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EFFECTS OF 8-WEEKS OF TRAINING CONDUCTED AT TWO AMBIENT TEMPERATURES ON BASIC PHYSIOLOGICAL CHARACTERISTICS AND HEAT STRESS LEVELS IN YOUNG, NON-TRAINING MEN

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Abstract:

Background: Adaptive changes to work in a warm environment are manifested by greater sweat secretion, a reduction in the time required to trigger this response, and a smaller volume of droplet sweat flowing down the skin, much of which is not evaporated. The aim of this study was to determine the effects of aerobic physical training at two different ambient temperatures of 21±0.50°C and 31±0.50°C on the level of exercise physiological responses of the body in young, non-trained men.

Material and Methods: Basic anthropometric measurements were taken, as well as baseline exercise tests to assess aerobic capacity and the efficiency of the body's exercise thermoregulatory mechanisms. After the 8-week training cycle completion, anthropometric and physiological tests were repeated. During the training cycle, at the first, middle and last workout, changes in rectal temperature and heart rate during training were assessed, as well as the assessment of its nuisance in Borg's scale. The efficiency of exercise-induced thermoregulatory mechanisms was assessed by the Kubica test. Two indices were used to examine the effect of heat stress: the Physical Strain Index and the Cumulative Heat Strain Index.

Results: Training at ambient temperatures of 21°C and 31°C did not significantly change the body's aerobic capacity (VO_2max), resulted in a significant and similar increase in the body's endurance level as demonstrated by an increase in the work time in the graded test; the time to reach the anaerobic threshold and an increase in maximal aerobic power; contributed to a higher level of efficiency of the body's thermoregulatory mechanisms. The repetitive physical stimuli at different ambient temperatures had a significant effect demonstrated by a decrease in the subjective feeling of the strenuousness of the work performed in the graded test, on each segment of the exercise load.

Conclusions: Understanding knowledge regarding the organism's response to thermal stimuli should enable training staff to optimize training programs and technologies while maintaining ongoing control of the organism's adaptive changes. In order to enhance the organism's tolerance to thermal and exertional stress, it is justified to conduct physical training under various thermal environmental conditions.

Introduction

As the temperature increases, sweating occurs, and the water component of sweat depletes the extracellular water pool. When staying at high temps, intracellular water supplies are also compromised, which can result in dehydration. Adaptive changes to work in a warm environment are manifested by greater sweat secretion, a reduction in the time required to trigger this response, and a smaller volume of droplet sweat flowing down the skin, much of which is not evaporated. As an athlete's physical performance increases, the intensity of sweating increases too, which indicates an improvement in thermoregulatory processes [1].

It is indicated that the body's responses to elevated intrinsic temperature [associated with the effect of physical activity] with the effect of extrinsic temperature [ambient temperature] are different [2]. The physiological responses of the human body subjected to a single physical activity at room or elevated ambient temperature have already been fairly well understood and documented by scientific studies [3,4]. There is much less information in the available literature about the effects of repetitive exercise at different ambient temperatures on the body's exercise adaptation mechanisms. This lack is particularly evident in the context of the current globalization. The dynamic development of sports contacts manifested by the organization of a large number of sports events in countries with different climatic conditions suggests paying more attention to the study of physiological mechanisms determining the efficient course of thermoregulatory functions during physical work in warm and hot environments. This applies not only to a single exposure to such an environment but also to the effects of training under thermally variable conditions.

Working in an environment with an elevated ambient temperature activates individual functional systems of the body to a greater extent than exercise at room temperature. The manifestations of adaptive responses are primarily changes in cardiac minute volume conditioned by an increase in cardiac stroke volume (SV), associated with the displacement of greater blood volume to the skin and changes in plasma volume (%∆PV) [4]. Improvements in the functioning of exercise-induced thermoregulatory mechanisms may be evidenced by both smaller absolute increases in internal body temperature and a slower rate of temperature rise in the first few tens of minutes of exercise. Previous reports indicate that under exercise performed at room temperature, rectal temperature (Tre) usually rises in the first 30-40 minutes, followed by a shorter or longer stabilization. The same work, performed in an environment with elevated air temperature causes Tre stabilization to occur earlier, when the exercise load is high or does not occur at all, and internal temperature rises throughout the exercise [5,6].

Beneficial physiological changes, similar to those that occur after systematic physical training, can also be achieved by acclimation of the human body to a high temperature environment [7-9]. Acclimation is a process that mainly leads to functional changes in the body, and the rate of acclimation to a high-temperature environment is higher when repeated heat exposure is additionally accompanied by physical exercise [10]. These changes, are characterized, among other things, by an increase in perspiration [11] and smaller increases in internal body temperature. Thus, a crossover between the effects of training and acclimation to high temperatures can be indicated. However, the exact mechanisms linking these two processes are not yet sufficiently elucidated.

The primary purpose of this study was to try to determine the effects of 8 weeks of aerobic physical training at two different ambient temperatures of 21±0.50°C and 31±0.50°C at a constant relative humidity of 40±3% on the variation in the level of exercise physiological responses of the body in young, non-trained men.

Material and Methods

Study protocol

The study began with the recruitment of volunteers, then a study group meeting the recruitment criteria was selected from this group and randomly divided into equal subgroups. Each subgroup performed workouts at individually selected intensities at one of the two studied temperatures. After a wash-out period (6 months), the training conditions were switched. Men initially training at 21°C performed workouts at 31°C this time, while those training at 31°C followed a training program at room temperature, after the individual training loads had been redetermined. The results were combined and statistically analyzed.

Before starting a single training cycle, basic anthropometric measurements were taken, as well as baseline exercise tests to assess aerobic capacity and the efficiency of the body's exercise thermoregulatory mechanisms. Based on the exercise tests, training loads were developed and an 8-week training cycle was started. After its completion, anthropometric and physiological tests were repeated. During the training cycle, at the first, middle and last workout, changes in rectal temperature and heart rate during training were assessed, as well as the assessment of its nuisance.

