ACT. It is possible to see that temperature of tibia is higher that the temperature of thigh. This may suggest that the tibia anterior muscle done a lot of work so application of thermal imaging during training can easily give us information about functioning and effort of the chosen muscle parts.

Analyzing the Figure 2 and Figure 3 we can also notice that the average body surface and body core temperature are different for amateur group and group with training plan. However the plots of the curves for both group are similar, but the values of temperature are different. We might supposed that organism of woman with training plan has got more effective thermoregulation mechanisms than amateurs. It seems that trained organism expel heat to environment better than amateur because the temperature of trained women is lower in most cases. It might mean that organism of trained person is being protected from hyperthermia better. It also seems that the temperature changes between intervals may give us possibilities to determine the training level of subject.

Based on the data showed in Table 1 we can see the decrease of average body surface temperature and average body core temperature. It might supposed that body is activating some overheat mechanisms like sweating due to physical effort and followed the evaporation of sweat with the heat exchange. The body core temperature decreasing may be caused by sweat in the eye corner during measure. It should be consider if there is some better method to check the body core temperature, e.g. the ear thermometer.

Moreover thermal imaging performed before and after 1 month of regular training (Fig. 4) showed very clearly the differences in temperature plots. It might supposed that after the 1 month training plan the thermoregulation processes are more active and more efficiency in body cooling.

It is known fact that the physical activity has got a big impact on health. It entails the positive effects for the cardiovascular system and respiratory system. The increase of erythrocytes level in blood, rising up the hemoglobin content and growth volume of blood is causing by regular physical activity. In result the body's aerobic capacity is increasing and its derivative as a body and core temperature changes can be determined by thermal imaging.

5. Conclusions:

- Performed studies showd that the average body surface temperature is decreasing due to short and dynamic training – ACT
- The heat produced by sportsman organism during ACT causes that the increase of average body surface temperature is visible even after the 15 minutes after training.
- Clear difference in body temperature response is visible between amateur and women with training plan groups.
- The difference in average body surface temperature change ΔT obtained before and after the 1 month of regular exercise is statistical significant.
- Such results may point that thermal imaging finds its place as a non-invasive technique to determine the training level of subject.

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