Acta of Bioengineering and Biomechanics
Vol. 17, No. 2, 2015

Original paper
DOI: 10.5277/ABB-00105-2014-03

The influence of breaststroke swimming on the muscle activity of young men in thermographic imaging

JAN NOVOTNY[1]*, SILVIE RYBAROVA[1], DAN ZACHA[2],
JAN NOVOTNY, JR.[1], MARTINA BERNACIKOVA[1], WAEL AWAD RAMADAN[3]

[1] Faculty of Sports Studies of Masaryk University, Brno, Czech Republic.
[2] Centre of Physical Education and Sports of University of Defence, Brno, Czech Republic.
[3] Faculty of Physical Education of Mansura University Mansoura, Egypt.

The aim of this work is to describe and assess energetic-metabolic activity of selected muscles of upper extremities and body during breaststroke swimming through infrared thermography as electromyography cannot display such muscle activity. Thermograms were taken of 25 students from the University of Defence immediately and 15 minutes after swimming 1,000 m focused on 20 regions of interest, i.e., corresponding to selected agonists and synergists in upper extremities and body. We used FLUKE TiR infrared hand camera. It was found that there is a significant increase (normalized units) 15 minutes after swimming in triceps brachii (on the right prior to swimming 0.950 and after swimming 0.994; on the left prior to swimming 0.947 and after 0.990), and in side, rear and front parts of the deltoid muscles. On the contrary, there was a significant relative decrease in temperature in pectoralis, rhombic and lower trapezius, erector spinae lumbalis and latissimus dorsi. It can be concluded that swimming 1,000 m breaststroke affected significant increase in the temperature of regions of interest, i.e., corresponding to agonists and synergists of upper extremities for the swimmer's forward motion. A relative decrease in temperature occurred rather in body muscles. The problem of biased results due to water cooling was solved by using thermograms taken only in the 15th minute after getting out of water and calculating relative temperatures with normalized units.

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

1. Introduction

Measuring energetic-metabolic activity of certain muscles or muscle groups presents a significant technical problem. Current methods of judging the rate of aerometabolic muscular activity during human motion are based on analysing exhaled air and calculating oxygen intake [21]. However, this method of indirect calorimetry provides information on total body energetic requirements only.

A very good method to measure individual muscle activity is electromyography. This method provides information on electric muscular activity which is prior to metabolic activity itself. In recent years, results of electromyographical studies have been published on muscular activity during swimming [6], [14].

Still, these are not parameters which originate in ongoing or finished energetic-metabolic activity of specific muscles or muscle groups.

Solving the problem by using infrared thermography

Mechanical effectiveness of human muscular work is about 50% [2]. Large amounts of chemical energy in muscles are transformed into heat during muscle contractions. Total muscle heat is a sum of their static, shortening and regeneration heat [15]. Higher working metabolic activity and perfusion of

---

* Corresponding author: Jan Novotny, Faculty of Sports Studies of Masaryk University, Faculty of Sports Studies, Kamenice 5, 62500 Brno, Czech Republic. Tel: +420549498662, e-mail: novotny@fsps.muni.cz

Received: June 3rd, 2014
Accepted for publication: August 6th, 2014

muscle tissue result in a significant increase in muscular temperature. Heat energy is then transferred to close adjacent tissues including skin through fluids flowing in vessels [23].

Thermography displays heat energy radiation from the body. Subsequently, temperature of selected points or areas of skin surface is calculated [25].

Displaying increased metabolic muscular activity via thermography is used in sports medicine while diagnosing myositis caused by overload [4]. A number of authors have described heat changes in the body surface during human physical activity outside water [9]–[13], [16]. However, scientific papers on heat changes caused as a result of moving in water are very scarce [24], [28].

Muscle activity during breaststroke swimming

Human motion in water is made possible through the activity of a large number of muscles. Due to the knowledge of in motion apparatus anatomy and biomechanics [8], [17]–[20], it is possible to define specific muscles and muscle groups which are involved in breaststroke swimming. A simplified overview of the muscle groups is presented in Table 1.

Table 1. Simplified overview of agonists and synergists of upper extremities during breaststroke swimming

Swimming phase	Joint movement	Main agonists and synergists
Swimmer's forward motion due to backward water pressure	Ulnar and palmar duction of wrist; forearm pronation; flexion and extension in elbow joint; flexion and adduction and inner rotation of humerus in shoulder joint.	Mm. manus et antebrachii – flexores digitorum et carpi, m. pronator teres, m. pronator quadratus, m. pectoralis major et minor, m. subscapularis, m. coracobrachialis, m. latissimus dorsi, m. teres major et minor, m. triceps brachii, m. brachialis.
Preparatory phase, bending and stretching upper extremities forward	Radial and dorsal duction of wrist; forearm supination; dorsal flexion, abduction; external rotation and arm elevation in shoulder joint; elbow joint extension; wrist extension.	m. supinator, m. biceps brachii, m. deltoideus – pars lateralis et anterior, m. trapezius – pars superior, m. elevator scapulae, m. infraspinatus, m. supraspinatus, m. serratus anterior.