Ethics Declaration

The research was carried out in the Laboratory of Physiological Basis of Adaptation (PN-EN ISO 9001: 2015), Central Scientific and Research Laboratory, University of Physical Education in Krakow during September - October 2019. The respondents gave written consent to participate in the research, were explained the purpose and method of the research, and were informed about the possibility of resignation at any stage without giving a reason. The project was approved by the Bioethical Committee of PMWSZ in Opole (No. KB/56/N02/2019) in accordance with the Declaration of Helsinki.

Study Group

Fifty non-training volunteers were recruited to participate in the study, 20 of whom met the recruitment criteria that ware: male gender, non-training, no use of stimulants or dietary supplements, age in the range: 19-24 years old. Exclusion criteria were: cardiovascular disease, history of heat stroke, systematic exercise, use of sauna or other heat treatments in the 3 months prior to joining the project.

Of the 20 volunteers qualified to participate in the experiment, 18 men completed the full program (2 did not sign up for the second test or dropped out for personal reasons).

Data Collection

Ambient temperature and relative humidity in the thermoclimatic chamber were controlled with a Harvia (Finland) thermohygrometer and an Ellab (Denmark) electrothermometer with accuracy ±0.5°C and ±3%, and air movement was controlled with a Hill catheterometer. During training and testing, the scheduled ambient conditions in the thermoclimatic chamber were kept unchanged: air temperature 21±0.5°C or 31±0.5°C, relative humidity 40±3% and air movement less than 1m/s.

Body height (BH) was measured with an anthropomentometer to the nearest 0.5 cm, body weight (BM) was measured to the nearest 0.1g (Tanita, VB 3000, UK). The thickness of the skin-fat folds on the posterior surface of the loosely lowered arm (triceps) and under the lower angle of the left scapula when the fold was grasped obliquely to the nearest 0.1 mm with a Harpend fold meter with a contact force of 20 g. The results of skin-fat fold measurements were used to calculate percent fat (% PF) and fat mass (FM) and lean body mass (LBM) according to the formula given by Slaugther et al. [12].

All physiological tests at this stage were carried out in the air-conditioned laboratory in the morning no earlier than 2 hours after a light meal.

Physiological tests

Exercise test to evaluate aerobic capacity

A graded test until volitional exhaustion was performed on a cycloergometer during which maximal heart rate (HRmax), peak oxygen consumption (VO_2max), maximal pulmonary ventilation (VEmax), maximal breathing frequency (FRmax), maximal tidal volume (TVmax) and the amount of total work performed (TW) were measured [13]. The graded test was conducted at an ambient temperature of $21\pm0.5°C$ and a relative humidity of $40\pm3\%$. It was preceded by a three-minute warm-up on a bicycle cycloergometer at a pedaling rate of 60 revolutions per minute (RPM) at an intensity of 110 watts, after which, power was increased by 25 watts every 2 minutes. The effort continued until the subjective feeling of not being able to maintain the desired pedaling rhythm, i.e. refusing to continue the effort at the specified pedaling resistance. During the test, the levels of cardiopulmonary indices were recorded based on the "breath-by-breath" method using an ergospirometer. Data were averaged every 30 s. The highest registered value of oxygen uptake was considered as peak oxygen uptake. The obtained maximum values of the graded tests made it possible to estimate the individual exercise load in the pivotal test.

During exercise, respiratory exchange parameters were recorded in 30-second sequences: minute oxygen uptake (VO_2), minute carbon dioxide excretion (VCO_2), respiratory quotient (RER). In each load segment, the degree of strenuous work was determined. Heart rate (HR) was also recorded continuously by telemetry.

Analysis of changes in the kinetics of respiratory exchange rates made it possible to determine the anaerobic threshold marking the appearance of uncompensated metabolic acidosis (TDMA) during graded exercise. It was assumed that the TDMA threshold occurs when changes in the level of respiratory parameters are as follows:

- a non-linear rapid increase in lung minute ventilation (VE) is observed [14,15],
- the respiratory equivalent value for CO_2 ($VE\text{-}VCO_2^{-1}$) reaches its lowest value and then begins to increase [16],
- the carbon dioxide content (F_ECO_2) of the expiratory air reaches its highest value [17],
- a sudden nonlinear increase in respiratory quotient [RQ] is observed [17].

Considering the above criteria, the time to reach threshold (DETDMA), heart rate at threshold (HRTDMA), and oxygen uptake at threshold (VO_2TDMA), and percentage of oxygen uptake (%VO_2max) at threshold TDMA were determined. Work done up to the TDMA threshold (TWTDMA) was also calculated. Parametry wysiłkowej przemiany oddechowej w teście stopniowanym analizowane były w sekwencjach 30-sekundowych za pomocą aparatu Ergospirotest Cortex Metalyzer R3 (Germany). The exercise test was performed by the subjects on a cycloergometer type ER 900 D - 72475 BIT2 (Jeager, Germany).

Heart rate (HR) in laboratory tests was recorded telemetrically with a Polar Vantage NV and Polar 610S cardiac monitor from Polar Elektro (Finland). Rectal temperature (Tre) was measured with an electrothermometer type MRV-A (Ellab, Denmark). Thermocouples for measuring rectal temperature at a depth of 15 cm were sheathed in a disposable sterile sheath each time, according to the manufacturer's instructions.

Lactate concentration (LA) in arterialized venous blood was determined 3 min after exercise with a Mini-photometer plus DR Lange, type LP - 20 from Dr. Lange (Germany). The degree of body dehydration was estimated from measurements of body weight (to the nearest 1 g) before and after exercise testing, and the volume of urine excretion.

