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INFLUENCE OF THE TEN SESSIONS OF THE WHOLE BODY CRYOSTIMULATION ON AEROBIC AND ANAEROBIC CAPACITY

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Abstract
Objectives: The aim of this study was to determine the influence of whole body cryostimulation on aerobic and anaerobic capacities. **Materials and Methods:** To test the hypothesis that whole body cryostimulation improves physical capacity, thirty subjects (fifteen males and fifteen females) undertook two ergocycle trials before and after the ten sessions of cryogenic chamber treatment. To assess baseline aerobic capacity, the progressive cycle ergometer test was applied. This allowed determination of maximal oxygen uptake and ventilatory thresholds. Twenty-second Wingate test was performed to assess baseline levels of anaerobic power. After finishing the treatments in the cryogenic chamber, the exercise protocol was repeated. Before the first, and after the last whole body cryostimulation, venous blood samples were drawn to determine basic blood values, including levels of erythrocytes, leukocytes and thrombocytes, hemoglobin concentration, and hematocrit. **Results:** There were no changes in aerobic capacity, in both females and males, after ten sessions of 3-minute-long exposures to cryogenic temperature (–130°C). Participation in the whole body cryostimulation caused an increase in maximal anaerobic power in males (from 11.1 to 11.9 $W \times kg^{-1}$; $P < 0.05$), but not in females. **Conclusions:** It can be concluded that whole body cryostimulation can be beneficial, at least in males, for increasing anaerobic capacity in sport disciplines involving speed and strength.

Key words:
Cryostimulation, Cryogenic temperature, Aerobic capacity, Anaerobic capacity

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INTRODUCTION

Whole body cryotherapy treatments have very wide application because of the complex influence of cold on the human body. The response of the body to cold temperatures occurs through changes in the endocrine system (increase in adrenocorticotropin concentration, β-endorphins, epinephrine, norepinephrine and testosterone concentration in men) [1–4], circulatory system (contraction of blood vessels in the skin, then their dilation and congestion of the skin) [5], neuromuscular system (reduction of muscle tension, decrease in nerve conduction velocity) [6] and immunological system (increase in cell-mediated and humoral immunity) [1,7–10]. Moreover, whole body cooling influences the prooxidant-antioxidant balance in blood [11–14], and has an anti-inflammatory [15] as well as an analgesic effect [6]. This analgesic effect is caused by the combination of increased β-endorphin concentration and decreased nerve conduction in afferent fibers, which are responsible for pain reception [2,16]. It should be stressed that hypothermia also has a positive effect on the psychological condition [17,18].

Such complex reactions should have a significant effect on physical work capacity. The available data on the effects of low temperatures on physical performance usually relate to the influence of local cryotherapy on the rate of post injury recovery [19,20], following local cooling treatments with liquid nitrogen, carbon dioxide, and ice packs or cold water immersion.

Benefits of cold therapy are observed not only in patients with different diseases but also in athletes for the treatment of sports injuries, and during recovery from high training loads and competition [19–24]. The application of low temperature treatments accelerates recovery after surgery, and reduces the reoccurrence of tissue disruption [25]. Of a great significance to athletes subjected to intense physical stress is the alleviation of pain, and decrease of post injury inflammation [20,22,25–27].

Effects of whole body cryostimulation on physical capacity have not been extensively studied. Long term research of the whole body cryostimulation is rare. The effects of whole body cryostimulation in a cryogenic temperature on human performance are practically non-existent. Thus, the main objective of this study was to investigate the effects of a ten-day-long series of whole body cryostimulation (once a day) on aerobic and anaerobic capacity.

MATERIALS AND METHODS

The research included 30 volunteers — students of physical education, both female, (n = 15) and male, (n = 15) with an average age of 21.6 years. Participants were divided into two groups because of gender differences in thermal regulation. Before the beginning of the experiment, all of the participants underwent a medical examination to confirm their health status, ability to perform exhaustive exercise and participate in cryostimulation.

Before the beginning of the study basic anthropometric data was collected, including: body height (BH), body mass (BM), body mass index (BMI), fat content (%Fat), fat mass (FM) and fat-free mass (FFM). The anthropometric variables considered in this work, their mean values and standard deviations are presented in Table 1.

