Acta of Bioengineering and Biomechanics
Vol. 20, No. 2, 2018

Original paper
DOI: 10.5277/ABB-01051-2017-04

Thermovision analysis of surface body temperature changes after thermal stimulation treatments in healthy men

KATARZYNA GRUSZKA[1], EDYTA SZCZUKA[2], IRENEUSZ CAŁKOSIŃSKI[3],
KRZYSZTOF A. SOBIECH[1], AGNIESZKA CHWAŁCZYŃSKA[1]*

[1] Faculty of Physiotherapy, University School of Physical Education Wrocław, Wrocław, Poland.
[2] Faculty of Sport Science, University School of Physical Education Wrocław, Wrocław, Poland.
[3] Faculty of Health Sciences, Medical University Wrocław, Wrocław, Poland.

Purpose: Among thermal stimulation treatments that have a beneficial effect on the human body general application of cold and various forms of massage are mentioned which can be assessed by means of thermovision analysis. The aim of the study was to evaluate changes in the distribution of surface body temperature under the influence of whole-body cryostimulation, classical massage and hot stone massage. *Materials and methods:* The study was conducted on a group of 40 men aged 20–24 years. They were subjected to a cryostimulation treatment at –120 °C and –140 °C, and to heat-stimulating treatments in the form of massages. Before the treatment, blood pressure and heart rate were measured. Temperature distribution in the 12 areas of the body surface was recorded using a Thermo Vision A20M Thermo Vision Camera with Therma CAM Researcher 2.8 software. *Results:* Statistically significant differences between cryostimulation treatments in the left upper limb and the back of the trunk were found. After heat-stimulating treatments, a statistically significant increase in temperature after classic massage was observed in the lower limbs, and a similar increase in temperature was noted in the rear of the pectoral girdle and of the trunk after hot stone massage. *Conclusions:* The thermovision analysis showed a great variation of body surface temperature depending on the body area. The higher changes in temperature, of up to 20%, were found within the upper and lower extremities in the group treated with cryostimulation. After heat-stimulating treatments, lower temperature differences, of 2–6%, were observed, the largest within the trunk and the lower limbs.

Key words: *thermovision, thermal imaging, cryostimulation, massage volcanic stone, men's body temperature*

1. Introduction

Thermal stimulation is the non-invasive application of low or elevated temperatures to induce physiological, systemic, or organ reflexes and defense reactions, beneficial and effective in maintaining the homeostasis of the human body [7], [13], [18]. It includes cryostimulation, which is the action of cryogenic temperatures, and heat stimulation, which is the action of warm (hand massage) and hot (hot volcanic stone massage) temperatures.

Cryostimulation is used, among others, in pain syndromes, degenerative changes of joints, oedema, treatment of depression, multiple sclerosis and sports medicine – treatment of injuries [6]–[8], [10], [11], [18].

Systemic cryostimulation takes place in cryochambers (cold exposure a the whole body including the head – whole body cryostimulation – WBC) or cryosuanas (cold exposure not including the head). Depending on the type of cryochamber used, the air temperature in the vestibule is around –60 °C, and in the main chamber it reaches from –100 °C to –160 °C. According to research by many authors, the optimal therapeutic temperature is between –120 °C and –140 °C. The chosen value of temperature depends on the therapeutic device used, its technical capabilities and must be adapted to the patient undergoing treatment. In the literature on the subject, the most frequently presented are studies on one temperature range [7], [8], [21],

* Corresponding author: Agnieszka Chwałczyńska, Department of Human Biology, Faculty of Physiotherapy, University School of Physical Education, al. I.J. Paderewskiego 35, 50-537 Wrocław, Poland. Phone: 0048713473356, email: agnieszka.chwalczynska@awf.wroc.pl
Received: November 21st, 2017
Accepted for publication: April 18th, 2018

[22], [24] or review articles comparing the work of many authors [6], [15], [16]. Few authors compare the effect of cryostimulation with different temperatures used on the same research group [11], [13]. This comparison is combined with other temperatures and, as in the case of Dębiec-Bąk, it is limited to general changes that occur in the segments of the human body. Generalized results indicated differences between temperatures below and above –100 °C [10], [11].

The opposite of cryostimulation is treatment using elevated temperature. Hot thermostimulation can include, among other things, classic massage or hot stone massage. Classic massage has a local and systemic effect. The thermal element is the therapist's hand and the phenomenon of skin friction against the skin. Hot volcano stones involve applying heated lava stones with high iron content and thermal capacity, providing beneficial physiological pH to the site of use, and throughout the nervous, blood, and lymphatic systems and muscles, at the same time reassuring and relaxing [1], [4], [5], [13], [25].

The majority of authors who take up the subject of thermostimulation present it in a therapeutic context, for medicine, sports or biological regeneration. The way changes that occur in the body under the influence of temperature depend on the disease entity being treated are described many times [6], [17], [20], [24]. Sports medicine describes the use of cryostimulation in the treatment of injuries, overloads and as an element of biological regeneration [6], [14], [19], and massage as a basis for therapeutic action in the training process [3], [4], [10], [12], [23], [25].

Both low and high temperature therapy primarily affect the functioning of the circulatory system. Vascular reactions, among others, can be observed due to changes in the surface temperature of the body, monitored by the use of thermal imaging cameras [9], [15]. The non-invasive, painless, and completely safe thermovision research tool analyses changes in the surface temperature of the body after thermal stimulation [8]. Thanks to that, it is possible to monitor the rate of change in surface temperature resulting from the action of a hot or cold medium [12]. Cholewka and coworkers, comparing temperature changes under the influence of cryostimulation in people with spondyloarthrosis (SP), ankylosing spondylitis (AS), and sciatica diseases, stated that thermovision imaging has a potential diagnostic value and can be used as a complement to previously used methods [7], [8].