Testing the efficiency of exercise-induced thermoregulatory mechanisms

The efficiency of exercise-induced thermoregulatory mechanisms was assessed by the Kubica et al. test [18]. The test determines the time of increase in rectal temperature (Tre) by 1.2°C during exercise on a cycloergometer, with a relative power of 53% VO_2max and RPM of 60 rpm. - min^{-1}, at an ambient temperature of $33\pm0.5°C$ and relative humidity of $70\pm2\%$, with air movement of about 0.5m/s. HR was recorded during exercise. The degree of strenuous work was assessed using the Borg scale [19]. Tre was recorded continuously, and sweating rate (SR) was recorded every 15 minutes. Before and after the trial, after drying the skin coverings with blotting paper, body weight (BM) was measured, and the degree of dehydration of the body was calculated on this basis (ΔBM).

The degree of strenuous work was determined using the 20-point Borg scale. Points 6, 7 - denote extremely light work, 8, 9 - very light, 10, 11 - fairly light, 12, 13 - fairly heavy, 14, 15 - heavy, 16, 17 - very heavy, 18, 19, 20 - extremely heavy [19].

Sweat rate (SR) intensity was determined on the back under the shoulder blade, using the blotting paper method [20] every 15 min. The capsules were weighed on an analytical balance type WPA - 60 (Radwag, Poland).

Training

After determining the relative training loads, the men began physical training 3 x per week at two different ambient temperatures at an individually adjusted intensity of $53\pm1\%$ VO_2max for approximately 8 weeks. In each training unit, the subjects pedaled for 70 minutes. Physiological indicators were measured before and after each workout. Monark Type 834 E (Sweden) mechanical cycloergometers were used for training in the thermoclimatic chamber. The pedaling rhythm was determined by a metronome.

Heat stress indexes

Two indices were used to examine the effect of heat stress: the Physical Strain Index (PSI) and the Cumulative Heat Strain Index (CHSI).

The PSI is based on heart rate (HR) and rectal temperature (Tre) measurements [21]. It depicts physiological strain expressed on a numerical scale of 0-10, where 0-2 points is very low or no strain, 3-4 low, 5-6 moderate, 7-8 high, 9-10 very high. It is expressed by the formula:

$$\mathrm{PSI} = 5 \cdot (T_{ret} - T_{re0}) \cdot (39{,}5 - T_{re0})^{-1} + 5 \cdot (HR_t - HR_0) \cdot (180 - HR_0)^{-1}$$

where: T_{re0}- rectal temperature at time t_0; T_{ret} – rectal temperature at a given time; HR_0- heart rate at time t_0; HR_t - heart rate in a given time;

The CHSI (Cumulative Heat Strain Index) [22] additionally takes into account the change in HR and Tre over time [recording continuously at minute intervals] and the index is expressed by the formula:

$$\mathrm{CHSI} = \left[\sum_0^t hb - f_{c0}\, t \right] 10^{-3} \left[\int_0^t T_{re}\, dt - T_{re0}\, t \right]$$

where: $\sum hb$ is the sum of heart contractions during the entire physical effort, $f_{c0}\, t$ is the product of the initial HR value and the duration of physical effort measured in minutes [t].

Statistical Analysis

All results were presented as arithmetic means with standard deviations. Data distribution was checked using the Shapiro-Wilk test. Homogeneity of variance within the groups was tested via Levene's test (variance of the analyzed parameters was similar in both groups). In order to assess the significance of differences between groups, and time changes, analysis of variance (ANOVA) with repeated measurements was used. Afterwards, post hoc analysis was carried out using Tukey's test. The Persona linear correlation coefficient (r) was used to estimate the strength and direction of the relationship between the variables. Statistically significant results were defined as a *p*-value of <0.05. The following software was used to perform the calculations: STATISTICA 13.1 (StatSoft, Tulsa, OK, USA).

Results

The group of men selected to participate in the experiment was fairly homogeneous in terms of calendar age. Lean body mass (LBM) was 66.28±5.66 kg and body surface area-to-body mass ratio (BSA-BM^{-1}) was 0.024±0.001 $cm^2 \cdot kg^{-1}$. Aerobic capacity as measured by VO_2max was 40.09±7.81 $ml \cdot kg^{-1}$ (3.09±0.44 $l \cdot min^{-1}$). In men qualified to participate in exercise training at 21°C and 31°C, the baseline results of these parameters were not significantly different. The intensity-individualized (53% VO_2max) repetitive physical stimuli applied for 8 weeks to the study volunteers did not change the levels of these biometric and structural indicators (Table 1).

Table 1. Statistical characteristics of the body mass (BM), fat mass (FM) and lean body mass (LBM) in the male subjects before and after a series of workouts at two different ambient temperatures

	$\bar{x} \pm SD$	MINIMUM	MAKSIMUM	*p*
BM before 21°C (kg)	77.66 ± 6.91	68.17	87.12	N.S.
BM after 21°C (kg)	77.47 ± 7.16	66.77	88.01	
BM before 31°C (kg)	77.49 ± 6.96	67.83	85.23	N.S.
BM after 31°C (kg)	77.01 ± 6.69	67.40	84.87	
FM before 21°C (kg)	11.37 ± 3.19	7.35	19.32	N.S.
FM after 21°C (kg)	10.72 ± 3.30	7.07	19.23	

FM before 31°C (kg)	10.98 ± 2.82	7.38	16.49	N.S.
FM after 31°C (kg)	10.10 ± 2.87	6.37	15.98	
LBM before 21°C (kg)	66.28 ± 5.65	56.11	73.25	N.S.
LBM after 21°C (kg)	65.88 ± 5.91	55.74	73.24	
LBM before 31°C (kg)	66.50 ± 5.23	58.11	73.46	N.S.
LBM after 31°C (kg)	66.62 ± 5.29	57.94	73.80	

Thus, for example, after completing a series of workouts at room temperature, men's BM decreased by only 0.2%, while in the group training at a higher ambient temperature it decreased by 0.7%. In the latter group, the changes in the level of structural indicators of the body after the workouts were slightly greater. For example, fat mass decreased by 5.7% and 8.0%, but the differences in the level of mean BM values before and after workouts were not statistically significant. The results of the analysis of variance for repeated measures did not show the existence of an interaction of these results in subjects training at different ambient temperatures.