Other synergists are muscles which stabilise the body (the spine) and make support for the movement of upper extremities. They are mainly deep back muscles and abdominal wall muscles.

Important are also muscles of lower extremities for the movement in coxal, knee and ankle joints. These muscle groups participate in the forward motion. They are also support to maintain position and body motion and the work of upper extremities.

Aims of the paper

The aim of this paper is to contribute to the knowledge in the area of temperature changes of the body surface caused as a result of energetic-metabolic activity of the muscles of upper extremities and body during breaststroke swimming.

The results should provide answers to the following questions:

1. What is the distribution of temperature on skin surface prior to and after swimming in this style? Is there a right–left symmetry of the temperatures?
2. What is the increase in temperature of the regions of interest in respective muscle agonists and synergists prior to and after breaststroke swimming?
3. Is there any relationship between the velocity of breaststroke swimming and the change in skin temperature?

2. Materials and methods

Measured group of persons

Twenty-five young men were measured – students from the University of Defence – who were not professional swimmers. They went swimming for one hour once per week within their curriculum. We present a basic characteristic of the group of men (mean values ± standard deviations): age 20.3 ± 1.29 y, height 183.9 ± 7.73 cm, weight 79.7 ± 10.52 kg, body mass index 23.53 ± 2.43 kg·m^{-2}.

Physical conditions in the hall: air temperature 27.9–28.1 °C, relative humidity 52.3–52.8%, roofed hall with air circulation up to 0.5 m·s^{-1}.

Skin adaptation before swimming: Students got adapted in the hall by the pool in standing position for 15 minutes after they had put on their swimsuits without taking a shower.

Swimming load

The students were swimming 1,000 m breaststroke in as short time as possible (relative to their own best time) in a 50-metre pool. They were swimming separately in three groups in two-metre wide lanes between 9 and 11 am.

Water temperature was 26.1–27.7 °C.

Infrared camera used

We used FLUKE TiR infrared hand camera with wave range within the infrared spectrum part of 7.5–14 μm, 23×17° lens, manual focus, temperature sensitivity of 0.1 °C, 480 × 640 pixel LCD display.

Procedure of taking thermograms

Thermograms were taken in standing position:

1. In static position prior to swimming (after 15-minute adaptation in swimsuit).
2. Immediately after swimming after short non-intensive drying with a towel without friction (approx. 30–60 seconds after swimming).
3. In the course of the 15th minute after swimming (without any other use of towel).

Each time, four thermograms were taken: from the front, from the back, from the right, and from the left. This means 12 thermograms for each student, i.e., 300 thermograms in total.

Thermogram analysis

Thermograms were analysed with special Smart View 2.0 software.

To depict the temperatures on skin surface, colour scale of high contrast was used.

To calculate temperatures of selected areas, we used a coefficient of infrared emissivity of human skin equal to 0.98.

We selected 20 regions of interest in each student, on both the right and left sides, relating to certain muscles or muscle groups (Table 2, Fig. 1). Such agonists and synergists of both phases of the swimmer's movement (Table 1) were selected which are close to skin and which are sufficiently large (circle skin area with the radius of at least 4 cm).

Table 2. Skin areas of the selected muscles, their parts or groups

Skin area abbreviation	Muscles, their parts or groups
Da	m. deltoideus – pars anterior
Dp	m. deltoideus – pars posterior
Dl	m. deltoideus – pars lateralis
Bb	m. biceps brachii
Tb	m. triceps brachii
Ts	m. trapezius – pars superior
P	m. pectoralis major et minor
R-Ti	m. rhomboideus major et minor, and m. trapezius – pars inferior
Ld	m. latissimus dorsi
Esl	m. erector spinae – pars lumbalis

Statistical data analysis

1. Basic data characteristics: mean values and standard deviations, analysis of normal distribution (Shapiro–Wilk W test and Kolmogorov–Smirnov test).
2. Tests of temperature differences on the right and lefts sides prior to and after swimming (non-parametric Wilcoxon test of pair samples).
3. Test of temperature relationships on the right and left sides (non-parametric Spearman's correlation test).

The problem of assessing skin temperature is caused by simultaneous temperature increase (working muscles) and decrease (skin cooling by water). Herefore, we have defined a relative temperature indicator and normalized units.