Thermovision analysis makes it possible to extend the research on the behavior of the human body during fitness and wellness exercise, in projects related to a healthy lifestyle [9]–[11], [13], [19].

In the available literature, there are no reports comparing changes in body surface temperature caused by the use of various forms of thermostimulation. In the case of cryostimulation, the most frequently presented results are from long-term use, with multiple therapies using one temperature. In few publications one can find a comparison of temperature changes taking place under different temperatures [10], [11], [13]. In the literature on the subject, no comparison of changes in surface temperature under the influence of cryostimulation and massage temperature made on one research group was found.

Therefore, the question should be asked whether the thermovision method can be used to assess the quality of thermostimulation used and to determine which ones cause more favorable changes in the subject, and whether there is a difference in the change in surface temperature of the body depending on the temperature of the thermostimant used.

The aim of this study was to assess changes in body surface temperature as a result of thermal stimuli (cold – cryostimulation, at –120 °C and –140 °C, heat – classical massage and hot volcanic stones massage), on a group of young men measured by thermovision method.

The innovation of this work is the combination of various forms of thermal stimulation and assessment of their impact on the human body taking into account the differences between individual areas of the human body.

2. Materials and methods

The study involved 40 healthy male student volunteers from the University School of Physical Education in Wroclaw, Poland, aged between 20 and 24 years, randomly divided into two groups of 20 subjects each. Table 1 presents data on the study groups: the first, cryotherapy – treated at a temperature of –120 °C and –140 °C (group 1), and the second, subjected to the volcanic hot stone massage (HSM) and classical massage stimulation (CM) (group 2).

The condition for qualifying for the research project was: male gender, age 20–24 years, BMI value within normative limits for a given sex and age, good health – no diagnosed chronic diseases, no infection associated with increased body temperature, The condition for exclusion from the study was: cold intolerance, competitive sporting activities, daily intensive activities (e.g., gym, fitness classes), skin changes occurring in the massage area, extensive tattoos, alco-

Table 1. Anthropometric characteristics of the groups

Group	Age [years]	Body mass [kg]	Body height [cm]	Body mass index [kg/m^2]	Body surface area [m^2]
Cryostimulation (Group 1)	23.16 ± 0.36	80.00 ± 6.60	182 ± 5.00	24.12 ± 1.57	2.01 ± 0.10
Massage stimulation (Group 2)	21.70 ± 1.81	77.33 ± 8.47	181 ± 7.00	23.46 ± 1.68	2.00 ± 0.11

hol consumption 48 hours before the test, earlier use of thermostimulation (sauna solarium), smoking cigarettes 1 hour before the test.

The research project, conducted with the permission of the Commission of Bioethics at the Wrocław Medical University (KB-1/2013), was carried out in two stages. There was a 14-day interval maintained between individual thermal exposures. Both groups did not participate in earlier thermostimulation studies. Thermovision studies were always carried out immediately before thermostimulation and up to 10 minutes after its completion.

Prior to the study, the subjects were made familiar with its objective and method, and gave their written consent to participate in a research project. They were informed about the safe way of breathing and the need to thoroughly dry themselves with a towel in order to remove drops of sweat. During the treatment in the cryogenic chamber, both in the vestibule (pre-chamber) and in its proper part (cryochamber), the subjects walked at a leisurely pace in a circle, keeping a safe distance between each other. There were never more than five people at the same time. The procedure for whole-body cryotherapy has been described in earlier papers [10], [11], [18], [19].

In step I, group 1 was subjected to a one-time three-minute whole-body cryotherapy (WBC) using CR-2002/05 Cryogenic Chamber (Creator, Poland) at –120 °C, and in the second step at a temperature of –140 °C.

The second group in stage I was subjected to relaxation massage with hot stones (HSM), and a classical massage (CM) to in stage II.

During the hot volcanic stone massage the subjects were positioned lying face down on a massage table. They were dressed only in cotton boxer shorts. For the procedure, selected basalt rocks were used, containing a high amount of iron, which have a high heat capacity. The stones were heated in a heater to a temperature of 60 °C.

There were four large stones, four medium-sized ones, and four stones of a small size. Additionally, seven other stones, including one uncut, put on the sacrum, were placed along the spine. In order to achieve better stone slip, each subject prior to the treatment had an initial five-minute massage, then the stones were laid for 30 minutes along the spine. The largest stone was laid on the sacrum, while the medium-sized stones were placed along the spine so that the last one was at the level of vertebra C5.

A massage involving stroking with stone edges, fan stroking and, at the end, stroking with whole stones was performed, with faster strokes as the subjects' tolerance to temperature increased. The purpose of the hot stone massage was to induce overall relaxation and obtain a large local accumulation of heat as well as to raise the pain threshold, increase the metabolic rate, and give the body a general cleanse.

The classic massage was performed on a massage table in the same body area and in the same position as the hot volcanic stone massage, within the same duration of time, i.e., 30 minutes. In the course of the massage, conventional techniques were used: stroking, rubbing, squeezing, and kneading. Each of the participants was informed about the course of the procedure, its purpose, indications, and contraindications. After the massage, each subject was recommended a 15-minute rest to cool down after the treatment and to not expose the heated body to the risk of catching a cold.

Before and immediately after the treatment, determination of hemodynamic parameters was performed in the subjects, which included measurement of blood pressure and heart rate. The measurement of blood pressure was performed on the left arm of the subjects sitting in a resting position.