Training at 21˚C resulted in a significantly greater increase in aerobic capacity as measured by maximal minute oxygen uptake (VO_2max). The increment of VO_2max was 0.27 L· min^{-1} compared to the average value before training. Training at an elevated ambient temperature did not cause significant changes in the level of VO_2max (Table 2).

Table 2. Selected physiological indices in a graded test and lactate concentration (LA) before and after training at two different ambient temperatures

	Temp (°C)	Before	After	Δ Befor / after	Δ 21°C / 31°C
$\dot{V}O_2$max (mL · kg^{-1} · min^{-1})	21	40.1 ± 7.8	43.0 ± 6.1	2.9 (NS)	(0.1) NS
	31	42.2 ± 6.8	43.1 ± 7.6	0.9 (NS)	
$\dot{V}O_2$max (L · min^{-1})	21	3.09 ± 0.43	3.36 ± 0.36	0.27 *	0.1 (NS)
	31	3.25 ±0.41	3.26 ±0.37	0.01 (NS)	
DE $\dot{V}O_2$max (min)	21	13.3 ± 1.8	16.1 ± 2.1	2.8 ***	0.1 (NS)
	31	13.2 ± 2.0	16.2 ± 2.0	3.0 ***	
TW (kJ)	21	146.2±28.5	193.9±37.9	47.7 ***	1.7 (NS)
	31	144.9±31.9	195.6±36.8	50.7 ***	
HR max (bpm)	21	191.0 ± 8.2	194.0 ± 9.4	3.0 (NS)	0.1(NS)
	31	192.0 ± 7.9	193.9 ± 7.2	1.9 (NS)	
LA (mmol · L^{-1})	21	13.21 ± 2.48	14.02 ± 2.04	0.81 (NS)	-0.23 (NS)
	31	13.35 ± 2.48	13.93 ± 2.00	0.58 (NS)	
MWL (W)	21	252.00 ± 48.60	292.50 ± 26.48	40.50 ***	-12.73 (NS)
	31	265.56 ± 25.76	293.33 ± 28.87	27.77 ***	

VO_2max (mL·kg^{-1}·min^{-1})- maximal oxygen uptake relative to body mass; **VO_2max** (L·min^{-1})- maximal global oxygen uptake; **DE VO_2max** (min)- difference in maximum oxygen consumption; **TW** (kJ)- total work ; **HRmax** (bpm)- heart rate maximum; **LA** (mmol·L^{-1})- blood lactate concentration; **MWL** (W)- maximum workload; *$p<0,05$; **$p<0,01$; ***$p<0.001$

Training at elevated ambient temperature, like training at room temperature, resulted in a statistically significant increment in work time (DE VO_2max). This increment averaged 3min for training at 31˚C and 2.8 min for training at 21˚C. Working time in the graded test after training was similar for both temperatures. Similar changes were observed in total work increment (TW). ΔTW was 47.7 kJ, for training at 21˚C and 50.7 kJ for 31˚C, respectively. No significant difference was observed between the total work performed in the graded test after training at the two tested ambient temperatures. Training did not cause statistically significant changes in maximum heart rate (HRmax).

Training at 21˚C caused significant changes in threshold oxygen uptake (TDMA) during the graded test. Threshold oxygen uptake increased by 9.2 mL· kg^{-1} after training at room temperature, corresponding to a 16.6% change from the baseline value. No significant change was observed in threshold oxygen uptake after training at elevated temperatures (Δ=3.3 mL· kg^{-1}; 6.6%) (Table 3).

Tabela 3. Characteristics of physiological indicators recorded at the TDMA threshold in a graded refusal test performed before and after workouts at two different ambient temperatures.

	Temp (°C)	Before	After	Δ Befor / after	Δ 21°C / 31°C
$\dot{V}O_2max$ (TDMA) (%)	21	64.0 ± 7.6	80.6 ± 5.9	16.6 ***	17.2 ***
	31	56.8 ± 11.3	63.4 ± 6.3	6.6 (NS)	
$\dot{V}O_2max$ (TDMA) ($mL \cdot kg^{-1} \cdot min^{-1}$)	21	25.3 ± 3.8	34.5 ± 4.4	9.2 ***	7.2 ***
	31	24.0 ± 6.1	27.3 ± 5.1	3.3 (NS)	
$\dot{V}O_2max$ (TDMA) ($L \cdot min^{-1}$)	21	1.96±0.25	2.70±0.27	0.73 ***	0.63 ***
	31	1.83 ± 0.36	2.07 ± 0.30	0.24 (NS)	
DE (TDMA) (min)	21	5.6 ± 1.6	7.9 ± 1.9	2.3 ***	0.5 (NS)
	31	5.0 ± 1.6	7.4 ± 1.6	2.4 ***	
TW (TDMA) (kJ)	21	46.1±16.4	70.6±24.3	24.5 ***	5.8 (NS)
	31	39.7±16.4	64.8±18.7	25.0 ***	
HR (TDMA) (bpm)	21	152.6 ± 7.6	156.1 ± 9.2	3.5 (NS)	2.3 (NS)
	31	150.4 ± 6.3	153.8 ± 10	3.4 (NS)	
WL (TDMA) (W)	21	164.5 ± 20.61	192.5 ± 26.48	28.0 ***	3.68 (NS)
	31	169.01 ± 27.46	193.33 ± 31.18	24.32 **	

$\mathbf{VO_2max_{(TDMA)}}$ (%)-threshold maximum oxygen consumption; $\mathbf{VO_{2(TDMA)}}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)- threshold oxygen uptake relative to body mass; $\mathbf{VO_{2(TDMA)}}$ ($L \cdot min^{-1}$)- threshold global oxygen uptake; $\mathbf{DE_{(TDMA)}}$ (min)- threshold duration of graded exercise; $\mathbf{TW_{(TDMA)}}$ (kJ)- threshold total work; $\mathbf{HR_{(TDMA)}}$ (bpm)- threshold heart rate; $\mathbf{WL_{(TDMA)}}$ (W)- threshold workload; *p<0,05; **p<0,01; ***p<0.001

Training at two different ambient temperatures resulted in a significant increase in working time [min] to threshold $DE_{[TDMA]}$. The time to anaerobic threshold on the graded test was similar after training at 21˚C and 31˚C, at 2.3 min and 2.4 min, respectively. No significant changes were observed in the threshold heart rate ($HR_{[TDMA]}$) after training at the two different ambient temps.

