Palestrica of the third millennium – Civilization and Sport
Vol. 16, no. 4, October-December 2015, 319–323

The effect of hypothermia on exercise capacity
Efectul hipotermiei asupra capacităţii de efort

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Abstract

Background. Hypothermia, which is a basal body temperature below 35°C, has numerous effects: cardiovascular, respiratory, neuromuscular, metabolic, immunologic, hormonal, renal, and gastrointestinal effects. The body's short-term adaptation to low temperatures is mainly accomplished through vegetative and somatic mechanisms.

Aims. The aim of the experiment was to observe in exercise-trained adult rats the effect of intermittent hypothermic stress on their aerobic exercise capacity, on the one hand, and the cardiovascular changes produced by hypothermic stress, on the other hand.

Methods. The research was conducted on groups of white Wistar rats (n=10 animals/group), thus: group I (the control group) was subjected to thermoneutral conditions, at a temperature of 18-20°C, in the laboratory; group II was subjected to intermittent hypothermia, at 12-13°C, in a cold room; group III was subjected to intermittent hypothermia of 4-5°C, in a cold room. The aerobic exercise capacity was tested based on the swimming test, and the cardiovascular changes during exercise were studied based on direct blood pressure and pulse measurement and on indirect pulse pressure and average blood pressure determination.

Results. A significant increase in the aerobic exercise capacity was noticed in animals that had undergone exercise-training for 14 days and were subjected to the following temperature conditions: 18-20°C, 12-13°C, 4-5°C, as compared to the original values; a significant decrease in the aerobic exercise capacity in animals that had undergone exercise-training for 14 days and were subjected to hypothermia conditions, as compared to the control group; and significant drops in CAE in animals that had undergone exercise-training for 14 days and were subjected to hypothermia conditions of 4-5°C, as compared to those subjected to hypothermia of 12-13°C.

Conclusions. Intermittent hypothermic stress causes a significant decrease in the aerobic exercise capacity in exercise-trained animals and affects the cardiovascular adaptation to exercise, causing bradycardia and hypotension.

Keywords: hypothermia, aerobic exercise capacity, cardiovascular adaptation.

Rezumat

Premize. Hipotermia, temperatura bazală a corpului <35°C, are numeroase efecte: cardiovasculare, respiratorii, neuromusculare, metabolice, imunologice, hormonale, renale, gastrointestinale. Adaptarea de scurtă durată a organismului la temperaturi scăzute se face în principal prin mecanisme vegetative şi mecanisme somatice.

Obiective. S-a urmărit experimental, la şobolani adulţi antrenaţi la efort, efectul stresului hipotermic intermitent asupra capacităţii aerobe de efort şi modificările cardiovasculare produse de stresul hipotermic.

Material şi metodă. Cercetările s-au efectuat pe loturi de şobolani albi, rasa Wistar (n=10 animale/lot), astfel: lotul I – lot martor supus condiţiilor termoneutre la temperatură de 18-20 C în laborator; lotul II – lot supus hipotermiei intermitente, de 12-13°C, în camera frigorifică; lotul III – lot supus hipotermiei intermitente, de 4-5°C, în camera frigorifică. Testarea capacităţii aerobe de efort (CAE) s-a făcut pe baza probei de înot, iar modificările cardiovasculare la efort s-au studiat pe baza determinărilor directe ale tensiunii arteriale şi pulsului şi indirecte pentru presiunea pulsului şi tensiunile arteriale medii.

Rezultate. S-au observat creşteri semnificative ale CAE la animalele antrenate timp de 14 zile, supuse condiţiilor de temperatură: 18-20°C, 12-13°C, 4-5°C, faţă de valorile iniţiale; scăderi semnificative ale CAE la animalele antrenate timp de 14 zile, supuse condiţiilor de hipotermie, faţă de lotul martor; scăderi semnificative ale CAE la animalele antrenate timp de 14 zile, supuse condiţiilor de hipotermie de 4-5°C, faţă de cele supuse hipotermiei de 12-13°C.

Concluzii. Stresul hipotermic intermitent determină scăderi semnificative ale capacităţii aerobe de efort la animalele antrenate şi afectează adaptarea cardiovasculară la efort, determinând bradicardie şi hipotensiune.

Cuvinte cheie: hipotermia, capacitatea aerobă de efort, adaptarea cardiovasculară.

Received: 2015, June 23; *Accepted for publication:* 2015, July 15;
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Introduction

Hypothermia is defined as a basal body temperature below 35°C, caused by environmental exposure to low temperature (below 18°C), drug intoxication or metabolic or nervous system dysfunctions (Meiman et al., 2015).