The thermovision test was carried out in accordance with the standards for thermal imaging. Testing was performed at the Cryotherapy Laboratory of the Creator Private Center for Preventive Treatment and Rehabilitation in Wroclaw, Poland. The research took place in the afternoon between 3:00 pm and 6:00 pm. Humidity and temperature in the laboratory were kept constant (relative humidity 60%, temperature 22 °C). Body surface temperature was taken before and immediately after the cryostimulation treatment. Before the temperature measurements the subjects did not engage in increased physical activity. Body temperature was registered with a ThermoVision A20M camera (temperature sensitivity 0,12°, temperature range –20 °C–900 °C, image resolution 160 × 120 pixels at the full frequency of the image frame 50/60 Hz, model

E40ABX, movi MED, USA) connected to a PC equipped with ThermaCAM Researcher ver.2.8 software (FLIR Systems, USA). The thermal imaging camera used is standardized and used only for the examination of the human body. Thermal imaging camera is a device used in the Cathedral Laboratory which is an element of the Central University Laboratory. The measuring place was devoid of point heat sources. The distance between the examined object (human body) and the measuring tool was 2 m.

Each photo was taken and the front and rear were examined. The temperature in individual body segments was determined using a program to calculate the values averaged for a given area. In present research, the body was divided into 12 research areas including segments of the human body. This map takes into account the physiological division of the body into the distal segments – upper limbs and lower limbs and the proximal part – trunk. During the development of thermovision images, the hands and feet were not taken into account, this was due to the technical conditions of using the cryochamber (obligatory shoes, socks on the feet and gloves). According to the Glamorgan Protocol to achieve reproducible results, the orientations of the human body were aligned in each view to assess the average temperature [2], [17], [18].

The temperatures reflected thermal maps in 12 areas of the human body, as shown in Fig. 1.

The initial or final temperature was not important but the temperature difference (TD) changes was calculated as the result of subtracting the value of the temperature after exposure (TA) before exposure to the temperature (TB).

In order to compare absolute values of changes, the percentage of changes was applied depending on the initial value. The percentage change of temperature after thermal stimulation was calculated via the formula:

$$D = \frac{TA - TB}{TB} * 100\%,$$

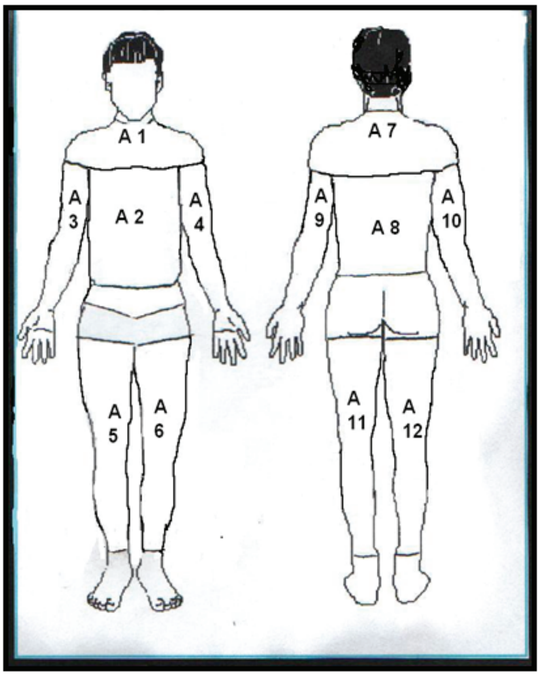
where:

D – % of surface body temperature change under the influence of thermal stimulation,

TB – surface hand temperature before the thermal stimulation,

TA – surface hand temperature after the thermal stimulation [10], [11], [13], [19], [20].

Statistical characteristics of the studied parameters are presented as the arithmetic mean and standard deviation (SD). With the Shapiro–Wilk test, the normality of the group was checked. Comparison of the mean values recorded for the two groups was performed using Student's *t*-test for independent samples. Spearman's rank correlation coefficient was calculated in order to examine the strength of associations between the variables. To compare the variables within



Body area	Description of area
A-1	Shoulder front
A-2	Trunk front
A-3	Right upper limb front
A-4	Left upper limb front
A-5	Right lower limb front
A-6	Left lower limb front
A-7	Shoulder rear
A-8	Trunk rear
A-9	Left upper limb rear
A-10	Right upper limb rear
A-11	Left lower limb rear
A-12	Right lower limb rear

Fig. 1. Thermal map of the examined body areas

the groups (before and after the stimulation), the Wilcoxon signed-rank test was used. In the analysis, the statistically significant level was set at $p < 0.05$. The analysis was performed by means of Statistica 9 PL software.

3. Results

Table 2 shows changes in surface temperature in the 12 examined body areas after the stimulation treatments. Statistically significant differences ($p \leq 0.05$) were found in upper limb areas, the greater change in temperature being noted after the treatment at –140 °C. In other areas only slight differences were observed, which did not differ statistically, most of which were higher after the treatment at –140 °C (Fig. 2).

After the massage stimulation, statistically significant differences were found after the hot stone massage, the shoulders and rear trunk, and after the classical massage, in front lower limbs.

