Acta of Bioengineering and Biomechanics
Vol. 19, No. 4, 2017

Original paper
DOI: 10.5277/ABB-00924-2017-03

Thermographic evaluation of muscle activity after front crawl swimming in young men

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Purpose: The information about the workload on individual muscles in the course of a specific physical activity is essential for targeted prevention, early diagnosis and suitable therapy concerning their overloading and injury. The aim of this study is to evaluate temperature changes in particular skin areas in the course of front crawl swimming, caused by muscle work. *Methods:* Thermograms were taken of 13 students of Defense University immediately and 15 minutes after swimming 1,000 m focused on 20 regions of the skin over the selected agonists and synergists in upper extremities and body. FLUKE TiR infrared hand camera was used. *Results:* The results indicated the significant increase in the relative temperatures in the areas of agonists of swimmers' movement – triceps brachii: from 0.952 to 0.997 of normalized units (nu) on the right and from 0.955 to 0.986 nu on the left. At the same time, the temperature of the muscles participating in lifting the arms above the water surface and stretching them forward – deltoids – increased as well (rear part: from 1.002 to 1.015 nu on the right and from 1.002 to 1.014 nu on the left, sides: from 1.008 to 1.023 nu on the right and from 1.011 to 1.023 nu on the left). *Conclusions:* In conclusion, the order of the other agonists is as follows: biceps brachii, pectoralis major muscle, and latissimus dorsi. This study provides the options for objective assessment of workload on specific muscles or muscle groups during front crawl swimming.

Key words: *infrared thermography, swimming, muscle activity*

1. Introduction

Information about the workload on particular muscles (agonists and synergists) in the course of a specific physical activity is essential for targeted prevention, early diagnosis and suitable therapy concerning their overloading and injury [5]. There is a higher risk on swimmers regarding the overload on the shoulder, followed by neck and back [24]. Moreover, objective measurement of the energetic and metabolic activity of specific muscles or muscle groups is also problematic. Current methods of evaluating the level of metabolic muscle activity in the course of human physical activity are based on analysis of the expired air and calculation of oxygen uptake. However, this method of indirect calorimetry only provides informations about the overall body energetic demands [14].

In sports, it was suggested by Gomez Carmona et al. [13] that injury prevention one of is the most essential applications of thermography. For instance, infrared thermography is used to avoid muscle, joints, or bone injuries, and enables detecting the symptoms of potential fatigue and overload before they turn into an injury. Different levels of training may lead to high risk of injuries for athletes. That is why all professionals in physical activity sports should be aware of the existence of the methods to overcome this problem and use them [13].

Estimation of energetic and metabolic activity of specific muscles on the basis of the calculation of performed mechanical work is not reliable because the

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Received: May 31st, 2017
Accepted for publication: August 1st, 2017

expanded work (input) depends on mechanical efficiency, which varies in individuals based on the techniques of the motions performed [1].

The prime movers at hand entry, hand exit, and recovery phases of crawl swimming are the upper trapezius, rhomboids, supraspinatus, the middle and the anterior deltoid, whereas in underwater phases, the main propulsive muscles are the pectoralis major and the latissimus dorsi. In all swimming phases, rotator cuff muscles are of great importance as they help stabilize the scapula and humerus. For example, the teres minor follows the activation of pectoralis major in all phases [22]. From another point of view, some authors say that the activation of biceps, triceps, brachioradialis, and flexor carpi ulnaris at the elbow was higher in the early pull-through phase, with brachioradialis and biceps being prime movers. More insight on the muscle activation at the wrist is given by Caty et al., she could reach a main conclusion which shows that flexor carpi ulnaris, and extensor carpi ulnaris are highly activated muscles in the early pull-through phase so as to stabilize the joint. So, it is necessary to make further discussions of the important muscles activated in the crawl technique other than triceps, deltoid, and the fact that the skin temperature over these muscles does not follow the trend of triceps and deltoid [6], [25].

