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USAGE OF THERMOGRAPHY AS INDIRECT NON-INVASIVE METHOD OF EVALUATION OF PHYSICAL EFFICIENCY. PILOT STUDY

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Annotation. _Introduction._ One of main features deciding on functional abilities and agility of a man is his conative efficiency. The aim of the study was to determine the influence of physical effort on changes of skin temperature of each body areas and the analysis of dependence between the body temperature and the level of maximum absorption of oxygen (VO2max). _Material and methods:_ The study group consisted of 7 women at about average age of 23.86 (±0.69) years. All participants of the study were healthy, did not have overweight nor chronic illnesses. They also did not do sport professionally. During the research each participant performed the effort in the form of 6 – 8-minute-long step Astrand – Rhyming test and then 10-12-minute-long run on the athletic track. Before and after the effort the women were examined by means of thermo visual cameras (temperature in front and back of the body). In the moment of effort ending studied persons had heart rate measured with heart rate monitor. _Results._ Statistically non-exchangeable temperature reduction of body surface on thighs, forearms, arms, trunk (both in front as well as the back) and behind shins was observed during the study. The greatest drop of about -1.13 °C, appeared behind shoulders, least, about -0.04 °C, on the back surface of the trunk. Only on front side of shins the temperature increased in non-exchangeable manner, about +0.06 °C. The important dependence ($p<0.05$) between the change of temperature in front ($r=-0.82$) and the back of the trunk ($r=-0.78$) as well as VO2max was shown. _Conclusions:_ The higher pulse was measured at the studied participant the lower VO2max values were. There is dependence between the thermal reaction and the efficiency – the greater drop of temperature on the trunk the higher VO2max was. Thermal observation can be therefore helpful as indirect estimation of the efficiency in medicine and rehabilitation.
Key words: thermography, physical, efficiency, assessment.

Introduction

One of main components conditioning undertaking of physical effort is physical efficiency of the organism. It is what decides whether the organism is able to undertake heavy physical efforts, and which loads it will not manage with. It influences also on how quickly after the effort we can return to state of rest, previous to the activity [1].

Physical efficiency of the organism in many cases is the element conditioning the course of rehabilitation. The level of physical efficiency plays special role in the cardio logical rehabilitation. Regular physical training reduces the risk of occurrences of metabolic illnesses and diseases of circulatory system. It was proven; that the regularly done physical training enlarges not only physical efficiency, but it also diminishes clinical symptoms of patients with incapacity of the left heart ventricle. Consequently, tolerance of physical effort and resistance to fatigue improves too. Patients are able to undertake new challenges and greater training-loads, and everyday activities often stop to be the hindrance for them. The rehabilitation of cardio logical patients lengthens the life and improves its quality [1 and 2].

Physical efficiency is also an important part of social and professional life of handicapped persons. Often its level decides on taking up professional work. Medical rehabilitation and an active life style favourably influence psychophysical condition of handicapped persons. Therefore, participation of these persons in rehabilitative camps and therapeutic exercises is essential [3].

Undertaking physical activity increases the level of physical efficiency, and consequently improves quality of life at patients with incapacity of kidney and patients struggling with overweight and obesity. Regular physical training is recommended also as the prophylaxis of osteoporosis [4].

Doing physical activity leads to distinct acceleration of calorification inside the organism, what is a result of increased metabolism of working muscles. The temperature of muscles at rest amounts about 36°C, and its rise follows at once after the beginning of effort and depending on the intensity it can increase to 38°C, and even 42°C (e.g. in thigh muscles) [5]. Warmth with enlarged muscular flow of blood penetrates far inside the body, due to that its temperature also increases. The rise of exertional temperature of internal organs is connected with the intensity of training. During prolonged efforts of endurance the stabilization of internal temperature follows after about 30-40 minutes, and its value is dependent on the workload expressed as the percentage of individual maximum receiving of oxygen (VO2max). This parameter is a subject to considerable individual differentiation and, depending on the level of physical efficiency, the body temperature can be higher or lower at different persons in spite of undertaking of effort with the same intensity [5].

A human organism, due to ability of maintaining constant body temperature and the calorific radiation of tissues, is an excellent object of thermo visual study. The distribution of temperature in different human body parts can serve as a diagnostic criterion and evidence the processes, which happen inside the organism. Thermo graphic research

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more and more often proves to be a valuable supplement of diagnostic research, and the main advantage is its entirely non-invasive and unlimited use regardless of age, gender or health condition.