The results of the test assessing the efficiency of thermoregulatory processes obtained during the test are shown in Table 4.

Table 4. Characterization of physiological indices assessing the efficiency of exercise thermoregulatory mechanisms performed before and after training at two different ambient temperatures

	Temp (°C)	Before	After	Δ Befor / after	Δ 21°C / 31°C
DE (min)	21	34.0 ± 12.3	57.5 ± 18.0	23.5 ***	3.5 (NS)
	31	39.6 ± 10.9	61.0 ± 17.6	21.3 **	
HRmax (bpm)	21	167.0 ± 10.0	157.0 ± 10.3	-10.0 *	3 (NS)
	31	168.0 ± 13.2	154.0 ± 10.8	-14.0 ***	
Borg scale (pt)	21	13.2 ± 2.6	9.9 ± 2.4	-3.3 *	1.7 *
	31	13.1 ± 2.8	11.6 ± 2.1	-1.5 (NS)	
SR ($mg \cdot cm^2 \cdot min^{-1}$)	21	0.49 ± 0.03	0.61 ± 0.06	0.12 ***	0.01 (NS)
	31	0.49 ± 0.09	0.60 ± 0.04	0.11 ***	
ΔTre/DE (°C/min)	21	0.038 ± 0.01	0.021 ± 0.001	-0.017 ***	0.001 (NS)
	31	0.033 ± 0.01	0.022 ± 0.001	-0.011 ***	
PSI index (pt)1	21	7.20 ± 0.56	6.84 ± 0.60	-0.36 (NS)	0.16 (NS)
	31	7.45 ± 0.87	6.68 ± 0.59	-0.77 (NS)	

CHSI index (pt)^2	21	75.3 ± 43.1	163.1 ± 79.3	87.8 **	27.1 (NS)
	31	90.1 ± 41.2	190.2 ± 92.9	100.1 **	
CHSI/DE (pt/min)	21	2.07 ± 0.61	2.71 ± 0.56	0.73 *	0.25 (NS)
	31	2.23 ± 0.60	2.96 ± 0.78	0.64 *	

DE (min)- duration of graded exercise; **HR max** (bpm)- heart rate max; **Borg scale** (pt)- workload perception level (points) according to the Borg Scale; **SR** ($\mathrm{mg \cdot cm^{2} \cdot min^{-1}}$)- intensity of sweating; **ΔTre/DE** (°C/min)- rate of change of rectal temperature per unit of work; **PSI** index (pt)- physiological strain index; **CHSI** index (pt)- cumulative heat stress index; **CHSI/DE** (pt/min)- rate of change of cumulative heat stress index per time; *p<0,05; **p<0,01; ***p<0.001

No significant intergroup differences were observed in PSI and CHSI values during a test assessing the efficiency of exercise thermoregulatory mechanisms performed before and after training at two different ambient temperatures. Both thermoregulatory training at elevated and room ambient temperatures led to a decrease in PSI values. The CHSI index as well as the relative index values (CHSI/DE) for both forms of training increased significantly (Table 5).

Table 5. A compilation of CHSI (Cumulative Heat Stress Index) and PSI (Physiological Strain Index) indices depicting the degree and magnitude of heat stress on the body during physical activity

	Temp (°C)	1st trening	Δ 21°C / 31°C	8th trening	Δ 21°C / 31°C	16th trening	Δ 21°C / 31°C
CHSI Index (pt)	21	268.6 ± 93.6	159.7 ± 98.4 **	248.4 ± 74.8	73.8 ± 88.7 **	214.3 ± 67.4	9.2 ± 41.9 (NS)
	31	428.3 ± 130.3		322.2 ± 120.3		223.5 ± 69.4	
PSI Index (pt)	21	6.7 ± 1.1	2.0± 1.3 **	6.1 ± 1.0	1.3 ± 0.9 ***	5.8 ± 1.0	0.3 ± 0.8 (NS)
	31	8.7 ± 1.5		7.4 ± 1.1		6.2 ± 0.9	

**p<0.01; ***p<0.001

Physical training at elevated ambient temperatures led to a significant reduction in the CHSI index measured in the last, 16th training. Significantly higher CHSI index values were observed for 1st and 8th training. Similar changes were observed for PSI index values.

Discussion

Human acclimatization and acclimatization to high ambient temperatures involve processes that lead to functional and even morphological changes in the body, resulting in an increase in physiological tolerance to thermal stimuli. The manifestation of the increase in this tolerance is the reduced involvement of organs and systems responsible for maintaining heat balance. The rate of acclimation to high temperature generally develops faster, and the process itself is stronger if repeated thermal treatments are accompanied by exercise [9]. Under these conditions, the overlap of exogenous heat and metabolic endogenous heat leads to a greater increase in core body temperature.