In Table 3 changes in systolic and diastolic blood pressure and heart rate before and after the thermal

Table 2. Changes in the surface temperature of 12 body areas after cryostimulation and massage stimulation

			Cryostimulation (Group 1)				Massage stimulation (Group 2)		
			–120 °C	–140 °C	*p*		Hot stone massage	Classical massage	*p*
Tested area			Mean ± SD	Mean ± SD			Mean ± SD	Mean ± SD	
Trunk	front	A-1	33.44 ± 0.76	33.54 ± 0.75	NS	**TB1***	33.15 ± 0.82	33.46 ± 0.67	NS
			31.56 ± 0.35	31.64 ± 0.98	NS	**TA1**	33.92 ± 0.66	34.29 ± 0.58	NS
			1.87 ± 0.51	1.90 ± 0.46	NS	**TD1**	0.77 ± 0.51	0.83 ± 0.51	NS
		A-2	32.96 ± 0.85	33.40 ± 0.80	NS	**TB2**	32.81 ± 1.22	33.20 ± 0.76	NS
			29.91 ± 0.37	29.89 ± 0.98	NS	**TB2**	34.13 ± 0.77	34.47 ± 0.57	NS
			3.05 ± 0.71	3.20 ± 0.79	NS	**TD2**	1.32 ± 0.73	1.27 ± 0.54	NS
	rear	A-7	33.11 ± 0.78	33.00 ± 0.94	NS	**TB7**	**33.05 ± 0.75**	**33.54 ± 0.73**	**0.044687****
			31.04 ± 0.38	30.85 ± 1.10	NS	**TA7**	33.81 ± 0.65	33.97 ± 0.67	NS
			2.07 ± 0.51	2.15 ± 0.34	NS	**TD7**	**0.76 ± 0.32**	**0.43 ± 0.30**	**0.002020****
		A-8	32.76 ± 0.88	32.94 ± 0.95	NS	**TB8**	**32.33 ± 1.15**	**33.03 ± 0.66**	**0.024353****
			29.92 ± 0.46	29.87 ± 1.00	NS	**TA8**	34.25 ± 0.80	33.85 ± 0.56	NS
			2.85 ± 0.59	3.07 ± 0.60	NS	**TD8**	**1.92 ± 0.65**	**0.82 ± 0.42**	**0.000000****
Upper limb	front	A-3	32.28 ± 0.86	32.69 ± 0.87	NS	**TB3**	31.84 ± 0.83	32.19 ± 0.77	NS
			28.68 ± 0.83	28.70 ± 1.01	NS	**TA3**	32.74 ± 0.81	33.22 ± 0.79	NS
			3.60 ± 0.61	3.98 ± 0.73	NS	**TD3**	0.90 ± 0.53	1.03 ± 0.48	NS
		A-4	**32.19 ± 0.91**	**33.08 ± 0.82**	**0.002388****	**TB4**	31.50 ± 0.87	32.01 ± 0.77	NS
			28.72 ± 0.86	28.75 ± 0.95	NS	**TA4**	32.54 ± 0.80	33.05 ± 0.83	NS
			3.47 ± 0.62	**4.33 ± 0.63**	**0.000100****	**TD4**	1.04 ± 0.57	1.04 ± 0.60	NS
	rear	**A-9**	**31.11 ± 0.84**	**31.89 ± 0.90**	**0.006652****	**TB9**	31.09 ± 0.89	31.32 ± 0.66	NS
			27.84 ± 0.94	27.49 ± 0.98	NS	**TA9**	31.64 ± 0.90	31.95 ± 0.82	NS
			3.27 ± 0.59	**4.41 ± 0.67**	**0.000001****	**TD9**	0.55 ± 0.33	0.63 ± 0.44	NS
		A-10	31.33 ± 0.79	31.22 ± 0.91	NS	**TB10**	30.95 ± 0.73	31.31 ± 0.70	NS
			28.28 ± 0.38	**27.00 ± 1.17**	**0.000039****	**TA10**	31.79 ± 0.70	31.91 ± 0.78	NS
			3.05 ± 0.60	**4.22 ± 0.75**	**0.000003****	**TD10**	0.85 ± 0.46	0.60 ± 0.41	NS
Lower limb	front	A-5	29.92 ± 0.97	30.15 ± 0.97	NS	**TB5**	29.95 ± 0.97	29.74 ± 0.96	NS
			23.95 ± 0.50	24.32 ± 0.98	NS	**TA5**	31.24 ± 1.00	31.47 ± 0.78	NS
			5.98 ± 0.57	5.83 ± 0.63	NS	**TD5**	**1.29 ± 0.54**	**1.74 ± 0.75**	**0.038344****
		A-6	29.92 ± 1.03	30.17 ± 1.01	NS	**TB6**	29.90 ± 0.89	29.63 ± 0.90	NS
			23.98 ± 0.58	24.28 ± 1.06	NS	**TA6**	31.19 ± 0.91	31.46 ± 0.77	NS
			5.94 ± 0.56	5.89 ± 0.64	NS	**TD6**	**1.30 ± 0.65**	**1.83 ± 0.77**	**0.023859****
	rear	A-11	30.18 ± 0.94	30.22 ± 0.89	NS	**TB11**	30.21 ± 0.83	30.23 ± .87	NS
			24.13 ± 0.51	23.96 ± 1.00	NS	**TA11**	31.60 ± 0.62	31.96 ± 0.76	NS
			6.05 ± 0.59	6.26 ± 0.57	NS	**TD11**	1.40 ± 0.56	1.74 ± 0.60	NS
		A-12	30.20 ± 0.92	30.22 ± 0.86	NS	**TB12**	30.26 ± 0.90	30.22 ± 0.93	NS
			24.13 ± 0.48	23.97 ± 0.99	NS	**TA12**	31.59 ± 0.72	31.92 ± 0.78	NS
			6.08 ± 0.60	6.26 ± 0.57	NS	**TD12**	1.33 ± 0.47	1.70 ± 0.67	NS

* TB – temperature before treatment (°C), TA – temperature after treatment (°C), TD – difference in temperature |TB – TA|, ** $p \leq 0.05$.