Electromyography – EMG is the most suitable way for assessing the individual muscles' activity. This method introduces information about electrical muscle activity which precedes metabolic activity itself. The new knowledge about the relation of increasing integrated electrical activity and power which the muscles apply against resistance [18] seems to be promising. Results of electromyography studies of muscle activity during swimming have been recently published [8], [12]. However, these parameters do not stem from ongoing or finished energetic and metabolic activity of specific muscles or muscle groups. Information about workload consequences can be introduced by local biopsy methods. However, this method is too invasive and, thus, not acceptable. What might be taken into consideration is the use of the ultrasonography of muscles, which can identify the change in muscle capacity which might be related to preceding work activity (increase in blood flow and accumulation of fluid in the tissue) [18].

The fact that catabolic reactions in the course of muscle work activity produce thermal energy which increases the temperature of adjacent skin pushes us to the use of infrared thermography [10]. According to Kraemera et al, muscle's mechanical efficiency work in human is relatively low, 20–25%. It implies that most of the muscle's chemical energy is transformed into thermal energy [18]. Higher metabolic activity and blood supply to muscle tissue lead to a significant increase in the temperature of muscles. Thermal energy is consequently transferred by fluid flow in blood vessels to adjacent tissue, including skin. Thermography shows the emission of thermal energy off the body [19].

The temperature changes of a swimmer were described by Zaidi et al. in 2007 [29]. The swimmer used, in turns, all four swimming styles each for 1 minute and there were 10-minute breaks between them. They defined the temperature of large body segments and they did not evaluate the areas corresponding to particular muscles. For example, dorsal arm included dorsal deltoid muscles and triceps. Similarly, Sillero-Quintana et al. used thermography to discover that the temperature of upper limbs decreased by 3.4 °C (from 32.8 to 29.4 °C) after swimming in pregnant women [13]. The temperature of their chest decreased from 32.4 °C to 30.5 °C. They do not mention the temperature of water in the swimming pool and they do not specify the load, either. On the other hand, sweat evaporation results in significant skin cooling and when the skin is dried completely, its temperature starts rising again [11].

The fact of the significant temperature increase in regions of agonists and synergists for the swimmer's forward motion was discovered by of thermographic evaluation of the muscular activity after breast stroke swimming [21].

The aim of this study was to find out and evaluate temperature changes of the skin on the arms and torso in the course of front crawl swimming, caused by muscle work. We would like to provide information relevant for targeted prevention, early diagnosis and suitable therapy concerning their overloading and injury.

There are two the main questions of the study. The first one is how the temperature of skin regions is corresponding to muscle agonists and synergists changed while swimming front crawl and the record one is to what extent the temperature distribution is side asymmetric.

2. Materials and methods

Participants

The participants of the study were 13 young students of the University of Defence who did not swim competitively. Participants avoided extrinsic factors which were affecting skin temperature, like physical activity, before the assessment. They went swimming once a week within the framework of their studies. Their average age was 20.6 ± 1.61, height was 181.8 ± 5.93 cm, weight was 81.6 ± 6.5 kg a body mass index 24.7 ± 2.18 kg·m^{-2}.

Procedure

Only specific muscles that are being activated during swimming were chosen for evaluation [15], [16]. Out of agonists and synergists of two main phases of arms motion (pressure against water and arm lifting above water surface) and torso work there were selected those muscles which are close to the skin and are sufficiently large (circular skin area with a diameter of at least 4 cm). Relevant skin areas were set, both on right and left side, in total 20 regions of interests – ROI: Da – m. deltoids – pars anterior; Dp – m. deltoids – pars posterior; Dl – m. Deltoids – pars laterals; Bb – m. biceps brachii; Tb – m. triceps brachii; Ts – m. trapezius – pars superior; P – m. pectoralis major et minor; R-Ti – m. rhomboids major et minor, and m. trapezius – pars inferior; Ld – m. latissimus dorsi; Esl – m. erector spinae – pars lumbar's.

Students had to swim front crawl for 1000 m in the fastest possible time (their personal best). The swimming pool was 50 meters long. They were swimming in 3 groups, in lanes which were 2 meters wide between 9 and 11 a.m. The temperature of the water was 26.1–27.7 °C, temperature of air in the hall was 27.9–28.1 °C, relative humidity 52.3–52.8% and air flow up to 0.5 m.s^{-1}. Average time of swimming was 25:18 min:sec (SD 3:54) and speed 0.673 m·s^{-1} (SD 0.108).