Heat stress is a combination of environmental and physical factors that place a heat load on a person during physical work. Heat stress increases the risk of heat-induced disorders such as heat cramps, heat exhaustion and ultimately heat stroke. The goal of any training program that prepares for working at elevated ambient temperatures is to optimize work performance. There are many ways to assess heat stress during physical activity at elevated ambient temperatures. In recent years, mainly two indices have become popular: the PSI [21] and CHSI [22]. These indices describe heat stress based on the measurement of HR and Tre, thereby reflecting the stress on the cardiovascular and thermoregulatory systems. Both indexes are based on the proportional contribution of the two components with the CHSI index additionally including the time of physical activity performed. Therefore, it can be used when the effort is the same for all subjects. The solution to this problem is our proposed expression of the CHSI in the unit of time [pt/min].

In the study conducted, subjective feelings of thermal stress (PSI and CHSI) were higher during workouts performed at 31°C than at 21°C (Table 5). This indicates that exercise at elevated temperatures is more stressful to the body than exercise at room temperature. It is noteworthy that in both the 8th and 16th workouts, both of these indices had a decreasing trend, indicating that the thermal stress decreased as the training process continued (Table 5). It should be noted that this process was much more effective for training performed at 31°C. Both of the observed indices (PSI and CHSI) can be suitable for objective assessment of thermal load during exercise and provide an excellent indicator regarding changes in the efficiency of thermoregulatory mechanisms.

During the initial phase of acclimation, the body's primary thermoregulatory response to the effects of an elevated and high ambient temperature is an increase in cutaneous blood flow due to the dilation of metaarterioles and arterioles and the opening of previously closed precapillaries and anastomoses in these areas. Maintaining increased blood flow through dilated cutaneous vessels is possible due to an increase in HR and SV, which affects the magnitude of cardiac minute volume (Q), a shift of blood from the visceral area to the skin, and an increase in plasma volume at the onset of thermal exposures [4,9].

However, the reaction of the cardiovascular system to physical effort is different, as evidenced by the results of Rowell's research [23]. During physical work in a hot environment, he found a smaller increase in cardiac output (Q) in men than during identical exercise in a cool environment, which was not compensated by a higher HR. In efforts at an intensity of 40-50% of VO_2max, cardiac output (Q) was lower than during such work at room temperature [24]. Maintaining oxygen uptake in these conditions at an appropriate level to meet the body's exercise needs is possible by increasing the arteriovenous oxygen difference.

Our own observations and reports by other authors indicate that aerobic training modifies the cardiovascular response, which is manifested, among other things, by a decrease in the exercise values of heart contraction rates, the so-called heart rate reserve, and an increase in SV [25]. In men, after training, although there were no significant changes in the level of HRmax in the graded test, it is noteworthy that, after their relativization, the highest number of heart contractions per unit of maximal power generated [W] decreased after training at room temperature from 0.73 to 0.66 contraction $\cdot$ W^{-1}, and after an exercise session at a higher temperature from 0.74 to 0.66 contraction $\cdot$ W^{-1} [$p<0.001$], which was the result of a significant increase in maximal aerobic power [MWL]. After training in a graded test on individual load segments, HR values were significantly lower [$p<0.001$], indicating an increase in exercise heart rate reserve. Physical training conducted under ambient hyperthermia led to improvements in aerobic mechanisms at a similar level as training conducted under normothermic conditions. However, no differences were observed between the workouts, in the time to achieve VO_2max and in the duration of the Kubica test [18], which may indicate that the decisive factor here was the influence of improving aerobic processes. It is also worth noting that both training under normothermic and hyperthermic conditions led to similar increases in sweating intensity (Table 4).

High and even elevated ambient temperatures have a significant impact on physical performance, with the physiological mechanism of the reduction in the body's exercise capacity under such conditions being very complex [18,26,27]. Prolonged exposure of the body to a thermal stressor results in a decrease in the ability of muscles to perform short-term efforts of maximum intensity, which is explained primarily by "impairment" of the function of the central and peripheral nervous systems. Degradation of aerobic capacity (VO_2max) under these conditions is a consequence of deterioration of cardiovascular function and dehydration of the body. Decreased blood volume has a significant negative impact on both the functioning of the oxygen supply mechanisms and the function of the muscle and nerve cells themselves [28].

Being in an environment with elevated (30-37°C) and high (80-100°C) ambient temperatures accelerates the process of thermal acclimation more pronouncedly than it does at lower ambient temperatures. When two stressors, thermal and exercise, act on the body simultaneously, the rate of adaptive change is higher under these conditions [4]. The results of the study by Żuchowicz et al. [13] indicate that each of these factors separately (endogenous and exogenous heat) can model the acclimation process. Endurance training improves the thermoregulatory mechanisms of athletes [2,9].

The efficiency of sweating depends on the ambient conditions, most importantly the ambient temperature and vapor saturation of the air [29]. The conditions in the thermoclimatic chamber where the workouts were carried out did not differ in humidity or intensity of air movement. Thus, temperature was the most important factor in the current project. However, it should be taken into account that it was a combined effect of the extrinsic temperature, controlled by conducting tests in the thermoclimatic chamber, and the intrinsic temperature. And this was conditioned by physical fitness and the work performed [30]. Due to the study protocol, the importance of gender, age and diurnal rhythms, which should also be taken into account when discussing the body's ability to thermoragulate and acclimate to high temperatures [31-33], can be ignored in this case. We observed that sweating intensity increased in both conditions studied. This indicates the importance of training time and exercise intensity in modulating this thermoregulatory function of the body. Temperature, on the other hand, will be of secondary importance here. From a practical point of view, it should be emphasized that sweating will be more intense in trained individuals regardless of training conditions.

In a study by Pilch et al. [2], greater weight loss, and consequently dehydration, was observed in athletes than in untrained individuals. The difference may be related to their higher percentage of body water and lower levels of body fat. It may also be due to more intense sweating [29]. In the present project, no significant changes in biometric-structural indices were observed in either group under the influence of 8 weeks of physical training. However, it is noteworthy that there was a reduction in body weight and fat, which indicates the correct direction of changes occurring under the influence of the physical exercise applied (Table 1).