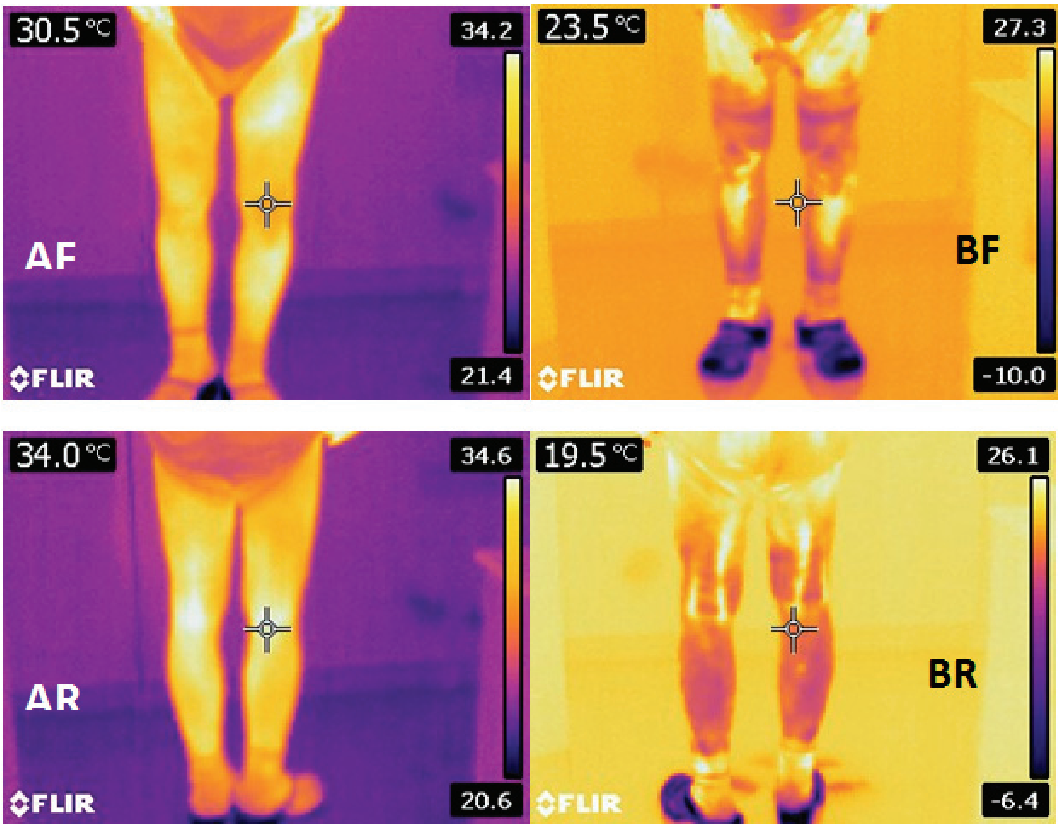


Fig. 2. Exemplary thermograms of the dorsal side of the lower limb recorded before entering the cryostimulation (AF – before front leg, AR – before rear leg) and after 3 min cryotherapy at –140 °C (BF – after front leg, BR – after rear leg)

Table 3. Changes in systolic and diastolic blood pressure and heart rate during thermal stimulation treatment

	SBP			DBP			HR		
Group	before	after	C	before	after	C	before	after	C
1 (–120)	123.84 ± 4.77	137.84 ± 5.54	14.00 ± 5.28	74.95 ± 3.73	82.53 ± 3.28	7.58 ± 3.44	74.95 ± 6.24	83.95 ± 7.34	9.00 ± 4.19
1 (–140)	123.28 ± 5.83	134.86 ± 6.90	11.58 ± 4.52	75.10 ± 3.36	83.93 ± 3.09	8.84 ± 2.47	76.68 ± 5.67	83.62 ± 5.82	6.95 ± 2.08
2 (HSM)	123.65 ± 7.89	127.8 ± 8.64	4.15 ± 3.31	73.3 ± 5.96	76.95 ± 5.61	3.65 ± 2.32	65.8 ± 5.64	68.95 ± 6.49	3.15 ± 2.87
2 (CM)	123.75 ± 6.53	132.00 ± 8.87	8.25 ± 5.10	76.25 ± 4.24	80.65 ± 4.45	4.40 ± 2.64	69.9 ± 7.40	74.15 ± 8.63	4.25 ± 2.83
1 (–120) v. 1 (–140)	NS	NS	NS	NS	NS	NS	NS	NS	NS
2 (HSM) v. 2 (CM)	NS	NS	**0.004551***	NS	**0.026458***	NS	NS	**0.037764***	NS

SBP – systolic blood pressure (mmHg), DBP – diastolic blood pressure (mmHg), HR – heart rate (bpm), C – difference blood pressure and heart rate, HSM – hot stone massage, CM – classical massage, * $p \leq 0.05$.

stimulation treatments are presented. There were no statistically important differences in the studied parameters after the cryostimulation at the temperatures of –120 °C and –140 °C. With massage stimulation, there was a statistically significant increase in the difference in systolic blood pressure before and after the treatment, as well as a statistically significant increase in diastolic blood pressure and heart rate after the treatment.

When comparing the changes in surface temperature of particular areas of the body, statistically important differences between the front and back of the body were noted (Table 4).

Greater temperature differences were observed after the cryotherapy treatments (–120 °C and –140 °C) (Fig. 3). The greatest changes in the cryostimulation process were observed in the upper and lower limbs, with slightly bigger ones after the treatment at –140°C.