Hypothermia has a variety of effects:

- cardiovascular effects (initially tachycardia, peripheral vasoconstriction, and consecutively, an increase in the circulating blood volume; as hypothermia progresses, bradycardia sets in, with the reduction of myocardial and blood vessel contractility) (Hauton et al., 2011; Schubert, 1995) and blood-related effects (bone marrow suppression and sideroblastic anaemia, reversible platelet sequestration, reduction of the coagulation activity and the intensification of fibrinolysis) (Mallet, 2002);
- respiratory effects: tachypnea is present in the early stages of moderate hypothermia, followed by a reduction of the respiratory minute volume, of O_2 consumption, and of CO_2 production; in the severe stages of hypothermia, hypoventilation and apnoea, tissue hypoxia, and sometimes pulmonary oedema progressively set in. The reduction of the respiratory function may be followed by a reduction in CO_2 elimination, which leads to the onset of respiratory acidosis (Polderman, 2008);
- neuromuscular effects: due to the reduction in cerebral circulating blood volume, confusion and amnesia set in and, at a later stage, apathy, impaired discernment, dysarthria, unconsciousness, and, ultimately, coma. In the moderate stages of hypothermia, shivering is initially intense but subsequently, as the temperature drops, it subsides. Joint and muscle stiffness sets in (Erecinska et al., 2003; Wartenberg & Mayer, 2008; Cahill et al., 2011; Castellani et al., 2006);
- metabolic effects: the metabolic rate drops by ~ 6-7% with each degree; on the other hand, the generation of lactic acid rises and metabolic acidosis occurs (Schubert, 1995; Mallet, 2002);
- immunological effects: reversible pancytopenia (leukocyte depletion, diapedesis impairment and impairment of neutrophil cell mobility and of the phagocytosis process, with a predisposition to infections) (Sessler, 2009);
- hormonal effects: a decrease in antidiuretic hormone and oxytocin secretion; an increase in the plasma level of corticoids, prolactin, and thyroid stimulating hormone (Staicu & Tache, 2011). Hypothermia that sets in rapidly may induce hyperglycaemia; if hypothermia develops slowly, glycogen stores are depleted and a state of hypoglycaemia may occur (Mallet, 2002);
- renal effects: high diuresis and saliuresis, a reduction in glomerular filtering, through a decrease in cardiac output and in the tubular function (Schubert, 1995; Mallet, 2002);
- gastrointestinal effects: a reduction in intestinal motility, absorption impairment, gastric erosions, deterioration of the hepatic function and of the lactic acid metabolic clearance rate, contributing to metabolic acidosis and pancreatic function impairment, with an increase of the serum amylase level (Schubert, 1995; Mallet, 2002).

Thermoregulation involves a balance between heat loss (thermolysis) mechanisms and heat production (thermogenesis) mechanisms, with the purpose of maintaining the body's thermal homeostasis (Mallet, 2002).

The body's short-term adaptation to low temperatures is achieved via: vegetative mechanisms (an increase of sympathetic tone and adrenaline secretion, and the stimulation of thyroxine production), somatic mechanisms (an increase of muscle tone, thermal shivering), and other mechanisms (favourable microclimate conditions, clothing) (Staicu & Tache, 2011; Gavhed, 2003; Barrett et al., 2010).

Objectives

The following were monitored in the case of adult rats subjected to physical exercise:

- the effect of acute intermittent hypothermic stress on their aerobic exercise capacity;
- the cardiovascular changes produced by hypothermic stress.

Hypothesis

Acute exposure to cold environment conditions causes the body to acclimate, with the conservation of heat through vasoconstriction and the stimulation of heat generation through chemical thermogenesis, a process stimulated especially by physical exercise, where observations have shown a decrease in the aerobic exercise capacity. Our aim was to study whether acclimation through laboratory-controlled acute exposure could influence the physical exercise capacity and cardiovascular adaptation.

Material and methods

The experimental studies conducted on rats were prospective longitudinal analytical studies. The research was carried out as per approval no. 189/8.04.2015 of the Bioethics Commission, in accordance with the legislation in force.

a) Period and place of the research

The research was carried out during the period February 1 – March 10, 2015, in the Experimental Physiology Laboratory of the "Iuliu Haţieganu" University of Medicine and Pharmacy, Cluj-Napoca.

Research protocol

b) Subjects and groups

The research was carried out on groups of white Wistar rats (n=10 animals/group), aged18 weeks, weighing 280-300 grams, kept under adequate vivarium conditions: temperature and humidity, normocaloric food of 20 g/day/animal consisting of granulated combined feed, and water ad libitum. During the research period, the legislation in force regarding animal protection was observed; at the end of the experiment, the animals were euthanised.