Table 1. Somatic characteristics of the female (F) and male (M) study participants

Variables	F		M	
	mean	SD	mean	SD
Age (years)	21.7	0.88	21.2	0.86
BH (cm)	165.9	7.19	182.3	7.64
BM (kg)	57.7	6.09	74.8	5.84
BMI ($kg \times m^{-2}$)	21.0	1.70	22.5	1.55
Fat (%)	20.8	4.69	11.7	2.29
Fat Mass (kg)	12.2	3.81	8.7	1.84
Fat-Free Mass (kg)	45.5	2.97	66.0	5.43

Progressive ergocycle test was applied to assess aerobic capacities. The test was performed on a bicycle ergometer, beginning with a work load of 1W per kg of fat-free mass ($1\ W \times kg_{FFM}^{-1}$) which was increased by half of this value ($0.5\ W \times kg_{FFM}^{-1}$) every 2 min until volitional exhaustion. During the exercise, the following variables were measured continuously: oxygen uptake (VO_2), expired carbon

dioxide (VCO_2), fraction of oxygen in expired air (FEO_2), fraction of carbon dioxide in expired air ($FECO_2$), minute ventilation (VE), tidal volume (TV), respiration frequency (RF), ventilatory equivalent ratio for oxygen ($VE \times VO_2^{-1}$), ventilatory equivalent ratio for carbon dioxide, ($VE \times VCO_2^{-1}$) and heart rate (HR). These values allowed calculation of the ventilatory aerobic (AT) and anaerobic (AnT) thresholds for each participant. To determine AT, the maximum value of FEO_2, significant increase in VE and the minimum value of $VE \cdot VO_2^{-1}$ were used, while maximum value of $FECO_2$, significant increase in VE, and the minimum value of $VE \times VCO_2^{-1}$ were used for the determination of AnT [28].

The Wingate test was preformed to assess anaerobic power and capacity of all participants [29]. This test was preceded by a 2 min warm-up with a load of 1 $W \times kg^{-1}$, and several 5 s accelerations. The final test was conducted for over 20 s with the load set at 7.5% body mass for men and 6.5% for women. The following variables of anaerobic power and capacity registered in the Wingate test were considered in the work: maximal anaerobic power of lower limbs (MAP), average power (AP), time to obtain and sustain MAP (t_{obt}, t_{sus}), fatigue index (FI), and total external work (W_{tot}).

Prior to and three minutes after each test (progressive and Wingate), capillary blood samples were drawn from the subject's finger tip to determine plasma lactate concentration (LA).

Two days after performing the tests of aerobic and anaerobic capacity, participants started ten sessions of 3-minute-long exposures to cryogenic temperature (–130°C), according to the generally accepted protocol for cryotherapy treatments in a cryogenic chamber:

1. Before entering the cryogenic chamber, participants dried their bodies thoroughly to eliminate the sensation of cold. To protect the upper airways, all participants breathed through a surgical mask. For protective purposes, all participants wore gloves, socks, special footwear and head bands to protect the ears. The males wore shorts while females wore bathing suits.
2. To achieve the initial adaptation to low temperatures, all subjects were introduced to the pre-chamber location, where for 3' they acclimatized to a temperature of –60°C, and later were placed for three minutes in the chamber where the temperature was maintained at –130°C.

After leaving the chamber, they entered a room where the temperature was about 19°C. The treatments were carried out from Monday to Saturday, between 3.00–3.30 p.m. The whole body cryostimulation was carried out in a modern, computerized cryogenic chamber.

Before the first and after the last treatment, venous blood samples were drawn to determine blood variables, including number of erythrocytes (RBC), hemoglobin concentration (Hb), hematocrit value (Hct), number of leukocytes (WBC) and thrombocytes (PLT).

Two days after the end of treatment in the cryogenic chamber, the exercise procedures (progressive and Wingate test) were repeated. All procedures were the same in both series of tests for females (F) and males (M) before cryostimulation — F1, M1 and after cryostimulation — F2, M2.