Thermovision imaging analysis which followed the stimulation with hot volcanic stone massage and

Table 4. Differences between the changes of temperature decrease in particular areas of the body /front and rear/

		Group 1 –120 °C		Group 1 –140 °C		Group 2 HSM		Group 2 CM	
		Mean	*p*	Mean	*p*	Mean	*p*	Mean	*p*
Trunk	Upper part (A-1–A-7)[1]	–0.20 ± 0.05	0.0000*	–0.25 ± 0.51	0.0398*	0.01 ± 0.52	NS	0.40 ± 0.50	0.0002*
	Lower part (A-2–A-8/	0.20 ± 0.16	0.0000*	0.13 ± 1.10	NS	–0.60 ± 0.61	0.0002*	0.45 ± 0.70	0.0019*
Upper limb	Right (A-3–A-10)	0.55 ± 0.81	0.0068*	–0.24 ± 1.02	NS	0.05 ± 0.63	NS	0.43 ± 0.54	0.0138*
	Left (A-4–A-9)	0.20 ± 0.84	NS	–0.08 ± 0.95	NS	0.35 ± 0.55	0.0004*	0.40 ± 0.65	0.0020*
Lower limb	Right (A-5–A-12)	–0.10 ± 0.19	0.0307*	–0.43 ± 0.16	0.0000*	0.04 ± 0.55	NS	0.04 ± 0.51	0.0314*
	Left (A-6–A-11)	–0.11 ± 0.29	NS	–0.37 ± 0.14	0.0000*	0.10 ± 0.77	NS	0.09 ± 0.68	NS

* $p \le 0.05$, [1] number of tested area (A-1 to A-12), UL – upper limbs, LL – lower limbs.

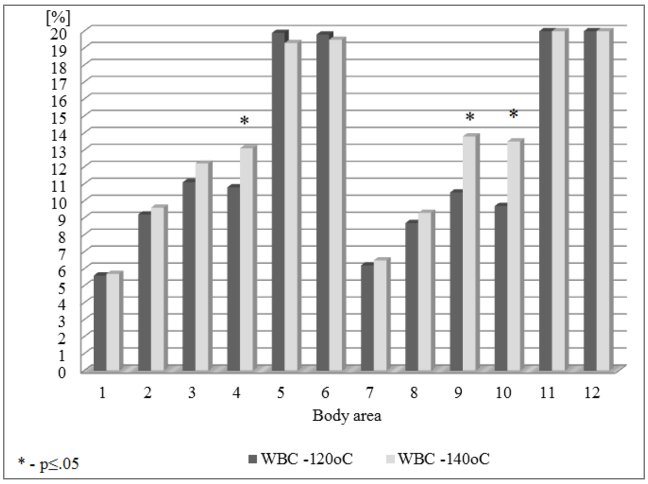


Fig. 3. Percentage difference (D) in surface body temperature after cryostimulation (–120 °C and –140 °C) in the tested body areas

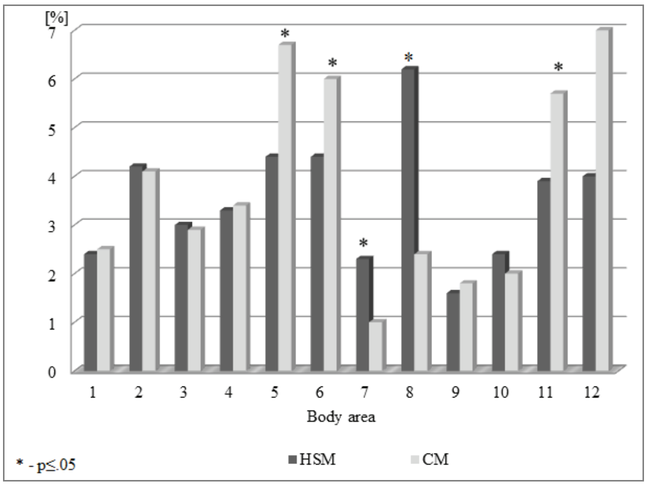


Fig. 4. Percentage difference (D) in surface body temperature after massage treatments

classical massage showed (Fig. 4) that there were two areas of elevated temperature. After the hot stone massage, a statistically significantly higher temperature was noted in A-7 and A-8, while after the classic massage in A-5 and A-6 (difference statistically significant) and A-11 and A-12 (difference not statistically significant). The highest percentage rise in temperature after the two massages increased to 6%, and was approximately three times lower, in absolute terms, than the cryotherapy treatments.

4. Discussion

Thermostimulation through the action of heat or cold affects the function of the circulatory system. One of the ways to assess the function of blood vessels is to check the hemodynamic values of the blood. In the present study, an increase in systolic and diastolic blood pressure and heart rate was observed in all forms of thermostimulation. These changes, however, were not statistically significant. Similar results were obtained by Dębiec-Bąk and co-workers in the case of cryostimulation and by Hinds and co-workers in the case of massage [11], [12].

During thermostimulation therapies, the surface temperature of the human body changes. Depending on the stimulus, a temperature drop of up to 90% can be observed [19]. The magnitude of changes depends not only on the length of exposure but also on the type of stimulant. In studies carried out in the aquatic environment, the body surface temperature changes were three times higher than those obtained in the case of dry cold treatments – cryostimulation. These differences were related to the chemical properties of the coolant. If the water temperature is not lower than 4 °C, changes even after short exposure (as in the case of a cold pressor test (CTP)-1 min) exceeded 30%. Extending the time, as in the case of cold water immersion, cause temperature drops within the torso by about 50–60% and on the lower limbs by even 90% [9], [19]. In the case of studies presented in the work, the changes are much milder.

Cryostimulation treatments carried out on the subjects reduced the surface temperature of the body from 5–20%, depending on the segment of the body.