The relative temperature of one area is calculated by the following formula:

$$RT\,[\mathrm{nu}] = \{(T\,[°\mathrm{C}]/AT\,[°\mathrm{C}])\}$$

RT – relative temperature of concrete area in normalized units (nu),

T – temperature of concrete area in grades of Celsius (°C),

AT – average temperature of all 20 measured areas in grades of Celsius (°C).

3. Results

Swimming

Reached times and velocities during 1,000 m breaststroke swimming (means and standard deviations): time (min:sec) 27:05 ± 3:57, velocity (m·s^{-1}) 0.627 ± 0.080.

Thermograms

Examples of thermograms in one student are presented in Fig. 1.

Thermograms prior to and 15 minutes after swimming do not contain any significant bias caused by dermal focuses and they were further analysed and assessed.

Thermograms taken in the first minute after swimming are significantly biased in 13 out of 25 students (52%) by dermal focus changes – cold focuses of water evaporation and hot focuses of skin perfusion by artery perforators. Therefore, all thermograms taken in the first minute after swimming were excluded.

For 10 out of 20 selected muscle areas, the hypothesis about normal distribution of values at 5% level of significance has been declined. Therefore we present next results in medians and percentile bands.

Statistic characteristics of the position and variability of muscle areas temperature are given in Table 3. Right–left temperature differences are significant only in 4 (40%) cases before swimming (Dp, Tb, Ld, Dl) and in 3 (30%) cases after swimming (Bb, Dp, Tb).