Body mass and body composition were evaluated with the use of electrical impedance (Tanita — Body Composition Analyzer, model TBF-300). To register variables of respiratory system, the ergospirometer Medikro 919 (Finland) was used. Heart rate was measured with a Polar sport-tester (Vantage NV). All tests were executed on a Monark 818E bicycle ergometer (Sweden). Blood lactate (LA) concentration was measured enzymatically using Biomerieux tests and Specol spectrophotometer (Carl Zeiss Jena, Germany).

Ethics

The research project was approved by the Bioethical Committee of the Regional Medical Society in Kraków. All participants gave their informed consent prior to their inclusion to the study.

Statistics

The obtained data was analyzed statistically. The results were presented as arithmetic means (Mean) and standard deviations (±SD). To determine the significance of differences between the series of examinations in females

(diff. F2 vs. F1) and in males (diff. M2 vs. M1) one-way analysis of variance (ANOVA) was applied. When a significant F-value was found, a Tukey's post-hoc tests were used to determine the source of significance, which was set at $P < 0.05$.

RESULTS

Influence of the whole body cryostimulation on aerobic capacity

There were no changes in aerobic capacity, in both females and males, after ten sessions of 3-minute-long exposures to cryogenic temperature (Table 2).

Lactate values were significantly ($P < 0.05$) higher in the second stage of the experiment, following the cryostimulation treatment. Post exercise lactate concentration increased significantly ($P < 0.05$) by 2.11 mmol×l^{-1} (7.61 vs. 9.72 mmol×l^{-1}) and the difference between values of post and pre exercise lactate concentration (ΔLA) was 1.54 mmol×l^{-1} in females. Similarly, changes in resting and post exercise lactate concentration in males were significant ($P < 0.05$) after the series of whole body cryostimulation. Post exercise lactate concentration increased by 3.36 mmol×l^{-1}, while the difference between pre and post exercise lactate concentration was 2.73 mmol×l^{-1}.

Participation in the whole body cryostimulation caused a marginal, statistically insignificant decrease in the aerobic threshold levels in both females and males (Table 3). The same tendency was observed in anaerobic threshold after treatments of whole body cryostimulation in both experimental groups (Table 4).

Influence of the whole body cryostimulation on anaerobic capacity

Ten sessions of 3-minute-long exposures to cryogenic temperature caused an increase in anaerobic capacity of male subjects. This was expressed by the rise of maximal anaerobic power, as well as other variables describing the ability to perform short and intensive physical exercise in males but not in females (Table 5).

In the male subjects, whole body cryostimulation caused a significant ($P < 0.05$) increase in relative values of peak power (11.1 vs. 11.9 W×kg^{-1}). A significant ($P < 0.05$) increase in mean power (723.9 vs. 756.1 W) was also observed, as well as an increase in total work (13.77 vs. 14.53 kJ) registered in the Wingate test after the whole body

Table 2. Physiological variables for the female (F) and male (M) participants during the progressive test at maximal intensity

Variables	F1		F2		M1		M2		Differences	
	mean	SD	mean	SD	mean	SD	mean	SD	F2 vs. F1	M2 vs. M1
T (min)	15.00	1.78	14.90	1.73	17.00	1.65	16.90	1.76	–0.10	–0.10
P max (W)	192.20	22.17	190.80	22.22	312.60	34.33	312.10	37.11	–1.40	–0.50
P max (W×kg^{-1})	3.40	0.45	3.30	0.43	4.20	0.36	4.10	0.44	–0.10	–0.10
VO_2 max (L×min^{-1})	2.70	0.30	2.60	0.35	4.20	0.39	4.10	0.34	–0.10	–0.10
VO_2 max (ml×kg^{-1}×min^{-1})	46.90	5.85	45.80	5.32	56.20	2.87	55.30	3.83	–1.10	–0.90
VE max (l×min^{-1})	94.80	12.14	91.60	14.27	160.80	17.03	158.30	23.38	–3.20	–2.50
TV max (l)	2.00	0.34	2.00	0.27	2.90	0.23	3.00	0.36	0	0.10
RF max (1×min^{-1})	47.70	8.70	46.80	7.56	55.90	5.50	53.00	9.92	–0.90	–2.90
HR max (bpm)	190.90	6.80	190.60	7.77	192.90	8.57	189.80	5.69	–0.30	–3.10
LA_{rest} (mmol×l^{-1})	0.92	0.40	1.49	0.36	0.98	0.35	1.61	0.37	0.57*	0.63*
LA_{exe} (mmol×l^{-1})	7.61	0.89	9.72	1.97	9.00	1.44	12.36	1.86	2.11*	3.36*
ΔLA (mmol×l^{-1})	6.69	0.96	8.23	1.83	8.02	1.40	10.75	1.82	1.54*	2.73*

* Significant differences at the $P < 0.05$ level.