Students were adapting to the temperature in the hall by standing in the hall for 15 minutes, after putting on the swimsuit without having a shower before. Thermograms were made before swimming and 15 minutes after swimming. There were always 4 thermograms – 1 from the front, 1 from the back, 1 from the right and 1 from the left. It means 8 per each student, which are 104 thermograms in total.

A handheld camera Fluke TiR was used with infrared spectral band 7.5–14 μm, accuracy: ± 5 °C, field of view 23 × 17 °, manual focus, thermal sensitivity 0.1 °C, display with 480 × 640 resolution and manufactured in the U.S.A. Thermograms were analyzed in a special program Smart View 2.0. manufactured in the U.S.A. For the presentation of the skin temperature a color palette with a high contrast was used. To calculate temperatures of the selected areas, a coefficient of infrared emissivity of human skin 0.98 was used.

Statistical analysis

To evaluate normality of data distribution, Shapiro–Wilk test was used. Medians and quartiles were used to express basic characteristics of the values of calculated temperatures. To test differences in temperatures before and after swimming and between the right and left side a nonparametric Wilcoxon signed-rank test (a paired difference test) was chosen. To test-relative temperatures of muscle regions before and 15 minutes after swimming, Wilcoxon test of their differences and Spearman test of relation between relative temperature and the speed of swimming were used. The level of statistical significance α was set to be ≤ 0.05.

The problem with evaluation of skin temperature which was being heated up by muscles and at the same time cooled down by water was solved by a relative indicator of temperature (*tR*) with normalized units (nu) for each ROI: *tR* [nu] = *t* / *tM*, where *t* is temperature of ROI [°C] and *tM* is mean of all 20 ROI [°C].

3. Results

The examples of thermograms of one student are presented in Fig. 1. Median and quartiles of skin temperatures in muscle regions are shown in Table 1. Before swimming and 15 minutes after swimming the temperature of triceps brachii (Tb) was significantly

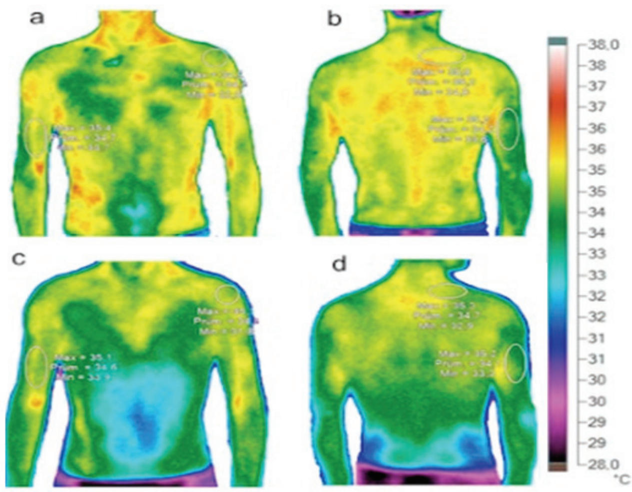

Fig. 1. Examples of thermograms with selected muscle regions. Thermograms a–b were made before swimming and c–d 15 minutes after swimming. In Fig. 1a), c) (view from the front) parts of front deltoid muscles and biceps brachii are highlighted. In Fig. 1b, d (view from the back) rear parts of deltoid muscles and triceps brachii are marked. Colourful temperature scale is from 28 to 38 °C. In 11 out of 20 previously set muscle regions rejected hypothesis about normal value distribution at level of significance of 5% was rejected

Table 1. Skin temperature (°C) of muscle regions before and 15 minutes after a 1000-meter swim – front crawl (n = 13), Wilcoxon test of differences in temperatures before and after swimming and between right and left side