Groups

The animals were exposed to low temperatures for 4 hours, on a daily basis, in the cold room of the Experimental Physiology Laboratory of the "Iuliu Haţieganu" University of Medicine and Pharmacy, Cluj-Napoca. The research was conducted on 3 groups of animals (n=10 animals/group):

- group I, the control group, which was subjected to thermoneutral conditions at a temperature of 18-20^0 C in the laboratory and was exercise-trained;
- group II, which was subjected to intermittent hypothermia (12-13°C), in the cold room;
- group III, which was subjected to intermittent hypothermia (4-5°C), in the cold room.

After being exposed, the animals of groups II and III were subjected to hypothermia and physical effort.

c) Tests applied

- The aerobic exercise capacity was tested based on the swimming test in a tank 100x40x60 cm in size, with a water level of 30 cm, the water being thermostatic at a temperature of 21-23ºC[101]. The measurements were made at 7 a.m. The duration of the test was timed (in seconds), from the moment the animals were immersed in the tank until they became exhausted (floating, tendency to sink or attempts to cling to the edge of the tank). The aerobic exercise capacity values were expressed in seconds. The duration of the physical exercise period was 14 days. The moments of time taken into study were day 1, day 7, and day 14.

- The cardiovascular changes under exercise conditions were studied based on direct blood pressure and pulse measurements and on indirect measurements of pulse pressure and average blood pressures, which was achieved with the aid of a tail cuff and the Biopack MP 150 device. Blood pressure values were expressed in mmHg and pulse values were expressed in cycles/min. The measurements were made one hour after the completion of the experiment, on day 14.

The calculation formulas used were the following:

$$PP = SBP - DBP$$

$$MAP = DBP + (SBP - DBP)/3$$

in which:

PP = pulse pressure, SBP = systolic blood pressure, DBP = diastolic blood pressure, MAP = mean arterial pressure.

d) Statistical processing

Descriptive statistics elements were calculated, the data being presented using centrality, localization, and distribution indicators.

For the testing of normal distribution, the Shapiro-Wilk test was used. Variance was tested via the F or Levene and/or Bartlett tests.

Statistical processing was performed using the Excel application (of the Microsoft Office 2007 package) and the StatsDirect v.2.7.2 program. The results were graphically represented via the Excel application (of the Microsoft Office 2007 package).

Results

The influence of hypothermic stress on the aerobic exercise capacity of exercise-trained animals (Table I)

In the statistical analysis of the exercise capacity values, *taking into account all three groups,* statistically highly significant differences were observed between at least two of the groups, on days 1, 7, and 14 ($p < 0.0001$).

In the statistical analysis of the exercise capacity values *for non-paired tests,* the following were observed:

- on day 1 – statistically highly significant differences between groups I-II, I-III, and II-III ($p < 0.001$);
- on day 7 – statistically highly significant differences between groups I-II, I-III, and II-III ($p < 0.001$);
- on day 14 – statistically highly significant differences between groups I-II, I-III, and II-III ($p < 0.001$).

In the statistical analysis of the exercise capacity values, *taking into account all three days (the moments of time),* statistically highly significant differences ($p < 0.001$) were observed between at least two of the days, in the case of all groups.

In the statistical analysis of the exercise capacity values *for paired tests,* the following were observed:

- in the case of group I – statistically highly significant differences between days 1-7, 1-14, and 7-14 ($p < 0.001$);
- in the case of group II – statistically very significant differences between days 1-7, 1-14, and 7-14 ($p < 0.01$);
- in the case of group III
- statistically highly significant differences between days 1-14 ($p < 0.001$);
- statistically very significant differences between days 1-7 and 7-14 ($p < 0.01$).

Cardiovascular changes through hypothermic stress, dependent on physical exercise (Table II)

In the statistical analysis of the pulse values, *taking into account all three groups,* statistically significant differences were observed between at least two of the groups ($p = 3.58 \times 10^{-15}$).

In the statistical analysis of the pulse values *for non-paired tests,* statistically highly significant differences were observed between groups I-II and I-III ($p < 0.001$).

In the statistical analysis of systolic blood pressure, *taking into account all three groups,* statistically highly significant differences were observed between at least two of the groups ($p = 0.0004$).

In the statistical analysis of systolic blood pressure *for non-paired tests,* the following were observed:

- statistically highly significant differences between groups I-II ($p < 0.001$)
- statistically very significant differences between groups II-III ($p < 0.01$).