Basing on above-reasons, the aim of this study was to qualify dependence between the thermal reaction of organism on the prolonged effort and the level of physical efficiency measured with the level of maximum absorption of oxygen (VO2max). Tests on verification of possibility of thermography utilization as the indirect method of estimating the efficiency in the physiotherapy were undertaken too.

Material and methods

There were 7 participants randomly chosen from students of the Warsaw Medical University for this study. They were aged 23–25 years (averagely 23.86 ±0.69). Each of studied persons stressed out, that her life is not related to any over average physical activity (e.g. high-performance sports, regular fitness training, participation in slimming programs etc.). All persons were healthy. For the influence on the thermoregulation as a result of the interview it was ascertained that none of participants had been pregnant. Participants did not have overweight nor obesity problems (BMI within the range 19.1-24.5).

The exercise of each participants consisted of ingress and descent from the step (the step test – 33 cm) in strictly defined tempo (45 times within 2 minutes) set by means of metronome. After 6–8 minutes of effort or achievement of suitable pulse level (steady-state) the examined person performed 10-minute-long run on the track (with defined in the test pulse as the state of functional equilibrium) (tab. 1). The above-activities each of participants performed after about 15-minute-long period of the acclimatization, at rest, in the room of thermo neutral temperature (20–22°C). Each participant performed the physical activity chosen for the examination in sports clothes with uncovered lower and upper limbs as well as the best part of the trunk.

After the acclimatization and before the beginning of effort in the step-test, all participants had photos taken with the thermo visual camera – imaging in front and the back of the body (the trunk, upper limbs, lower extremities, head and neck). Such examine with the thermo visual camera was also performed after the end of running on the track.

Each studied person was wearing heart rate monitor in time of the effort. In the moment of ending the effort the measurement of pulse was taken on the step. Values of the pulse in this moment were taken for assessment of maximum absorption of oxygen in compliance with the method of the Astrand-Rhyming test and for delimitation of the intensity with the track running. VO2max values read from the nomograph were subjected to statistical analysis [6].

Table 1

The course of the study for each participant

Thermal adaptation	Thermovision measurement	Step Test*	Heart rate measurement	Run	Thermovision measurement	End of the test
15 minut	X	6-8 minut	X	10 minut	X	X

* - the heart rate had to stay within the range 120-170 /min.

Thermo graphic imaging was made with the use of Flir A325 camera. The room temperature was set at 22-24°C, while the moisture 48-50% and these parameters were situated in so called „Golden Standard". Additionally external sources of warmth were eliminated. The analysis was done with the Researcher 2.9 Pro software. Each examined person had a thermograph taken from the distance of 3 m. It was the imaging of the front (F) and back (B) surface of the body (separately an upper and lower part). First images were made in resting conditions, after 15-minute-long

adaptation to thermal conditions present in the room, while following two images were made directly after the end of track test. Polar areas marking fields of measurement were appointed markers so that every time the analysis referred to the same surface.

Changes in temperature which happened as a result of the test were verified by means of the t-Student test for dependent data. Dependences between the height and the body mass, the level of BMI and HR, the temperature and VO2max were qualified by means of the Pearson's correlation coefficient. Values on the $p \leq 0.05$ level were accepted as statistically important.

Results

Five from the studied persons were characterized with the average efficiency (characterized with the VO2max level). According to the criterion of the American Heart Association, the good result was reached only by three studied persons (fig. 1).