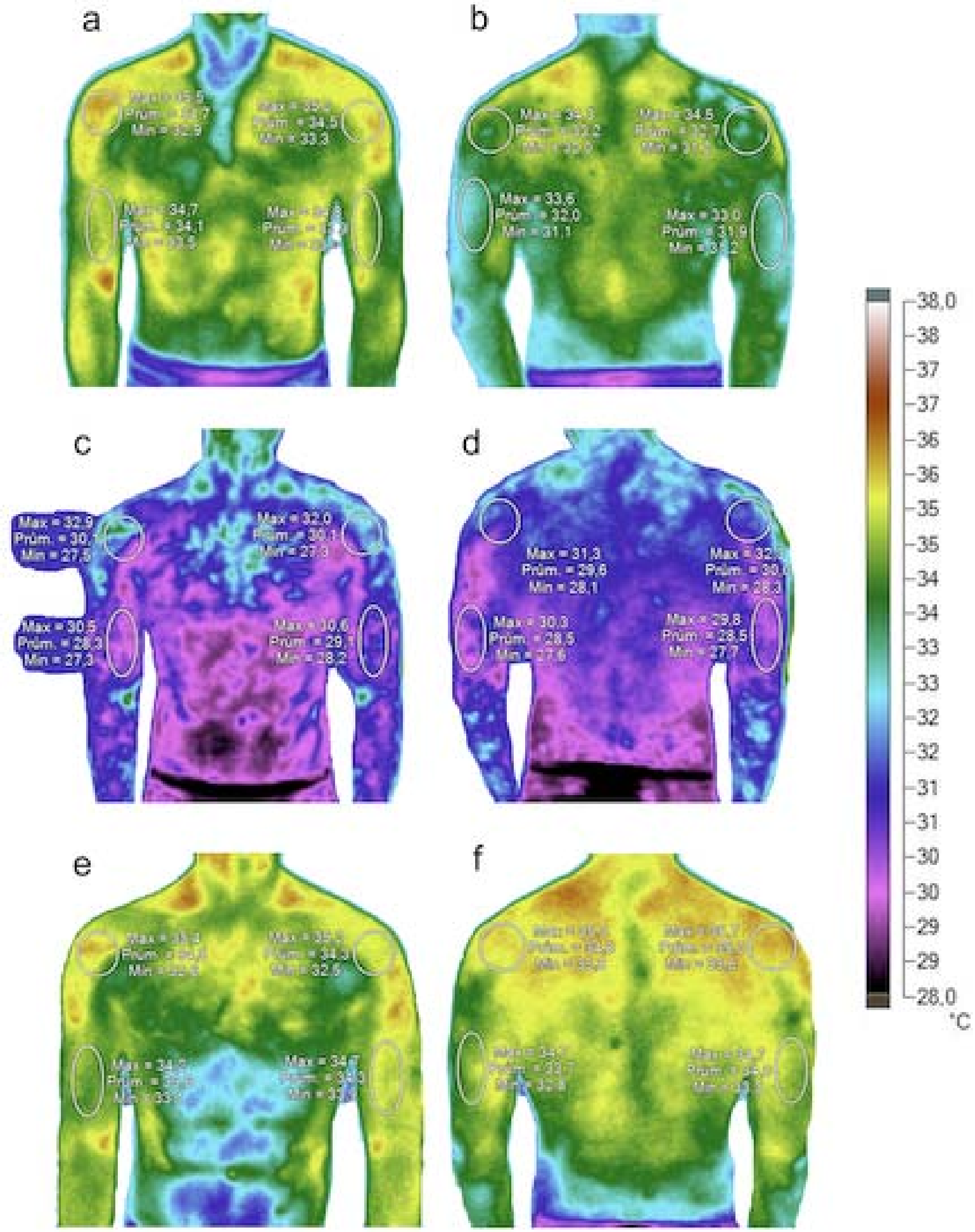

Fig. 1. Examples of thermograms with selected muscle areas: Before swimming (a, b), 1 minute after swimming (c), (d) and 15 minutes after swimming (e), (f). Front view (a), (c), (e): front part of deltoid muscle and arm biceps. Rear view (b), (d), (f): Rear parts of deltoid muscles and arm triceps. Colour scale from 28 to 38 °C

Analysis of temperature changes prior to and after swimming

Medians of temperatures after swimming are lower than before swimming (Table 4). Temperature decrease is statistically significant. The only exception where there was temperature increase is areas of m. triceps brachii, both right and left.

Table 5 presents calculated relative skin temperature of the regions of interest, the results of Wilcoxon's tests and their differences before and 15 minutes after swimming and the results of the

Table 3. Skin temperature (°C) of muscle areas before and 15 minutes after swimming 1,000 m breast-stroke ($n = 25$)

Muscle area	Before/ after	Right side			Left side			R-L difference			
		m_e	25%	75%	m_e	25%	75%	m_e	25%	75%	$W_{P\text{-}L}$
Da	bfr	34.8	34.1	35.1	34.7	34.0	35.1	0.0	–0.2	0.3	NS
	after	33.9	33.3	34.7	33.9	33.5	34.7	–0.1	–0.3	0.1	NS
P	bfr	34.3	34.0	34.7	34.2	33.7	34.8	–0.1	–0.3	0.2	NS
	after	32.9	32.0	33.6	33.0	31.7	3.4	0.0	–0.3	0.4	NS
Bb	bfr	34.3	33.9	34.7	34.2	33.7	34.8	0.1	–0.2	0.3	NS
	after	33.6	32.7	34.1	33.7	33.2	34.2	–0.2	–0.4	0.1	***
Ts	bfr	35.6	34.9	35.9	35.5	35.1	35.9	0.0	–0.2	0.2	NS
	after	34.6	34.0	35.0	34.6	34.0	35.3	0.0	–0.3	0.1	NS
Dp	bfr	34.8	34.1	35.2	34.7	34.0	35.0	0.2	0.0	0.5	***
	after	34.3	33.3	34.8	34.0	33.3	34.6	0.2	0.0	0.5	***
R-Ti	bfr	35.3	34.6	35.7	35.2	34.5	35.5	0.2	–0.1	0.3	NS
	after	33.8	33.3	34.3	33.8	32.8	34.5	–0.1	–0.2	0.2	NS
Tb	bfr	32.8	32.4	33.3	32.6	32.3	33.4	0.1	–0.1	0.4	***
	after	33.5	32.9	33.9	33.1	32.9	33.6	0.2	0.1	0.5	***
Ld	bfr	34.4	33.8	34.8	34.2	33.6	34.8	0.1	0.0	0.2	**
	after	33.0	32.3	33.9	32.9	32.2	33.7	0.1	–0.1	0.3	NS
Esl	bfr	34.5	33.8	34.8	34.5	33.7	34.8	0.0	–0.1	0.2	NS
	after	32.2	31.5	33.2	32.1	31.3	33.3	0.0	–0.2	0.2	NS
Dl	bfr	34.9	34.4	35.5	34.7	34.1	35.0	0.3	0.1	0.6	**
	after	34.4	33.7	34.9	34.0	33.8	34.7	0.1	–0.1	0.3	NS

Key: before/after – before or after swimming; 25% – 1st quartile; 75% – 3rd quartile; R–L – right–left; $W_{P\text{–}L}$ – results of Wilcoxon's tests of right–left difference; NS – non-significant difference; * – $p < 0.05$; *** – $p < 0.005$. Abbreviations of the areas are clarified in methods (Table 2).