Pokora et al. [34] found differences in body fluid distribution depending on the type of thermal stress applied. Exogenous thermal stress, in the form of sauna bathing, results in a greater loss of water from the extracellular space, and only then from the intracellular space. In contrast, exercise that generates endogenous thermal stress increases the contribution of cellular fluid to the total volume of water lost [34]. Therefore, one would expect differences after a series of workouts conducted at 21 and 31°C.

This project attempts to contrast the effects of two different types of body acclimation to work, exercise and exercise-thermal. In the first case during work at 21°C, excess heat of endogenous origin could be efficiently dissipated to the environment, and in the second case when it was hindered because the ambient temperature was close to the weighted average skin temperature.

Studying the physiological responses of the male body during exercise in an elevated temperature environment, it was observed that raising the internal body temperature before the start of aerobic exercise is inadvisable, as it can reduce the body's exercise capacity [35]. The effects of aerobic training deteriorate as the internal body temperature increases above the energy optimum of 38.0-38.3°C. When the value of heat potential reaches about 39°C, a significant decrease in work intensity and deterioration in the efficiency of aerobic supply mechanisms is observed. According to Guimarães [35], thermal homeostasis is essential for maintaining high efficiency of aerobic energy metabolism. According to Maughan et al. [36,37], aerobic exercise capacity is significantly impaired at high ambient temperatures and as a result of dehydration. Improvements in thermoregulatory mechanisms can be achieved by performing 10-15 training sessions at high ambient temperature lasting 40 to 100 minutes [38].

Endurance training conducted in a warm environment improved thermoregulatory mechanisms in exercisers [39], mainly due to increased sweat secretion through increased sweating. This resulted in rapid balancing of the body's heat balance and a greater contribution of secreted sweat to body cooling by increasing the volume of evaporative sweat. In an effort to achieve high thermoregulatory efficiency, Smorawinski et al. [39] recommended continuing aerobic training despite its diminishing effect on the body's performance, which was also consistent with the observations of Guimarães [35]. A person performing exercise at an elevated ambient temperature has lower exercise capacity than at a lower (room) temperature. It is noteworthy that 8-week physical training at an elevated ambient temperature improving thermoregulatory mechanisms contributed to the improvement of exercise performance.

Deterioration of the effects of thermal dressing in humans occurs very quickly, primarily when people move from a warm to a cold environment. After just 1, 2, 3 weeks, degradation occurs by 50%, 80% and 100%, respectively [40]. The effect of acclimation can be maintained for up to two months afterwards, provided that physical training continues after the thermal factor is turned off [41].

Physical changes in heat are manifested by a marked increase in internal body temperature, excessive growth of which is one of the factors limiting the body's ability to perform physical work. This is indicated by the study of Tyka et al. [27], which notes that the thermal factor modifies the height of the anaerobic threshold and affects the level of endurance. According to Harrison [42], aerobic physical training at room temperature can raise the efficiency of exercise thermoregulatory mechanisms to a higher level. These observations were consistent with the findings obtained by Kubica et al. [43] and Żuchowicz et al. [13], who observed similar changes in the efficiency of exercise thermoregulatory mechanisms in men after 10 days of daily training, which were expressed in smaller increases in Tre, skin temperatures and HR during 90 minutes of cycloergometer exercise.

From our own observations, we found that 8-week physical training of men (3 x weekly for 70 minutes each) at a relative intensity of 53%VO_2max at 21°C and 31°C did not significantly affect changes in the fitness level of the aerobic supply mechanisms. No significant differences in the level of absolute and relative magnitudes of maximal minute oxygen uptake (VO_2max) were found in the male subjects after the training period, which can probably be explained by the men's too, short period of training. However, the results of analysis of variance for repeated measurements showed a significant post-training increase in maximal exercise capacity (MWL) as illustrated by the level of maximal aerobic power.

The effect of the thermal factor on physical performance is significant, both in a positive and negative sense. With dehydration of the body reaching 2.5% to 5%, physical performance decreases. Among other things, a decrease in skeletal muscle endurance, strength and power is noted. During dehydration of the body, blood flow in muscle capillaries deteriorates, leading to an increase in the content of hydrogen ions in the blood, an increase in carbon dioxide pressure and a decrease in bicarbonate content. Changes in metabolism perhaps contribute to the formation of a slight metabolic acidosis. Reduced exercise capacity of the body may persist for more than one day [44]. When the body is dehydrated, the secretion of antidiuretic hormone increases, the effect of which is to reduce urine excretion and stimulate thirst. Under thermal conditions, the renin-angiotensin-aldosterone system is also activated. The combined action of these hormones, counteracts the excessive lowering of blood pressure as a result of dehydration and activation of the cutaneous circulation [44]. The rational use of thermal dressing can lead to an improvement in the exercise adaptive responses of the body, increasing the ability to perform in a hot environment. This can be used by athletes going to competitions and even workers going to work in "warm countries."

After physical training, a number of adaptive changes were observed in the bodies of the men studied. The duration of the graded test (DE), which was taken as the primary indicator of the current level of endurance, increased significantly in men training at room ambient temperature by 21% and by 22.6% in men training at higher ambient temperature. At the same time, maximal aerobic power (MWL) increased by 12% and 14%, respectively. In contrast, there were no significant differences in the level of gains in these parameters in subjects trained under different ambient thermal conditions (Table 2).