In the statistical analysis of diastolic blood pressure, *taking into account all three groups,* statistically very significant differences were observed between at least two of the groups ($p = 0.017$).

In the statistical analysis of diastolic blood pressure *for non-paired tests,* statistically highly significant differences were observed between groups I-III ($p < 0.001$).

In the statistical analysis of the mean arterial pressure values, *taking into account all three groups,* statistically

Table I

Comparative analysis for the (dry) exercise capacities in the case of the studied groups and statistical significance.

Group	Day	Average	SE	Median	SD	Min.	Max.	p			
I	1	1863.1	18.9106	1874	59.8005	1770	1937	Day 1		Group I	
	7	2305	28.8074	2308	91.097	2181	2418	I-II	2.3×10^{-17}	d1 - d7	3.65×10^{-9}
	14	2704.7	29.389	2694	92.9361	2592	2876	I-III	8.89×10^{-19}	d1 - d14	3.81×10^{-11}
II	1	943	21.4326	927	67.7758	863	1068	II-III	5.22×10^{-9}	d7- d14	1.05×10^{-9}
	7	1129	15.8015	1158	49.9689	1041	1175	Day 7		Group II	
	14	1481.7	31.2972	1508.5	98.97	1339	1581	I-II	< 0.0001	d1 - d7	0.002
III	1	638.3	11.3823	624	35.994	594	693	I-III	< 0.0001	d1 - d14	0.002
	7	758.3	7.68411	751.5	24.2993	732	787	II-III	< 0.0001	d7- d14	0.002
	14	977.6	17.3251	985	54.7869	903	1062	Day 14		Group III	
I-II-III	1	1.63×10^{-27}		Days 1-7-14	group I	2.38×10^{-18}		I-II	< 0.0001	d1 - d7	0.002
	7	< 0.0001			group II	< 0.0001		I-III	3.5×10^{-18}	d1 - d14	1.83×10^{-8}
	7	< 0.0001			group III	< 0.0001		II-III	< 0.0001	d7- d14	0.002

Table II

Comparative analysis for the values of pulse (cycles/min), systolic blood pressure, diastolic blood pressure, mean arterial pressure (mmHg), and pulse pressure in the case of the studied groups and statistical significance.

	Group	Average	SE	Median	SD	Min.	Max.		p
Pulse	I	93.9	1.5308	93.5	4.8408	87	101	I-II	5.75×10^{-10}
	II	68.9	0.9481	69.5	2.9981	64	73	I-III	9.64×10^{-11}
	III	66.4	1.2401	65.5	3.9215	61	73	II-III	0.1277
	I-II-III				3.58×10^{-15}				
Systolic blood pressure	I	84	0.6325	83.5	2	82	88	I-II	< 0.0001
	II	69.6	1.3013	71	4.1150	60	73	I-III	0.6823
	III	82.9	2.5318	85.5	8.0062	69	91	II-III	0.0016
	I-II-III				0.0004				
Diastolic blood pressure	I	65.1	1.2863	64	4.0678	60	73	I-II	0.0877
	II	61.4	1.5861	60	5.0155	54	69	I-III	0.0003
	III	58.1	0.6046	58	1.9120	55	61	II-III	0.0757
	I-II-III				0.0017				
Mean arterial pressure	I	71.4	1.0229	70.7	3.2348	67	78	I-II	0.0003
	II	64.13	1.2474	64.17	3.9447	59	70	I-III	0.0021
	III	66.37	1.0357	67.83	3.2752	60	69	II-III	0.2024
	I-II-III				0.0009				
Pulse pressure	I	18.9	0.9244	19.5	2.9231	15	22	I-II	0.0002
	II	8.2	1.7565	7.5	5.5538	2	19	I-III	0.1082
	III	24.8	2.4258	25.5	7.671	14	34	II-III	4.46×10^{-5}
	I-II-III				0.0001				

highly significant differences were observed between at least two of the groups ($p = 0.0009$).

In the statistical analysis of the mean arterial pressure values *for non-paired tests,* the following were observed:

- statistically highly significant differences between groups I-II ($p < 0.001$);
- statistically very significant differences between groups I-III ($p < 0.01$).

In the statistical analysis of the pulse pressure values, *taking into account all three groups,* statistically highly significant differences were observed between at least two of the groups ($p = 0.0001$).

In the statistical analysis of the pulse pressure values *for non-paired tests,* statistically highly significant differences were observed between groups I-II and II-III ($p < 0.001$).