Table 4. Differences in temperature before and 15 minutes after swimming, comparison with Wilcoxon's test

Muscle area	Right side		Left side	
	Median temperature difference (after) minus (before) (°C)	Wilcoxon (after) minus (before) (p)	Difference in median temperature (after) minus (before) (°C)	Wilcoxon (after) minus (before) (p)
Da	–0.9	**0.000146**	–0.8	**0.000214**
P	–1.4	**0.000035**	–1.2	**0.000031**
Bb	–0.7	**0.000060**	–0.5	**0.004903**
Ts	–1.0	**0.000419**	–0.9	**0.000618**
Dp	–0.5	**0.007440**	–0.7	**0.004676**
R-Ti	–1.5	**0.000052**	–1.4	**0.000195**
Tb	+0.7	0.085310	+0.5	0.217318
Ld	–1.4	**0.000207**	–1.3	**0.000332**
Esl	–2.3	**0.000035**	–2.4	**0.000046**
Dl	–0.5	**0.010324**	–0.7	**0.020804**

Key: p – level of significance during Wilcoxon pair difference test. Abbreviations of areas are clarified in methods (Table 2).

Table 5. Relative temperatures of muscle areas before and 15 minutes after swimming, their differences and relationships of such differences to velocities of swimming ($n = 25$)

Muscle area	Side	Relative temperature (nu)						$W_{\text{bfr-after}}$	Spearman test (R)
		Before swimming			15 min after swimming				
		m_e	25%	75%	m_e	25%	75%		
Da	R	1.007	1.000	1.012	1.011	1.004	1.019	NS	–0.304348
	L	1.005	1.002	1.015	1.012	1.005	1.021	↑	–0.327075
P	R	0.997	0.987	1.007	0.978	0.967	0.988	↓↓	–0.071146
	L	0.994	0.988	1.002	0.981	0.965	0.989	↓↓↓	–0.267787
Bb	R	0.999	0.988	1.008	0.999	0.984	1.008	NS	0.116601
	L	0.994	0.988	1.006	1.002	0.991	1.013	NS	0.144269
Ts	R	1.031	1.025	1.036	1.027	1.025	1.034	NS	**0.522727***
	L	1.032	1.027	1.038	1.033	1.024	1.040	NS	**0.491107***
Dp	R	1.008	0.995	1.015	1.017	1.010	1.026	↑	–0.116601
	L	1.002	0.990	1.008	1.011	0.995	1.021	↑↑	–0.000988
R-Ti	R	1.019	1.011	1.026	1.006	0.997	1.012	↓↓↓	–0.119565
	L	1.015	1.005	1.024	1.005	0.995	1.016	↓	0.157115
Tb	R	0.950	0.941	0.963	0.994	0.987	1.008	↑↑↑	0.281621
	L	0.947	0.934	0.962	0.990	0.978	1.002	↑↑↑	**0.464427***
Ld	R	0.999	0.992	1.003	0.993	0.975	1.000	↓	–0.330040
	L	0.990	0.986	1.003	0.989	0.971	0.997	↓	–0.164032
Esl	R	0.997	0.989	1.002	0.965	0.950	0.972	↓↓↓	–0.320158
	L	0.997	0.986	1.002	0.967	0.948	0.974	↓↓↓	–0.189723
Dl	R	1.012	1.000	1.017	1.023	1.011	1.038	↑↑↑	**–0.473320***
	L	1.008	0.992	1.011	1.021	1.007	1.032	↑↑↑	–0.300395

Key: nu – normalized units; m_e – median; 25% – 1st quartile; 75% – 3rd quartile; $W_{\text{bfr-after}}$ – Wilcoxon difference test before and after swimming; R – right side; L – left side; NS – non-significant difference; ↑/↓ - significant increase or decrease ($p < 0.05$); ↑↑/↓↓ – significant increase or decrease ($p < 0.01$); ↑↑↑ – significant increase ($p < 0.005$); R – Spearman's correlation coefficient; * – statistically significant relationship ($p < 0.05$). Abbreviations of areas are clarified in methods (Table 2).