As in our own research and other authors, the largest changes were recorded in the lower limbs, while the smallest in the trunk [7], [8], [11], [13], [21], [22]. Using two temperatures during cryostimulation sessions (–120 °C and –140 °C) no statistically significant differences were observed in the majority of the subjects' body segments. Similar results were obtained Dębiec-Bąk and colleagues who compared the WBC treatments at four different temperatures from –60 °C to –140 °C. At the same time, they observed statistically significant differences between temperature changes depending on the time of cold exposure [11]. Similar differences between temperature changes depending on the refrigerant used were presented in Costello and colleagues by comparing the results of many authors using, among others, cryotherapy such as whole body cryotherapy, cold spray, cryotherapy cuffs, frozen peas, cold water immersion, ice and cold packs. The results of these tests show the importance of the cooling factor and its physicochemical properties, but mainly its thermal conductivity [6].

Many authors look for a relationship between differences in skin surface temperature in thermal stimulation processes and the thickness of the subcutaneous adipose layer and the BMI [3], [20]. Zalewski and colleagues in their research on a group of men with different BMI did not find a relationship between the decrease in body surface temperature and the value of the weight-increase index [24]. However, the BMI index indicates the relation of body mass to height, but does not take into account body composition, and above all, muscle mass or fat component. Despite the lack of dependence between temperature changes and the BMI index, as shown by Zalewski, the research included people with similar anthropometric values. As observed in the research, important may be not so much the BMI index as the body composition. Based on the results presented in this study, it can be assumed that the surface temperature drops in the lower extremities after the cryostimulation are greater at the front of the body than at the back. This can be explained by the skeletal and anatomical structure of the lower limb, which is better insulated in the rear with a subcutaneous layer composed of muscle and fat tissue. The adipose tissue, with its low thermal conductivity and relatively low vascularity, acts as an insulating layer to protect the body against getting cold and, at the same time, blocks the transport of heat from the interior of the body [3]. Differences between changes in body temperature depending on the weight of fat or muscle tissue are not yet described, as it requires further research.

WBC is systemic and the massage used in the work included one segment of the body. In the case of hot stone massage, thermal imaging confirmed its local action, significantly increasing the segment subjected to thermostimulation. Similarly to Witoś and co-workers, temperature changes did not exceed 2–3 °C even though the temperature of the stones was 60 °C [23].

In the case of classic massage, its operation was more generalized. Significant lesions were also observed in the lower limbs, which were not subjected to thermal stimulation. Although the therapist's hand was not heated, as it would be with stones, the changes turned out to be higher. Similar results on the generalized effects of segmental massage were presented in the work by Adamczyk-Bujniewicz and Kubacki, who observed a greater increase in body temperature within unmasked thighs in relation to the lumbar area [1]. In his works, Boguszewski emphasizes the generalized effect of classic massage assessed with thermovision studies [3], [4]. In the presented studies, the temperature changes, although generalized, did not exceed 1 °C [1], [4], [5]. Hinds and co-workers, who evaluated the usefulness of the massage in the post-exercise phase, made higher changes in their research. Based on their studies, the temperature in subjects undergoing deep massage after physical exertion was 2.5 °C higher than in those who did not receive a massage [12]. Similar results of the reaction to deep massage were presented by Żuk and co-workers, simultaneously confirming the generalized reaction of the body to the action of a massage therapist [25].

The thermovision method gives the possibility of showing even small temperature changes. In the case of hot stone massage, local effects limited to the A-8 area were confirmed, in which statistically significant changes were observed, whereas in the case of classical massage the thermovision method confirmed its systemic effect.

Thanks to the application of the assessment of changes in body surface temperature using the thermovision method, it is possible to assess the effect of various temperatures on the subject. The thermovision method proved to be effective both in the case of significant temperature differences observed in the case of cryotherapy and with slight changes in thermal treatments.

The obtained data has educational value because of the small amount of available literature on the subject [24].

The results obtained by using the thermal imaging analysis encourage further study of persons of different sexes and ages who choose a healthy lifestyle.

Based on the obtained results, the following conclusions can be drawn:

1. Thermal imaging tests are a good tool for assessing changes in body surface temperature after using various forms of thermostimulation. They enable more precise assessment of changes in individual segments of the human body, in comparison with the method based on hemodynamic blood values.
2. The body's response to systemic cryotherapy varied depending on the body segment, it was stronger in the limbs than in the trunk.
3. Classic massage in the evaluation of the thermal imaging showed a more systemic effect, compared with the hot stone massage.

References

[1] ADAMCZYK-BUJNIEWICZ H., KUBACKI J., *Local and distant thermal changes as the reaction to the massage application*, Balneologia Polska, 2006, 3, 170–175.

[2] AMMER K., *The Glamorgan protocol for recording and evaluation of thermal images of the human body*, Thermol. Int., 2008, 18, 125–129.

[3] BANFI G., LOMBARDI G., COLOMBINI A., MELEGATI G., *Whole-body cryotherapy in athletes*, Sports Med., 2010, 40, 509–517.

[4] BOGUSZEWSKI D., ADAMCZYK J.G., ANDERSZ N., MROZEK N., PIEJKO K., JANICKA M., BIAŁOSZEWSKI D., *Impact of classical massage on temperature, strength and flexibility of upper limbs muscles in healthy men*, TSS, 2015, 22 (2), 71–75.

[5] BOGUSZEWSKI D., ADAMCZYK J.G., URBAŃSKA N., MROZEK N., PIEJKO K., JANICKA M., BIAŁOSZEWSKI D., *Using thermal imaging to assess the effect of classical massage on selected physiological parameters of upper limbs*, Biomedical Human Kinetics, 2014, 6, 146–150, DOI: 10.2478/bhk-2014-0024.

[6] COSTELLO J., MCINERNEY C.D., BLEAKLEY C.M., SELFE J., DONNELLY A.E., *The use of thermal imaging in assessing skin temperature following cryotherapy: a review*, J. Therm. Biol., 2012, 37 (2), 103–110.