Muscle region	Before /after	Right side			Left side			R-L difference			
		m_e	25%	75%	m_e	25%	75%	m_e	25%	75%	W_{R-L}
Da	before	34.3	33.7	34.6	34.2	33.8	34.4	0.0	–0.1	0.3	NS
	after	34.3	33.9	34.9	34.7	34.1	35.1	0.2	–0.2	0.3	NS
P	before	34.0	33.9	34.2	33.9	33.5	34.3	–0.2	–0.4	0.2	NS
	after	33.6	32.6	34.0	33.9	32.7	34.1	0.0	–0.1	0.3	NS
Bb	before	33.7	33.3	34.7	34.0	33.3	34.8	0.1	–0.1	0.2	*
	after	34.1	33.6	34.4	34.0	33.8	34.2	0.1	0.0	0.2	NS
Ts	before	35.2	35.0	35.4	35.1	35.0	35.3	0.0	–0.1	0.2	NS
	after	34.8	34.3	35.4	35.0	34.5	35.4	0.2	0.0	0.2	NS
Dp	before	34.4	34.0	34.5	34.1	34.0	34.5	0.0	–0.3	0.5	NS
	after	34.7	34.2	35.1	34.6	34.1	34.9	0.1	–0.2	0.2	NS
R-Ti	before	34.7	34.4	35.0	34.6	34.4	34.8	–0.1	–0.5	0.0	NS
	after	34.0	33.6	34.8	34.3	33.2	34.8	–0.2	–0.4	0.0	NS
Tb	before	32.3	31.8	33.0	32.4	32.1	33.1	–0.1	–0.2	0.1	NS
	after	34.0↑↑↑	33.5	34.2	33.8↑	32.6	34.0	–0.1	–0.2	0.1	NS
Ld	before	34.1	33.6	34.4	33.8	33.5	34.5	0.1	–0.1	0.2	***
	after	33.8↓↓↓	33.0	34.0	33.7↓	32.3	34.1	0.0	–0.2	0.0	NS
Esl	before	34.1	33.8	34.4	34.1	33.8	34.2	–0.1	–0.2	0.2	NS
	after	33.1↓↓↓	32.4	33.2	33.1↓↓	32.7	33.4	0.2	0.0	0.3	NS
Dl	before	34.2	33.9	35.0	34.5	33.8	34.7	0.4	0.2	0.5	NS
	after	34.8	34.6	35.2	34.7	34.4	35.2	0.0	–0.2	0.1	NS

Note: before/after – before or after swimming; 25% – 1st quartile; 75% – 3rd quartile; R-L – right-left; W_{R-L} – Results of Wilcoxon test of right-to-left difference: NS – insignificant difference; * – $p < 0.05$; *** – $p < 0.005$; ↑ – significant increase ($p < 0.05$); ↓↓ – significant decrease ($p < 0.01$); ↑↑↑/↓↓↓ – significant increase or decrease ($p < 0.005$). Da – m. deltoids – pars anterior; Dp – m. Deltoids – pars posterior; Dl – m. deltoids – pars lateralis; Bb – m. biceps brachii; Tb – m. triceps brachii; Ts – m. trapezius – pars superior; P – m. pectoralis major et minor; R-Ti – m. rhomboids major et minor, and m. trapezius – pars inferior; Ld – m. latissimus dorsi; Esl – m. erector spinae – pars lumbalis.

higher (on the right p = 0.004166; on the left p = 0.028057). In biceps brachii (Bb) there was a minor increase in temperature of particular skin region on the right side. In pectoralis major muscle (P) and latissimus dorsi (Ld) there was an insignificant decrease in temperature. In deltoid muscle there was a statistically insignificant increase in temperature in their rear (Dp) and side parts (Dl). There was evidence of a significant decrease in temperature in the lower part of erector spinae – Esl (on the right p = 0.003729; on the left p = 0.007916). Right-to-left differences in temperatures (column on the very right side) are significant only in 2 cases (10%) in biceps brachii and latissimus dorsi before swimming (Bb and Ld).