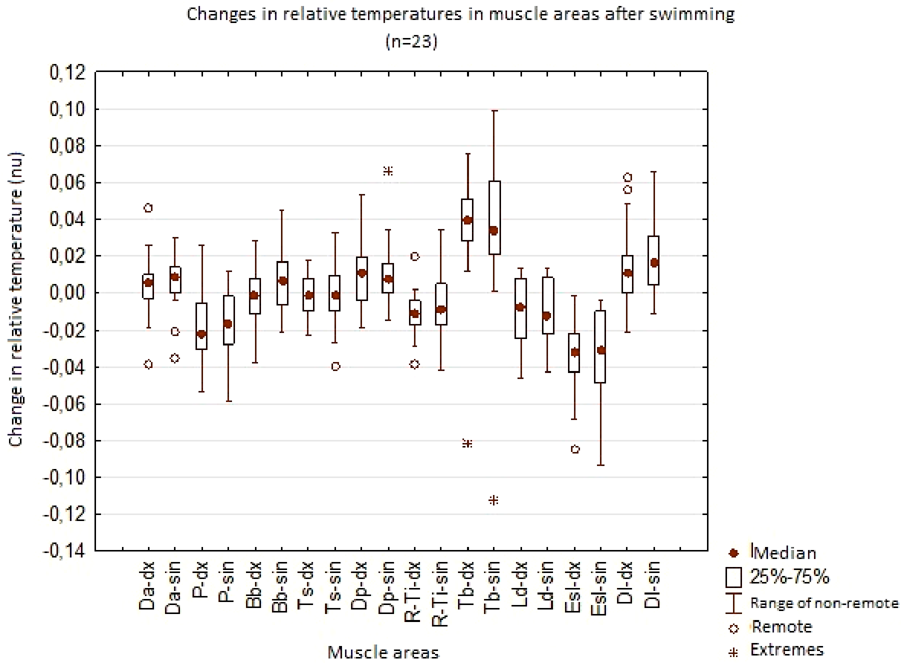

Fig. 2. Changes in relative temperatures in individual muscle areas after swimming.
Key: 25% – 1st quartile; 75% – 3rd quartile. Abbreviations of the areas are clarified in methods (Table 2)

relationship of such differences to velocities of swimming.

After swimming, there was *a relative increase in temperature* mainly on both sides in the areas of m. triceps brachii and sides of m. deltoideus. Visible is also an increase in temperatures of rear parts of m. deltoideus on both sides and slightly less also in the case of the front parts of deltoid muscles on the left.

On the contrary, there was a *relative decrease in temperature* on both sides in the area of m. pectoralis, mm. rhomboidei et trapezius inferior, latissimus dorsi and erector spinae lumbalis.

With swimming velocity, relative temperature significantly increased in the area of m. trapezius – pars superior on both sides and m. triceps brachii left. *Relative temperature decreased significantly with increasing velocity* in the case of the side part of deltoid muscle on the right side.

A better overview of changes in relative temperatures after swimming in individual muscle areas (differences compared with temperatures before swimming) is presented in Fig. 2.

4. Discussion

In total, skin temperature was lowered by water because water temperature was lower than that of the body and air, which is in compliance with long-familiar facts about the effects of cooler water [3], [22], [24]. The only exception when skin temperature increased was the area of arm triceps. This can be explained by the fact that during swimming these muscles work very intensively because they drive the swimmer forward against water resistance. Additionally, this area may be less cooled by water counter-current.

We expected an increase in temperature in other agonists of the swimmer's forward motion – m. latissimus dorsi and m. pectoralis. The explanation why this did not occur could probably be looked for in relatively lower intensity of work (if compared with m. triceps brachii) and larger contact area with the skin through which heat is transferred to water.

An available reference on the effects of swimming on the distribution of temperature on the body surface is Zaidi et al. [28], which is a one-case study with completely different methods (swimming 4 × 100 m using four styles with 10-minute breaks; skin areas irrespective of the muscle areas).

Surface temperature of all selected areas of the back (m. trapezius – pars superior, mm. rhomboids et m. trapezius – pars inferior, m. latissimus dorsi and m. erector spinae – pars lumbalis) before swimming (Table 3) is higher than average temperature of the back 33.3 °C which was found by Akimov et al. [1] in 23.5 ± 4.9 year-old differently trained endurance athletes. This may have been caused by the fact that they performed the examination in a room with slightly lower temperature (21–22 °C). The conclusions of their work speak about higher temperature of the back in athletes with higher aerobic capacity. On the contrary, our students who could be expected to have higher aerobic capacity due to higher speed of swimming, had lower temperature in the area of back muscles.

Statistically significant positive relationship of swimming velocity to increasing relative temperature (Table 5) in the area of upper part of trapezius and left-sided arm triceps is rare.

In the case of left-sided triceps, main agonists of the swimmer's forward motion, this is in compliance with logical assumption of reaching higher speed due to more intensive muscle work. It is also in compliance with the result of Wilcoxon difference test of such values before and after swimming (Table 5). However, the results of the correlation test are not in compliance with this in right-sided triceps. It can be assumed that the relationships of temperature changes in relation to swimming velocity could be affected by inter-individual diversity of the students' swimming technique.

Due to the fact that Boon et al. [5] described that skin temperature of clavicular region increases after immersion into cold water because of the BAT activity, we cannot exclude a partial influence of supraclavicular BAT on the skin temperature at the dorsal superior trapezius region after swimming. We did not measure temperature of the nearest region of periclavicular BAT which has been documented by Symonds et al. [26] as well as we did not measure anterior skin region of the superior trapezius because we considered a powerful thermic source of great blood vessels in the region (arteria et vena subclavia). We assume that there is no influence of BAT on the temperature on these specific regions: deltoids, trapezius, biceps, latissimus, rhomboids and pectorals. Positron-emission tomography images have shown that the BAT is not distributed in these locations [27].