Table 3. Physiological variables for the female (F) and male (M) participants during the progressive test at the aerobic threshold (AT)

Variables	F1		F2		M1		M2		Differences	
	mean	SD	mean	SD	mean	SD	mean	SD	F2 vs. F1	M2 vs. M1
T (min)	4.7	1.02	4.2	1.41	5.9	1.59	5.7	1.78	–0.5	–0.2
P (W)	75.8	10.59	70.3	16.13	130.3	26.94	126.9	30.75	–5.5	–3.4
P ($W \times kg^{-1}$)	1.3	0.20	1.2	0.26	1.8	0.35	1.7	0.39	–0.1	–0.1
VO_2 ($l \times min^{-1}$)	1.3	0.17	1.2	0.22	2.0	0.29	1.9	0.32	–0.1	–0.1
VO_2 ($ml \times kg^{-1} \times min^{-1}$)	21.7	2.44	20.5	2.68	26.1	4.60	25.9	3.87	–1.2	–0.2
VE ($l \times min^{-1}$)	27.9	4.03	28.1	5.68	37.3	8.63	41.4	6.82	0.2	4.1
TV (l)	1.4	0.33	1.3	0.26	1.8	0.46	1.9	0.43	–0.1	0.1
RF ($1 \times min^{-1}$)	20.8	3.76	22.8	4.32	21.1	5.10	22.0	4.18	2.0	0.9
HR (bpm)	132.0	10.88	130.1	6.12	134.0	10.70	131.0	8.24	–1.9	–3.0
%VO_2max	47.1	7.03	45.2	7.18	48.1	8.10	46.1	6.28	–1.9	–2.0
%HRmax	69.1	4.51	68.3	3.01	69.5	3.80	69.4	4.31	–0.8	–0.1

Table 4. Physiological variables for the female (F) and male (M) participants during the progressive test at the anaerobic threshold (AnT)

Variables	F1		F2		M1		M2		Differences	
	mean	SD	mean	SD	mean	SD	mean	SD	F2 vs. F1	M2 vs. M1
T (min)	10.6	1.85	10.2	0.97	11.0	2.38	10.5	1.56	–0.4	–0.5
P (W)	142.8	23.87	137.1	10.90	214.4	44.95	208.0	32.09	–5.7	–6.4
P ($W \times kg^{-1}$)	2.5	0.44	2.4	0.29	2.9	0.53	2.8	0.36	–0.1	–0.1
VO_2 ($l \times min^{-1}$)	2.0	0.34	1.9	0.28	2.9	0.42	2.8	0.35	–0.1	0.1
VO_2 ($m^l \times kg^{-1} \times min^{-1}$)	35.0	5.90	33.3	4.50	38.2	5.04	37.4	3.63	–1.7	–0.8
VE ($l \times min^{-1}$)	50.1	8.57	49.3	6.66	68.5	12.83	67.9	9.38	–0.8	–0.6
TV (l)	1.8	0.38	1.8	0.31	2.5	0.41	2.5	0.38	0	0
RF ($1 \times min^{-1}$)	28.0	4.91	28.2	4.96	28.1	6.09	27.5	4.01	0.2	–0.6
HR (bpm)	167.6	12.65	168.2	12.12	165.4	7.92	159.7	11.45	0.6	–5.7
%VO_2max	74.8	8.00	72.7	6.11	69.4	8.31	66.6	4.83	–2.1	–2.8
%HRmax	87.7	4.59	87.4	4.22	85.9	2.47	84.5	4.58	–0.3	–1.4

cryostimulation. Additionally, a significant ($P < 0.05$) decrease in time to reach peak power from 6.67 to 5.92 s in the post-cryogenic treatment test was registered. However, the changes in time to sustain peak power were not significant.