The statistically significant increase in work capacity after the men's eight-week training session was associated, among other things, with the later appearance of their anaerobic threshold, with significantly higher power output by 19% and 16%, respectively. The training effect was also manifested in changes in percentage oxygen uptake [%VO_2max] after both training sessions. As reported by Tyka et al. [27], during exercise with gradually increasing power output at elevated ambient temperature (37°C) in men, the threshold for uncompensated metabolic acidosis (TDMA) appeared earlier and at lower exercise intensity than during such work at room ambient temperature [21°C]. Similar results were found in our study, where, at the beginning and end of the experiment, the threshold for uncompensated metabolic acidosis (TDMA) appeared earlier during work at a higher ambient temperature (31°C) and at a lower power than at room temperature. It is noteworthy, however, that after 8-week training treatments, the aforementioned differences clearly decreased, which may indicate the positive role of the thermal factor in the process of adaptation and exercise acclimation of the body. Other researchers observed a significant increase in the time to reach the anaerobic threshold (TDMA) in men after thermal treatments, consisting of passive and active heating of the body [13]. Such observations have application value and should be taken into account in programming and individualizing training loads.

Our own findings do not support the suggestion of other researchers that the thermal factor can modify aerobic capacity, and were consistent with the observations of Kubica et al. [45] on this topic. After a period of thermal acclimation of the male body to high temperature conditions, he found no statistically significant changes in the level of aerobic capacity [VO_2max].

On the basis of our own observations, we can conclude that physical training of men carried out at room and elevated ambient temperatures did not lead to significant changes in the level of maximal oxygen uptake, and thus did not improve the exercise mechanisms of aerobic supply of the body. Perhaps, as signaled earlier, this was influenced by too short a training period and a small number of training units per week. According to the standards of the American Heart Association, the aerobic capacity of the male subjects at the beginning of the experiment, averaging 40.09 $ml\cdot kg^{-1}$, was at an average level.

The favorable post-workout changes in the body's exercise capacity (increase in MWL) observed in the subjects were also the result of improvements in exercise thermoregulatory mechanisms, which was, among other things, noted by other researchers working on this topic [39, 46]. After both training sessions, a significant increase in graded exercise time and an increase in maximal aerobic power were accompanied in parallel by smaller increases in temperature (rectal and dermal) than in baseline studies. These changes were statistically significant.

Improvements in men's thermoregulation after training were also influenced by changes in sweating intensity. The time of rectal temperature rise of 1.2°C in a standard test in a thermoclimatic chamber, considered by Kubica et al. [18,45] as an exponent of the efficiency of exercise thermoregulatory mechanisms, prolonged significantly after training sessions, indicating good acclimation of the men's organism to work in an elevated ambient temperature and humid environment.

The conjecture that training with an identical physiological cost performed at an elevated ambient temperature would improve the body's thermoregulatory performance to a greater extent than exercise performed at room temperature was not confirmed. However, it is noteworthy that although the effect of both types of training was similar, with an identical physiological cost, the absolute volume of work performed by men training at an ambient temperature of 31°C was significantly lower than those training at room temperature.

The assessment of the strenuousness of human work according to the Borg scale [19] is often used by physiologists, especially during prolonged or graded physical exertion, to monitor the subjective feeling of fatigue in the body. This type of monitoring of the body's workload was used in men at the beginning and end of the experiment in both exercise tests (the graded test and the Kubica test [18]). After 8 weeks of training in the last highest load segment of the “to refusal” test, a statistically significant increase in the duration of the test was not accompanied by significant changes in the perception of strenuous work (Table 4). After the end of training in both groups of men, the duration was significantly prolonged, mainly due to a decrease in the rate of increase in rectum temperature. These changes were accompanied by statistically significant decreases in average scores of 23.7% and 11.5% compared to the baseline values of this index. This pattern of results indicates that both repeated physical stimuli at room ambient temperature and the same loads in a warm environment similarly model the psychological state of feeling the strenuousness of exertion (Table 4).

One of the primary mechanisms protecting the body from hyperthermia of endo and exogenous origin is the evaporation of sweat from the skin. In this pathway, the body can lose up to about 60% of excess heat energy [47]. A good indicator of the body’s adaptation to working in a warm environment is, among other things, the intensity of sweating (SR) and the body’s water reserves [48]. After completing a series of workouts at both ambient temperatures, a significant increase in SR was found in the last 15 minutes of the thermoclimatic chamber test. However, there were no statistical differences in the post-workout values of this indicator in men trained at room and elevated temperatures (Table 4).

To summarize the present study, it can be concluded that the use of PSI and CHSI to determine heat load during exercise is reasonable and can be an excellent indicator to assess the efficiency of thermoregulatory mechanisms. The improvement of these mechanisms was manifested by an increase in the body’s exercise capacity after both forms of physical training. The physical training applied modified the physiological responses of the body in both cases, but the duration of a single training unit as well as their amount was most likely too small for the changes to be statistically significant. The results obtained can be an excellent source material for physical preparation coaches and also an important indication for further research into thermoregulatory mechanisms and the body’s reactions during staying and working at elevated ambient temperatures.

Conclusions

Eight weeks of physical training (3 times a week for 70 minutes each) with a physiological cost of 53% VO_2max at ambient temperatures of 21°C and 31°C and relative humidity of 40±3% did not significantly change the body’s aerobic capacity (VO_2max). Aerobic training at both ambient temperatures resulted in a significant and similar increase in the body’s endurance level as demonstrated by an increase in the work time in the graded test, the time to reach the anaerobic threshold and an increase in maximal aerobic power. Physical training at both ambient temperatures contributed to a higher level of efficiency of the body’s thermoregulatory mechanisms, which was manifested, among other things, in a decrease in the rate of increase in rectal temperature and more efficient cooling of the skin coverings during work, as well as in an increase in the time of effort required to achieve the test’s target increase in rectal temperature by 1.2°C. Exercise and exercise-thermal training contributed equally to the improvement of the systemic mechanisms responsible for sweat excretion, as demonstrated by a statistically significant increase in sweating rate (SR), in individual segments of the Kubica test duration. The repetitive physical stimuli applied to the men at different ambient temperatures had a significant effect on the subjects’ psyche, as demonstrated by a decrease in the subjective feeling of the strenuousness of the work performed in the graded test, on each segment of the exercise load.

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