An accurate and quantitative expression of the muscular activity is a problem. The use of infrared thermography is based on a relation between muscular thermogenic activity during exercise [2], [12], [15] and following temperature changes of the skin nearest to specific muscle [6], [9], [28]. The accuracy of thermographic evaluation of muscular activity could be researched in the future.

5. Conclusions

Our results have contributed to the knowledge of temperature changes in skin which occur due to working activity of the muscles during breaststroke swimming in university students:

- In examined group of persons, we have declined normal distribution of temperature in 50% of muscle areas of upper extremities and body.
- In nearly all areas, the right–left difference in temperatures is not significant.
- As a result of breaststroke swimming, there was the most radical increase in temperature in the area of arm triceps – agonists of the swimmer's forward motion.
- There was also high, though only relative, increase in temperature in the side parts of m. deltoideus which are agonists of stretching the arms forward.
- There was a smaller relative increase in temperature in the area of rear parts of m. deltoideus which thus participate in the forward motion (synergists) and front parts of m. deltoideus which ensure stretching the arms forward.
- There was a relative decrease in temperature in the areas of other synergists of the swimmer's forward motion: breast muscles, rhombic muscles with lower parts of m. trapezius and latissimus dorsi. Water cooling was probably stronger than heating by working activity. There was a similar decrease in temperature also in erector spinae pars lumbalis.
- There was a significant increase in relative temperature with increasing velocity during swimming mainly in left arm triceps (agonist during forward motion) and upper parts of m. trapezius (agonists of stretching the arms forward).
- Thermograms from the first minute after swimming are biased nearly in half of the swimmers due to dermal changes (cool focuses of water evaporation, warm focuses of artery perfusion) and could not be used for the assessment of working activity.
- The problem of assessing temperature changes in individual muscle areas which is caused by the conflict of heating skin by working muscles and cooling by water during swimming was partially solved by introducing relative – normalized – temperature units.
- If we want to take assessable thermograms after swimming, it is necessary to restrict water evaporation from the skin by a short drying with a towel by placing it to the skin (approx. during 20 seconds) immediately after swimming without friction and wait until the focuses of dermal changes disappear in about 15 minutes.

Acknowledgments

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.

References

[1] Akimov E.B., Andrev R.S., Arkov V.V., Kirdin A.A., Saryanc V.V., Sonkin V.D., Tonevitsky A.G., *Thermal "portrait" of sportsmen with different aerobic capacity*, Acta Kinesiologiae Universitatis Tartuensis, 2009, 14, 7–16.

[2] Åstrand P.O., Rodahl K., Dahl H.A., Strøme S.B., *Textbook of Work Physiology*, Physiological Bases of Exercise, 4th ed., Human Kinetics, 2003.

[3] Bärtsch P., Nielsen Johannsen B., Leppäluoto J., *Physical activity and environment*, [in:] *Textbook of Sports Medicine*, M. Kjaer et al. (eds.), Blackwell Publishing, 2003, 226–249.

[4] Ben Eliyahu D.J., *Infrared thermography in the diagnosis and management of sports injuries: A clinical study and literature review*, Chiropr. Sport Med., 1990, 4(2), 46–53.

[5] Boon M.R., Bakker E.H., Van der Linden R.A.D., Arias-Bouda L.P., Smit F., Verberne H.J., Van Marken Lichtenbelt W., Jazet I.M., Rensen P.C.N., *Supraclavicular skin temperature as a measure of ^{18}F-FDG uptake by BAT in human subjects*, Plos One, 2014, 9, 1–8.

[6] Clark R.P., Mullan B.J., Pugh L.G., *Skin temperature during running – A study using infrared colour thermography*, J. Physiol., 1977, 267, 53–62.

[7] Conceição A., Silva A., Barbosa T.M., Louro H., *Observation and technical characterization in swimming: 200 m breaststroke*, Rev. Bras. Med. Esporte, 2013, 19(1), 56–61.

[8] Čihák R., *Anatomie*, Grada/Avicenum, 2006.

[9] Čoh M., Širok B., *Use of the thermovision method in sport training*, Facta Universitatis: Physical Education and Sport, 2007, 5(1), 85–94.

[10] Fernandes A.A., Amorim P.R.S., Primola-Gomes T.N., Sillero-Quintana M., Férnandez Cuevas I., Silva R.G., Pereira J.C., Marins J.C.B., *Avaliação da temperatura da pele durante o exercício através da termografia infravelmelha: uma revisão sistemática*, Revista Andaluza de Medicina del Deporte, 2012, 5(3), 113–117.