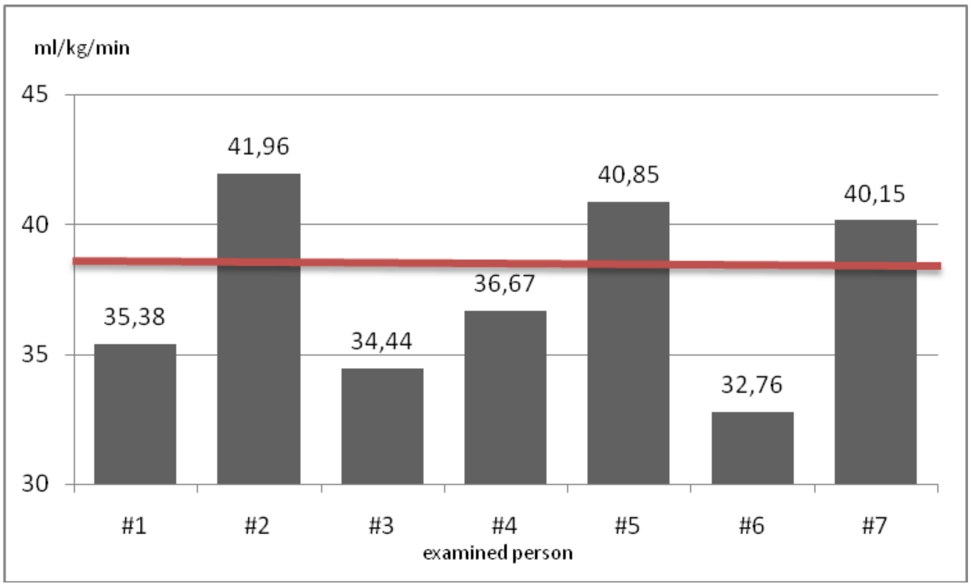

Fig.1. Results of the Astrand-Rhyming test after the reading of nomograph („the good result”, according to American Heart Association, was marked with the line).

Table 2

Temperature changes of the body surface of studied persons occurring due to realized physical effort

	FRONT					BACK				
	Shin	Thigh	Trunk	Fore-arms	Arms	Shin	Thigh	Trunk	Fore-arms	Arms
BEFORE	31,62 ±1,13	32,26 ±1,43	33,18 ±2,26	31,02 ±1,91	32,04 ±0,99	32,00 ±1,18	31,99 ±1,97	34,01 ±2,18	31,07 ±1,16	32,32 ±1,33
AFTER	31,68 ±1,14	31,99 ±1,52	32,85 ±2,70	30,92 ±2,19	31,90 ±1,06	31,84 ±1,44	31,76 ±1,99	33,97 ±2,15	30,91 ±0,93	31,19 ±1,11
CHANGE	p>0.05									

Due to effort the average superficial temperature of the trunk (both sides) and thighs and forearms (in front) dropped (tab. 2). However, there were no statistically essential changes ($p>0.05$). The large range of results requires attention too, because this decrease referred only to some studied persons and mean values, while at some research participants there was observed also the temperature rise. The greatest differentiation of results appeared on front and back of the trunk, where changes of superficial body temperature from -2.2 to +2.2°C were noted.

Correlation analysis showed its significant level ($p<0.05$) for the front ($r=-0.82$) and back of the trunk ($r=-0.78$). It means that the greater decrease of temperature on this trunk, the higher VO2max was. There was no statistically important dependence ($p>0.05$) between VO2max and BMI and the frequency of heart contractions.

Discussion

The analysis of dependence of obtained pulse at the end of undertaken exercises (about 15-minute-long step test and the run) did not show its dependence on VO2max and the body mass of the examined persons. It is convergent with the results by, among others, Thomas et al. (1993) which ascertained that age, gender, quantity of adipose tissue, body mass nor length of lower limbs significantly correlate with VO2max. They infer, that the maximum consumption of oxygen is dependent on many factors simultaneously, which result in the large variability of data [7]. However, strong negative correlation was observed. The higher pulse was obtained by the person in the last part of the effort, the lower VO2max level calculated with Astrand-Rhyming nomorgram was.

Similar dependence was observed by Chudecka and Lubkowska (2012) at volley-ball players training for 90 minutes. They noticed that the higher pulse the lower VO2max at training sportsmen. Additionally they noted that drops of temperature on the front body surface were greater than on the back. It means that the organism gets rid of the excess of internal warmth more or in the first instance through back body surface (shoulders, back, buttocks, thighs) than through front [8]. It explains obtained in the study greater temperature drops on the front surface of the trunk and the back one of lower limbs and only the minimum-difference (-0.04°C) on the back surface of the trunk at research participants.

It is doubtless that the warmth generated in muscles during the effort must be taken (convectively by blood) and sent to organs and distant areas from working muscles, and when this does not suffice outside. It seems that the large body surface (back or front one) is a foreground-area of warmth rendition (in the way of convection, but also perspiration and vaporization of the sweat). Akimov et al.. (2009) ascertained, that the temperature always grows close to the nape, along the centre line of the body (near the spine), until the lumbar region and it has the shape of the perpendicular belt, whereat the more toward the sides, temperature decreases . Additionally in the analysis Akimov showed the statistically essential correlation between VO2max and the superficial temperature of the back of the trunk [9].

On the other side, as Adamczyk (2013) proves, there is statistically significant dependence between the thermal reactions visualized in thermo visual image and the level of oxygenic efficiency measured by means of VO2max. The higher efficiency of the organism translates to greater efficiency of mechanisms of thermoregulation, what in turn, in thermo visual image, causes the greater reduction of exertional temperature of the body surface. The author explains this as the result of efficient rendition of warmth through perspiration. In this context the temperature rise at the progressive effort can testify about the low efficiency [10].