Significant changes were observed in pre and post exercise lactate concentrations after the whole body cryostimulation in females and males. In females, the post exercise lactate concentration increased significantly ($P < 0.05$) by 2.53 $mmol \times l^{-1}$ in the second phase of the experiment. The pre and post exercise lactate concentration difference was 3.24 $mmol \times l^{-1}$.

In male subjects, the post exercise lactate concentration significantly ($P < 0.05$) increased by 3.33 $mmol \times l^{-1}$ in the

Tab. 5. Variables characterizing anaerobic power and capacity for the female (F) and male (M) participants

Variables	F1		F2		M1		M2		Differences	
	mean	SD	mean	SD	mean	SD	mean	SD	F2 vs. F1	M2 vs. M1
Rev (nr)	37.50	2.50	38.20	3.44	41.70	2.02	44.50	1.66	0.70	2.80*
Rhythm ($1 \times min^{-1}$)	136.30	8.14	139.50	12.86	151.10	9.74	161.70	5.99	3.20	10.60*
Wtot (kJ)	8.25	0.91	8.44	1.17	13.77	1.13	14.53	1.08	0.19	0.76*
MAP (W)	500.65	56.98	513.96	79.21	830.27	71.45	854.94	102.22	13.31	24.67
MAP ($W \times kg^{-1}$)	8.68	0.51	8.90	0.82	11.12	0.72	11.90	0.44	0.22	0.78*
AP (W)	436.12	47.28	447.47	64.47	723.93	58.59	756.13	55.81	11.35	32.2*
AP ($W \times kg^{-1}$)	7.56	0.46	7.75	0.69	9.69	0.49	10.22	0.37	0.19	0.53*
FI ($W \times kg^{-1} \times s^{-1}$)	0.16	0.04	0.17	0.05	0.21	0.06	0.23	0.05	0.01	0.02
t_{obt} (s)	7.89	1.24	7.19	1.08	6.67	1.06	5.92	0.70	–0.70	0.75*
t_{sus} (s)	3.75	1.07	3.80	0.55	3.76	0.97	3.80	0.51	0.05	0.04
LA_{rest} ($mmol \times l^{-1}$)	1.05	0.41	1.76	0.13	0.91	0.17	1.89	0.09	0.71*	0.98*
LA_{exe} ($mmol \times l^{-1}$)	1.05	0.41	1.76	0.13	0.91	0.17	1.89	0.09	0.71*	0.98*
ΔLA ($mmol \times l^{-1}$)	6.17	1.30	9.41	1.93	7.03	0.87	10.36	1.23	3.24*	3.33*

* Significant differences at the $P < 0.05$ level.

Table 6. Basic morphological blood variables for the female (F) and male (M) participants

Variables	F1		F2		M1		M2		Differences	
	mean	SD	mean	SD	mean	SD	mean	SD	F2 vs. F1	M2 vs. M1
RBC ($106 \times \mu l^{-1}$)	4.58	0.12	4.45	0.14	5.21	0.11	4.90	0.21	–0.13*	–0.31*
HGB ($g \times dl^{-1}$)	13.40	0.39	12.59	0.40	15.22	0.54	14.33	0.69	–0.81*	–0.89*
HCT (%)	40.03	0.90	38.09	1.11	45.55	1.17	42.66	1.71	–1.94*	–2.89*
Leukocytes ($10^3 \times \mu l^{-1}$)	5.11	0.31	5.17	0.37	4.65	0.70	5.07	0.89	0.06	0.42
PLT ($10^3 \times \mu l^{-1}$)	217.80	18.29	219.90	19.30	224.00	41.03	227.30	35.87	2.10	3.30

* Significant differences at the $P < 0.05$ level.

second phase of the experiment, while the differences between pre and post exercise lactate concentration were higher by 2.34 $mmol \times l^{-1}$.

Influence of the whole body cryostimulation on blood cell count

Ten sessions of treatments of whole body cryostimulation caused significant changes in several blood variables in both experimental groups (Table 6). In female subjects, the number of erythrocytes decreased from 4.58 to 4.45 million/mm^3 after the treatments. Significant ($P < 0.05$) decreases in hemoglobin concentration (13.4 vs. 12.6 g/100 ml) and haematocrit values (40 vs. 38.1%) were also observed. There were no changes in the number of leukocytes and thrombocytes.