[7] CHOLEWKA A., DRZAZGA Z., SIERON A., STANEK A., *Thermovision diagnostics in chosen spine diseases treated by whole body cryotherapy*, J. Therm. Anal. Calorim., 2010, 102, 113–119.

[8] CHOLEWKA A., DRZAZGA Z., SIEROŃ A., *Monitoring of whole body cryotherapy effects by thermal imaging; preliminary report*, Phys. Med., 2008, 22, 57–62.

[9] CHWAŁCZYŃSKA A., GRUSZKA K., CAŁKOSIŃSKI I., SOBIECH K.A., *Thermovision analysis changes of human surface temperature in cold pressor test*, BioMed. Res. Int., 2015, art. ID 783642 [5 p.], DOI: 10.1155/2015/783642.

[10] DĘBIEC-BĄK A., PAWIK Ł., SKRZEK A., *Thermoregulation of football players after cryotherapy in thermography*, J. Therm. Anal. Calorim., 2016, 126 (3), 1633–1644, DOI: 10.1007/s10973-016-5623-3.

[11] DĘBIEC-BĄK A., SKRZEK A., PODBIELSKA H., *Application of thermovision for estimation of the optimal and safe parameters of the whole body cryotherapy*, J. Therm. Anal. Calorim., 2013, 111, 1853–1859.

[12] HINDS T., MCEWAN I., PERKES J., DAWSON E., BALL D., GEORGE K., *Effects of massage on limb and skin blood flow after quadriceps massage*, Med. Sci. Sports Exerc., 2004, 36 (8), 1308–1313.

[13] GRUSZKA K., *Thermovision evaluation of the body surface temperature distribution after some thermal stimulation application*, Doctoral thesis, Pomeranian Medical University in Szczecin, Szczecin 2014.

[14] KLIMEK A.T., LUBKOWSKA A., SZYGUŁA Z., CHUDECKA M., FRĄCZEK M., *The influence of the ten session of the whole body cryostimulation on aerobic and anaerobic capacity*, IJOMER, 2010, 23, 181–189.

[15] MATOS F., NEVES E.B., NORTE M., ROSA C., REIS V.M., ALVES J.V., *The use of thermal imaging to monitor skin temperature during cryotherapy: a systematic review*, Infrared Phys. Techn., 2015, 73, 194–203, DOI: 10.1016/j.infrared.2015.09.013.

[16] MOREIRA D.G., COSTELLO J.T., BRITO C.J., ADAMCZYK J.D.G., AMMER K., BACH A.J.E., COSTA C.M.A., EGLIN C., FERNANDES A.A., FERNÁNDEZ-CUEVAS I., FERREIRA J.J.A., FORMENTI D., FOURNET D., HAVENITH G., HOWELL K., JUNG A., KENNY G.P., KOLOSOVAS-MACHUCA E.S., MALEY M.J., MERLA A., PASCOE D.D., PRIEGO QUESADA J.I., SCHWARTZ R.G., SEIXAS A.R.D., SELFE J., VAINER B.G., SILLERO-QUINTANA M., *Thermographic imaging in sports and exercise medicine: A Delphi study and consensus statement on the measurement of human skin temperature*, J. Therm. Biol., 2017, 69, 155–162.

[17] PODBIELSKA H., SKRZEK A., *Wykorzystywanie niskich temperatur w biomedycynie*, A. Skrzek (eds.), Oficyna Wydawnicza Politechniki Wrocławskiej, 2012, 33–38.

[18] RING E.F.J., AMMER K., *The technique of thermal imaging in medicine*, Thermol. Int., 2000, 10, 7–14.

[19] SOBIECH K.A., CHWAŁCZYŃSKA A., GRUSZKA K., JĘDRZEJEWSKI G., *Zastosowanie termowizji w ocenie zmian temperatury powierzchniowej ciała po kąpieli morsów (regular winter swimmer)*, PAK, 2014, 60, 1112–1115.

[20] SOBIECH K.A., SKRZEK A., DĘBIEC-BĄK A., GRUSZKA K., SOCHA M., JONAK W., *Dynamics of body temperature changes in women due to the whole-body cryotherapy: preliminary communication*, Acta Bio-Optica Inform. Med., 2009, 15, 315–318.

[21] WESTERLUND T., OKSA J., SMOLANDER J., MIKKELSSON M., *Thermal responses during and after whole-body cryotherapy (–110 °C)*, J. Therm. Biol., 2003, 28, 601–608.

[22] WESTERLUND T., SMOLANDER J., UUSITALO-KOSKINEN A., MIKKELSSON M., *The blood pressure responses to an acute and long-term whole-body cryotherapy (–110 °C) in men and women*, J. Therm. Biol., 2004, 36, 264–268.

[23] WITOŚ M., DEMCZUK-WŁODARCZYK E., PODBIELSKA H., *Termowizyjna ocena zmian temperatury w okolicy grzbietowej pod wpływem masażu relaksacyjnego gorącymi kamieniami*, Acta Bio-Opt. Inform. Med., 2009, 15, 239–243.

[24] ZALEWSKI P., BUSZKO K., KLAWE J.J., TAFIL-KLAWE M., LEWANDOWSKI A., SŁOMIŃSKI K., PANOWICZ I., *Influence of the whole body cryotherapy on the body temperature in chosen regions in reference to the body mass index*, Acta Bio-Opt. Inform. Med., 2009, 15, 129–136.

[25] ŻUK M., DĘBIEC-BĄK A., PAWIK Ł., SKRZEK A., *Influence of massage deep in quadriceps soccer players, in isokinetic testing and thermography*, Journal of Education, Health and Sport, 2016, 6 (7), 236–251.