Discussions

Our results show the following:

- a significant increase in the aerobic exercise capacity of animals that were exercise-trained for 14 days, subjected to the following temperature conditions: 18-20°C, 12-13°C, 4-5°C, as compared to the initial values;
- a significant decrease in the aerobic exercise capacity of animals that were exercise-trained for 14 days, subjected to hypothermia conditions, as compared to the control group;
- a significant decrease in the aerobic exercise capacity of animals that were exercise-trained for 14 days, subjected to hypothermia conditions of 4-5°C, as compared to the ones subjected to hypothermia of 12-13°C.

Like all environmental stressors, thermal stress represents an event ranging from deterioration in performance to life-threatening pathology. In athletes, for example, immersion in cold water causes cardiovascular problems, by reducing circulating blood volume, due to hydrostatic squeeze and cold-induced vasoconstriction, producing diuresis during immersion (Tipton & Bradford, 2014). The cold shock response on initial immersion includes a gasp response, uncontrollable hyperventilation, tachycardia, hyperventilation and an increase in circulating levels of stress hormones (Tipton, 1989).

When the muscle and deep body temperature is lowered, there is a drop in the maximum aerobic capacity (Tipton, 1999). Cooled muscle is required to use anaerobic metabolism at lower submaximal workloads; this can result in an earlier appearance of blood lactate (Choi et al., 1996) and more rapid depletion of carbohydrate stores and, as a consequence, an earlier onset of fatigue (Martineau & Jacobs, 1988; Bergh, 1980).

Globally, the decrease in the aerobic exercise capacity (AEC) under the influence of hypothermic stress can be due to:

- the activation of certain vegetative mechanisms, with peripheral vasoconstriction;
- the constriction of the arrector pili (hair-raising) muscles;
- the increase in the sympathetic tone and adrenaline secretion;
- the increase in the production of thyroxine and its effect of enhancing calorigenesis by adrenaline;
- somatic mechanisms: the position of the animals, muscle tone increase, thermal shivering;
- the activation of antioxidant mechanisms (Xing et al., 2014);
- the subsiding of hypothalamic hypothermia (Staicu & Tache, 2011; Fonseca et al., 2014; Brazaitis et al., 2012);

Our results show that the cardiovascular indicators that were measured one hour after exercise, on day 14, indicate cardiovascular adaptation:

- a significant decrease in the pulse rate of animals subjected to hypothermia (groups II and III), as compared to the control group (group I);
- a significant decrease in systolic blood pressure, mean arterial pressure, and pulse pressure in the case of the group subjected to hypothermia of 12-13°C, as compared to the control group;
- a significant decrease in systolic blood pressure and pulse pressure in the case of the group subjected to hypothermia of 4-5° C, as compared to the group subjected to hypothermia of 12-13°C.

The cardiovascular changes under the influence of intermittent hypothermic stress may be due to the influence of the temperature of the thermogenic hypothalamic centre of the posterior and lateral hypothalamus, inhibited by the anti-thermal centre situated in the anterior hypothalamus in interrelation with the hypothalamic centres (Staicu & Tache, 2011).

Exercise under hypothermic conditions may induce significant changes in anabolic hormones and circulating inflammatory mediators. Also, hypothermia may occur in athletes competing during open water swimming events (Castro et al., 2009). During passive hypothermic recovery or rewarming, the choice of the oxidative substrate for sustaining shivering is regulated entirely by changes in the carbohydrate oxidation rate (Haman et al., 2007).

In human competitions, there is a continuous search of legal means for improving athletic performance. Precooling techniques can be used, for example, in order to improve intermittent sprint exercise performance (Castle et al., 2006).

In fact, cold therapy (cryotherapy) is widely used to treat sports injuries, as a recovery method following training and competition that may cause some level of traumatic muscle injury (Barnett, 2006; Wilcock et al., 2006) and also, for the recovery between training sessions in order to reduce muscle soreness (Lane & Wenger, 2004; Yanagisawa et al., 2003).

The influence of hypothermia on the body's exercise capacity may be involved in:

- mountain climbing at medium and high altitudes and mountain climbing in areas that are more difficult to access;
- sporting activities in the cold season: sledding, alpine skiing, cross-country skiing, biathlon, Nordic sports;
- activities under difficult climatic conditions: cold, snow, wind, fog, winter season activities;
- military applications of the mountain gendarmes and mountain troops;
- the activities of mountain rescuers and personnel working in high-altitude weather stations.

Conclusions

1. Acute intermittent hypothermic stress causes significant drops in the aerobic exercise capacity of exercise-trained animals.
2. Acute intermittent hypothermic stress affects cardiovascular adaptation to effort, causing bradycardia and hypotension.

Conflicts of interests

Nothing to declare

Acknowledgments

This paper represents a partial exploitation of the results of the fist author's current thesis.

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