In Table 2 the calculated relative temperatures of skin in muscle regions, results of Wilcoxon tests of the differences before and 15 minutes after swimming and results of relation between these differences and speed of swimming are collected. From the relative temperatures point of view, there is a significant increase in temperature evident especially in triceps brachii (Tb) and on sides (D1) and in the rear part (Dp) of deltoids on the left part and also in the front part of m. deltoids (Da). Relative decrease in temperature is evident on both sides of m. erector spinae lumbalis (Esl) and on the right in rhomboids and lower part of trapezius muscle (R-Ti). There was only an insignificant increase in temperature in biceps (Bb). In the case of pectoralis major muscle the temperature remained nearly the same and in the case of latissimus dorsi (Ld) temperature slightly decreased along with rising speed of swimming, relative temperature in the front part of m. deltoids on the left significantly increased. Statistically insignificant relation is evident in rhomboids and lower part of trapezius muscle (R-Ti), on the left and on the right.

In Figure 2 changes in relative temperatures on particular muscle regions after swimming.

Table 2. Relative temperatures of muscle regions before and 15 minutes after swimming,
Wilcoxon test of their differences and Spearman test of relation between relative temperature and the speed of swimming (n = 13)

Muscle region	Side	Relative temperature (nu)						*W* before-after	Spearman test (R)
		Before swimming			15 minutes after swimming				
		m_e	25%	75%	m_e	25%	75%		
Da	R	1004	0.996	1.008	1.008	1.004	1.019	NS	0.197802
	L	0.999	0.996	1.007	1.020	1.010	1.028	↑↑	0.593407*
P	R	0.998	0.987	1.001	0.987	0.976	0,999	NS	0.104396
	L	0.993	0.989	0.996	0.991	0.981	1.003	NS	–0.005495
Bb	R	0.998	0.990	1.007	1.004	0.991	1.010	NS	0.186813
	L	1.001	0.987	1.010	0.999	0.992	1.011	NS	0.324176
Ts	R	1.030	1.027	1.034	1.028	1.017	1.035	NS	0.236264
	L	1.024	1.021	1.040	1.023	1.018	1.042	NS	0.373626
Dp	R	1.002	1.001	1.010	1.015	1.008	1.026	↑	0.192308
	L	1.002	1.001	1.007	1.014	1.010	1.020	↑↑↑	0.010989
R-Ti	R	1.016	1.011	1.023	1.005	1.000	1.010	↓	0.428571
	L	1.014	1.013	1.019	1.009	0.993	1.014	NS	0.532967
Tb	R	0.952	0.947	0.969	0.997	0.988	0.999	↑↑↑	–0.142857
	L	0.955	0.946	0.963	0.986	0.973	0.993	↑↑	0.302198
Ld	R	0.999	0.990	1.007	0.990	0.984	0.995	NS	0.197802
	L	1.001	0.987	1.004	0.986	0.979	0.994	NS	0.115385
Esl	R	0.999	0.993	1.005	0.966	0.962	0.971	↓↓	–0.153846
	L	0.996	0.987	1.002	0.970	0.959	0.975	↓	0.197802
Dl	R	1.008	0.996	1.016	1.023	1.011	1.027	↑	–0.111888
	L	1.011	1.002	1.013	1.023	1.019	1.025	↑↑↑	0.016484

Note: nu – normalized units; me – median; 25% – 1st quartile; 75% – 3rdquartile; W – before-after – Wilcoxon test of differences in temperatures before and after swimming; R – right side; L – left side; NS – insignificant difference; ↑/↓ – significant increase or decrease ($p < 0.05$); ↑↑/↓↓ – significant increase or decrease ($p < 0.01$); ↑↑↑ – significant increase ($p < 0.005$); *R* – Spearman correlation coefficient; * – statistically important relation ($p < 0.05$). Da – m. deltoids – pars anterior; Dp – m. deltoids – pars posterior; Dl – m. deltoids – pars lateralis; Bb – m. biceps brachii; Tb – m. triceps brachii; Ts – m. trapezius – pars superior; P – m. pectoralis major et minor; R-Ti – m. rhomboids major et minor, and m. trapezius – pars inferior; Ld – m. latissimus dorsi; Esl – m. erector spinae - pars lumbalis.