The same changes in blood variables occurred in the male participants. During the experiment in this group a significant ($P < 0.05$) decrease in number of erythrocytes (5.21 to 4.9 million/mm^3), hemoglobin concentration (15.2 to 14.3 g/100 ml) and hematocrit values (45.6 to 42.7%) were observed. The changes in the number of leukocytes and thrombocytes were not significant.

DISCUSSION

The review of literature shows a lack of data regarding the influence of a very low temperature (whole body cryostimulation) on physical work capacity. Most researchers have addressed the effects of local cold treatments, where particular parts of the body were cooled or whole body was immersed in cold water on the level of chosen motor abilities or physical work capacity, under different temperatures [30–36]. Others evaluated the influence of cooling on the rate of recovery following injuries [19,22,27]. Whole body cryostimulation has a significantly greater effect on the entire organism, affecting all of its systems. Considering the fact that physical effort in most sport disciplines involves the entire body, and that the treatment could be directed toward all muscle groups as well as other organs strongly engaged during exercise, it can be assumed that whole body cryostimulation could influence physical work capacity. Till now, however, there was no such study on the effect of whole body cryostimulation in cryogenic temperature on aerobic and anaerobic capacity.

The results of this study did not confirm the hypothesis that whole body cryostimulation improved aerobic capacity, since we did not observe any changes in aerobic capacity in either female or male subjects after ten sessions of treatment. Moreover, there was a tendency for aerobic capacity to decrease in both groups. This was expressed by an insignificant decrease in maximal oxygen uptake and ventilatory aerobic and anaerobic thresholds. These tendencies could be explained by a significant drop in the number of erythrocytes and the accompanied decrease in hemoglobin concentration and hematocrit value. On the contrary, Banfi et al. [7] demonstrated that whole-body cryotherapy had no effect on hematological values of either red blood cell count or leukocytes and platelets.

A positive influence of pre-cooling procedures on submaximal bouts of exercise in warm conditions was observed by Duffield and Marino [33], yet those experiments were related to application of ice and cold water. Also, the research of Uckert & Joch [37] indicated that cooling with ice-cooling vest applied 20 min before exercise increased running endurance in warm conditions. Local or whole body cooling before endurance exercise allows for a greater thermal stress during prolonged work of submaximal intensity [30,34].

The research presented here indicates a significant increase in anaerobic power as a consequence of ten sessions of the whole body cryostimulation, particularly in male subjects. The benefits of whole body cryostimulation were visible not only in significant changes of peak power but also in average power, total external work, and in the time to reach Pmax. Other authors also confirm the benefits of cooling, especially in relation to short, supramaximal exercise [33].

Our research showed a significantly higher plasma lactate concentration after progressive endurance test as well as in the Wingate test after cryogenic treatments. It seems that pain tolerance to fatiguing exercise improves after 10 days of whole body cryostimulation.

Post-exercise increase in plasma lactate concentration without change in exercise duration and Pmax suggests an increase in anaerobic glycolysis during progressive exercise after ten sessions of cryostimulation. It is likely that repeated exposure to cold and the accompanying shivering thermogenesis cause an adaptable increase in the activity of anaerobic glycolitic enzymes.

Another factor influencing these metabolic changes during exercise might include increased norepinephrine concentration following whole body cryostimulation, which has been confirmed by other authors [2]. The relationship between the concentration of catecholamines and the level of the anaerobic threshold is generally recognized.

With the recognized benefits of cryostimulation/cryotherapy in athletes, it is evident that this type of a treatment should be recommended during recovery (reduction of muscle tension and edema, anti-inflammatory effect, pain reduction, post-injury improvement). However, the influence of cryostimulation on red blood cell system has not been fully recognized yet. The results of the studies carried out thus far are difficult to interpret and compare due to differences in study protocols. Hence, it is crucial to continue research in this area to better understand the influence of cryostimulation in athletes.

CONCLUSIONS

1. A series of ten whole body treatments in a cryogenic chamber caused a significant increase in anaerobic power and capacity in men.
2. It seems that in sport disciplines with a predominance of anaerobic metabolism it could be advisable to incorporate whole body cryostimulation treatment in the training process, at least in men.

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