[11] Fernández-Cuevas I., Sillero Quintana M., García-Concepción M.A., Gómez Carmona P., Marins J., *Evolution of skin temperature after aerobic exercise*, 17th Annual Congress of the European College of Sport Sciences ECSS, 04/07/2012–07/07/2012, Brujas, Bélgica, 2012.

[12] Fernández Cuevas I., *Effecto del entrenamiento de resistencia, velocidad y fuerza en la temperatura de la piel a través de la termografía infrarroja*, Tesis doctoral europea, Universidad Politécnica de Madrid, 2012.

[13] Ferreira J.J.A., Mendonça L.C.S., Nunes L.A.O., Andrade Filho A.C.C., Rebelatto J.R., Salvini T.F., *Exercise-associated thermographic changes in young and elderly subjects*, Ann. Biomed. Eng., 2008, 36(8), 1420–1427.

[14] Figueiredo P., Sanders R., Gorski T., Vilas-Boas P., Fernandes R.J., *Kinematic and electromyographic changes*

during 200 m front crawl at race pace, Int. J. Sports Med., 2013, 34(1), 49–55.

[15] GANONG W.F., *Přehled lékařské fyziologie*, Review of Medical Physiology, Grada/Avicenum, 1999.

[16] CHUDECKA M., SZCZEPANOWSKA E., KEMPIŃSKA A., *Changes of thermoemission of upper extremitest in female handball players – the preliminary study*, Medicina Sportiva, 2008, 12(3), 99–102.

[17] JAZRAWI L.M., ZUCKERMAN J.D., YOUNG B.H., DAY M.S., *Biomechanics of the elbow*, [in:] M. Nordin, V.H. Frankel (eds.), *Basic Biomechanics of the Musculoskeletal System*, Baltimore: Wolters Kluwer Health, Lippincott Williams and Wilkins, 2012, 343–362.

[18] JORDAN CH.J., JAZRAWI L.M., ZUCKERMAN J.D., *Biomechanics of the shoulder*, [in:] M. Nordin, V.H. Frankel (eds.), *Basic Biomechanics of the Musculoskeletal System*, Wolters Kluwer Health, Lippincott Williams and Wilkins, 2012, 322–343.

[19] KLION M., JACOBSON T., *Triathlon Anatomy*, Human Kinetics, 2013.

[20] PALASTANGA N., SOAMES R., *Anatomy and Human Movement. Structure and Function*, 6th ed., Churchill Livingstone Elselvier, 2012.

[21] PLACHETA Z. et al., *Zátěžová diagnostika v ambulantní a klinické praxi* (*Stress diagnostics in ambulanory and clinic practice*), Grada/Avicenum Praha, 1999.

[22] SAWKA M. N., CASTELLANI J.W., CHEUVRONT S.N., YOUNG A.J., *Physiologic systems and their responses to conditions of heat and cold*, [in:] P.A. Farrel et al. (eds.), *ACSM′s Advanced Excercise Physiology*, Wolters Kluver/Lippincott Williams & Wilkins, 2012, 567–602.

[23] SILBERNAGL S., DESPOPOULOS A., *Atlas fyziologie člověka* (*Atlas of human physiology*), Grada/ Avicenum, 2004.

[24] SILLERO-QUINTANA M., CONDE-PASCUAL E., GOMEZ-CARMONA P.M., FERNANDEZ-CUEVAZ I., GARCÍA-PASTOR T., *Effect of youga and swimming on body temperature of pregnant women*, Thermology International, Appendix 1, 2012, 22(3), 143–149.

[25] STAVRATJEV M., *Infračervená termovize a její diagnostické využití*, (*Infrared thermovision and its diagnostic using*, Dissertation,), University of J.E Purkyně, 1973.

[26] SYMONDS M.E., HENDERSON K., ELVIDGE L., BOSMAN C., SHARKEY D., PERKINS A.C., BUDGE H., *Thermal imaging to assess age-related changes of skin temperature within the supraclavicular region co-locating with brown adipose tissue*, J. Pediatr., 2012, 161, 892–898.

[27] VOSSELMAN M.J., BRANS B., VAN DER LANS A.A.J.J., VAN BAAK M.A., MOTTAGHY F.M., SCHRAUWEN P., VAN MARKEN LICHTENBELT W.D., *Brown adipose tissue activity after a high-calorie meal in humans*, Am. J. Clin. Nutr. 2013, 98, 57–64.

[28] ZAIDI H., TAIAR R., FOHANNO S., POLIDORI G., *The influence of swimming type on the skin-temperature maps of a competitive swimmer from infrared thermography*, Acta Bioeng. Biomech., 2007, 9(1), 47–51.