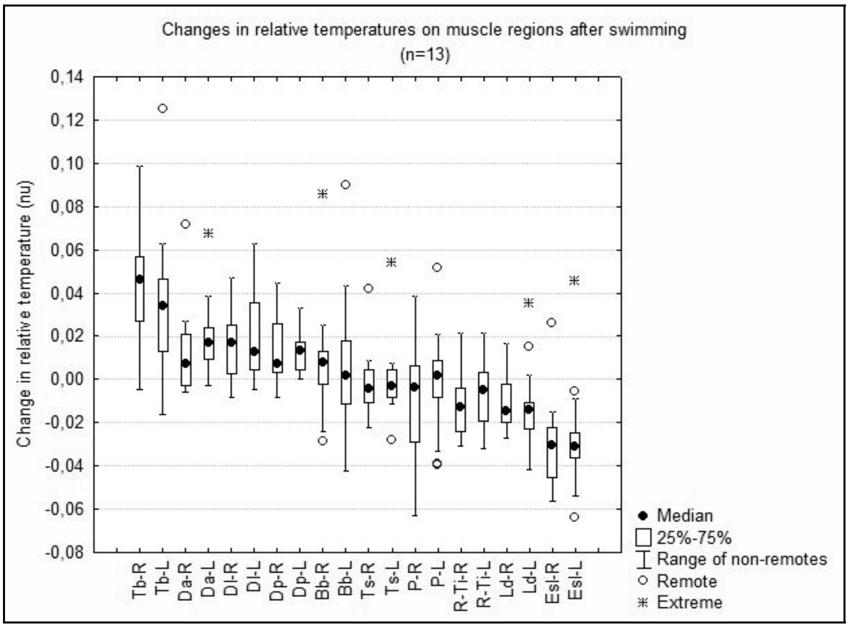

Fig. 2. Changes in relative temperatures on particular muscle regions after swimming Note: 25% – 1st quartile; 75% – 3rd quartile. Tb – m. triceps brachii; Da – m. deltoids – pars anterior; Dl – m. deltoids – pars lateralis; Dp – m. deltoids – pars posterior; Bb – m. biceps brachii; Ts – m. trapezius – pars superior; P – m. pectoralis major et minor; R-Ti – m. rhomboids major et minor, and m. trapezius – pars inferior; Ld – m. latissimus dorsi; Esl – m. erector spinae – pars lumbalis; R – right; L – left

4. Discussion

Expected increase in temperature of the skin regions corresponding to the main agonists of forwarding movement was proved in triceps brachii. There was a statistically significant increase in both relative and absolute temperature. These findings are partially in line with the results of Wade & Veghte [28], who measured the highest temperature in 4 swimmers after a 500-meter swim (temperature of water 23.5 °C) in the following muscles: deltoids, trapezius, triceps and biceps brachii and pectoralis major muscle. They did not specify either the order of the muscles (from the highest temperature to the lowest) or the values of temperatures. They did not specify whether they calculated with the temperatures of skin spots or skin regions. The results do not contradict the results by Zaidi et al. [29], who observed just one swimmer. These authors discovered a significant increase in temperature in large segments of the whole arms. The view of these segments from the back includes triceps and dorsal part of the deltoid. The front part of segment covers biceps and anterior part of the deltoid. This means that these segments do not exactly correspond with two selected regions of agonist of swimmer´s moving forward. The authors state that the highest temperatures correspond to the zones closest to the vital organs of the swimmer (abdomen, chest, back). After swimming, in all analyzed techniques, these were the areas with the smallest variation, but always considerably higher (always more than 1 °C) than the variation reported in this study, in any of the reported regions of interest, except in the triceps.

The present study has adopted different techniques from those employed by Zaidi et al. [29]. In that study only one swimmer has been studied and the had to perform 4×100 m, 100m per each technique, with 10-minute intervals. As for the study conducted by Domingues et al. [9], participants had to perform 7×200 m protocol in every testing day, one for each technique. It is noteworthy that the intensity of each exercise is not the same, and that may explain the observed differences. The thermal response of the swimmer has been evaluated by Zaidi et al. in four techniques: backstroke, breaststroke, freestyle, and butterfly. In our study the thermal response of swimmers in front crawl technique was evaluated. Domingues et al. have shown that the changes happened in skin temperature after the exercise, outside water, have been referred to in previous studies, but only few of those studies have focused on these changes after exercising in water although this might provide a strong evidence of the importance of heat dissipation in that environment [9], [29].