The part of other authors also evidences the occurrence of temperature decrease on the body surface due to the effort, what is connected with the occurrence of the sweat and further its evaporation from the skin [11-13]. This can prove good rendition of the warmth. Therefore, if we notice the drop of skin temperature, it may indirectly inform us about the higher readiness to effort. This effect was confirmed for numerous kinds of preparatory exercises used in the warming up [10].

During effort there is increase of blood flow in working muscles, and this happens this with the cost of diminution of perfusion by visceral organs and cutaneous coats, especially in close area to muscles working most intensely [14].

Johnson and Robinson showed that quickly at the beginning effort leads to skin temperature reduction (skin vasospasm) because blood runs to nearby working muscles [15].

In a little smaller degree the limitation of the perfusion appeared in forearms (drop of skin temperature: behind forearms -0.16°C, forearms in front -0.1°C and on shins -0.16°C. Instead on front side of shins there was minimum-increase (+0.06°C), which can prove little meaning of this area of the skin in thermoregulation, or for the nearness to the tibial bone this area of the skin does not take part in thermoregulation (quite large front-paracentrical surface of bone adheres directly to skin and separates it from muscles of the calf). That is why it is an important thermal barrier which blocks the warmth flow from muscles of calves to the skin in front of tibia.

Research with the use of thermo visual method at those exercising on cycle ergometer was run, among others, by Torii and Zontak. In turn Zaidi examined swimmers, and Ludwig applied thermography at those practicing breathing exercises [11, 16-18]. In this research changes in temperature of coats in different body areas - both drops (Torii) as well as rises (the rest of quoted above), were observed.

Ferreira (2008) assessed changes of temperature at younger and senior citizens. Bertraming (2008) studied schedules and local changes of temperature, among others of deltoid muscle [19 and 20]. Merla (2005) first and only yet published the research with the use of thermo visual camera at trained and not trained before, during and after the effort. This research could be the guideline for the elaboration of standardized thermo graphic study in clinical and sports practice [21].

The occurrence of the first drop of skin temperature from the area above the intensely working muscles at not trained people (ones leading rather sitting life style) was observed by Formenti and co. (2013). It is also described by other authors [22]. Merla (2012), at those tested on the track, in the twelfth minute of the effort, observed decrease of temperature on the skin of whole frontal part of body, and only in the resting phase the skin temperature increased to the value from before the effort [23]. Adamczyk (2012) observed drops of temperature in the area close to quadriceps during the warming up before the training. The statistically significant decrease was obtained for the intensive warm-up with the utilization of elastic band, though light 10-minute-long warming up or 5-minute-long one combined with the warming up with the use of elastic band also caused, though statistically non-exchangeable, temperature reduction in the area close to quadriceps [13].

Research run in the present work are partly coherent with observations of other authors. Its interpretation however must take into consideration the kind of effort, its intensity and the time of thermo visual measurement from the beginning of the effort (or possibly after its end). The characterization of research participants is very important for the interpretation too. Different results will be obtained for persons who trained and those who have not trained. The results will also differ for small children, adults and the elderly, and probably also for both genders. All the more it seems, that after suitable standardizing of official investigative records the thermography as the method should find the wide use in the rehabilitation and sport, as well as in the clinical diagnostics (assessment of possibility of using suitable trainings for persons after heart failure, with heart disease, arterial hypertension, diabetes etc.). Basing on initial results of thermogram it is possible to recommend, to forbid or to modify the suitable kind of the training for a person. It would improve the safety of trainings, but also their effectiveness. Moreover, with the observation of thermal reaction of the organism on physical effort we can assess the level of efficiency, what in the physiotherapy seems to be essential.

Conclusions

1. Pulse values are connected with values of the maximum absorption of oxygen (VO2max).
2. As the result of undertaken effort the average temperature of each body part (with the exception of the front surface of shins) decreased. Large surfaces of the body such as e.g. the trunk are the best place to observe thermal reactions of the organism on.

3. It was not univocally decided whether there is any dependence between the body temperature and the level of maximum absorption of oxygen (VO2max). This demands more methodically composite investigative experiment which can be based on results obtained in this research.
4. The thermo visual camera can prove to be a helpful tool used for assessment of progress during the process of rehabilitation; for planning the course of rehabilitation; for analyses and assessment of preparation of professional sportsmen as well as those unprofessional ones. It can also be a valuable diagnostic device at ill.

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