In this study, it was recognized a minimal right-to-left asymmetry of the temperatures before and after swimming (≤0.5 °C), which does not contradict the difference in temperatures of the arms 0.49 °C published by Sillero-Qiuntana et al. [13]. These differences approximately correspond with right-to-left differences in temperature at rest and with load outside water, such as in athletes and footballers. Our hypothesis concerning the relationship between the skin temperature in the area of agonists of swimmer's movement forward (biceps, triceps, pectoralis major muscle and latissimus) and the speed of swimming was not proved (Table 2). Both slower and faster students tried to achieve the best performance with the maximum effort. It is presumed that the higher speed of swimming was achieved by better swimming technique and higher mechanical efficiency [4], [7], [20].

In addition to causing local changes in temperature of working muscles, the physical exercise affects also the temperature of areas not involved directly in the physical exercise. Unfortunately, no comprehensive knowledge is available on the dynamics of temperature change which could be detected by thermal camera of the body's surface during physical activity (and which changes are due to thermoregulation), or how these changes depend on physiological parameters or body composition. This study has assumed that thermoregulatory mechanisms may depend on the training level of subjects. It was also assumed that body composition (fat content) and skin thickness of the analyzed area could function as an endogenous insulator of heat and may hinder heat dispersal [28].

During dynamic exercise, the prolonged act of sweating leads to a decrease in skin temperature. Shortly after the physical exertion, the vascular system redistributes blood flow and reduces blood flow to skin. After exercising a long time the core body temperature increases due to metabolic heat production that depends on the intensity and effort. Through the thermographic evaluation of the muscular activity after breaststroke swimming, the temperature increase in agonists and synergists for the forward motion of the swimmer could be discovered [28].

The question is whether the temperature of upper trapezius during swimming in water was affected by thermogenic activity of brown adipose tissue – BAT. The ascertained fact is the increase in supra-clavicular temperature in 24-year old men after cooling. In this study, supraclavicular BAT localization was discovered by PET-CT scanner. Regarding the participants, the decrease in temperature in these parts, close to upper trapezius involved in stretching arms forward, was only minimal. It is not possible that these results would be significantly affected by BAT because this area was checked only from the rear. But supraclavicular BAT localization is rather in the front. The front view of the region of upper trapezius was eliminated due to the higher temperature of big retro-clavicular vessels [3].

5. Conclusions

The increase in skin temperature has been proved on arms where the agonists of movement forward are located (by 1.7 °C, 0.04 nu). In the course of front crawl, triceps may be related to muscle work and they are active metabolically. As for other agonists, they are ordered as follows: biceps, brachii, pectoralis major muscle, and latissimus dorsi. Another increase has been proven in temperature of deltoid muscle, and occurred in the movement when the arm was on the water surface. The temperature measured before swimming and 15 minutes later was symmetric (the right to left is ≤0.5 °C). However, it was not proved that the skin temperature on muscle agonists has been increased due to faster movement forward. The results of the study might be useful in assessing the load put on the muscles of the upper limbs and torso during front crawl swimming for non-professional young swimmers.

These differences may be explained by muscle work, genetic factors, muscle oxygenation and muscle fibre. Thus, the studies which investigate skin temperature and metabolism, especially while doing exercise should take into consideration the current outcomes. In the end, it would be interesting to measure each muscle oxygenation and muscle expression of lactate transporters in all the genetic profiles of MCT1 and ACTN3 polymorphism to see if an overexpression appears in one of them and, in turn, in favor of a better tolerance to muscle fatigue.

Acknowledgements

The work has been supported by Masaryk University, Brno, Czech Republic, by way of research project MUNI/A/0804/2013 – *Reaction and adaptation of people to specific stress in sport.*

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