ORIGINAL ARTICLE

Heat stress levels in judokas during a special performance test conducted at two different ambient temperatures

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Manuscript Preparation
E Funds Collection

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Received: 12 April 2023; **Accepted:** 04 May 2023; **Published online:** 18 May 2023

AoBID: 16226

Abstract

Background & Study Aim: The exercise metabolism of a judoka during a tournament bout or a single training unit is based primarily on anaerobic processes. Under such conditions of physical stress, significant damage to muscle cells occurs, greater than in typically aerobic efforts. Among the strongest stimuli causing these changes are the mechanical and metabolic stresses associated with the physiological cost of exercise, which can be exacerbated when working at elevated ambient temperatures. The aim of our research was to obtain knowledge about the relationship between the effect of a special fitness test conducted at two different ambient temperatures and the level of heat stress in judokas.

Material & Methods: The study was carried out among a group of 15 professional judo athletes aged 20.65 ±2.03 years with an average aerobic capacity level. The research protocol consisted of two main parts with separate tasks. Part one was the preliminary study (stage I, II and III), and part two was the main study (stage IV and V). The performance tests were conducted during the starting period and took place in a thermoclimatic chamber and an air-conditioned laboratory. In Stage I, selected anthropometric and circulatory indicators were measured. Stage II involved the male subjects performing an exercise test assessing anaerobic and aerobic capacity with the lower limbs (LL) and after seven days with the upper extremities (AA) (stage III). The Wingate test for lower limbs (LL) and upper limbs (AA) was used to assess anaerobic capacity indices. After a minimum of 2h after completing the Wingate Test, the subjects took a test to assess aerobic capacity. To assess aerobic capacity, a direct method was used – a test with gradually increasing load performed on a cycloergometer to refusal to continue due to extreme fatigue. The test determined physiological indicators at the level of the second ventilation threshold (VT2) and at the maximum level (VO2max). In the main study (stage IV and V), half of the male subjects performed 5 restrictive pulse exercise sequences on a foot cycloergometer and hand cycloergometer in a thermoclimatic chamber at 21 ±0.5°C (stage IV) and the other half at 31 ±0.5°C (stage V), relative humidity 50% ±5%. After the seven days the subjects rejoined stages IV and

V. This time, the first group of subjects performed the exercise at 31 ±0.5°C and the second half at 21 ±0.5°C. The interval effort was characterized by pulsatile, alternating, time-varying loading of the upper and lower extremities during anaerobic exercise series punctuated by 15-minute rest intervals.

Results: In the Wingate test with the lower extremities, the maximum anaerobic power (RPP) was 12.12 ±0.87 W · kg^{-1}, and with the upper extremities it was 7.00 ±0.56 W · kg^{-1}. Total work (TW) in the test with the lower extremities was 21.85 ±4.26 kJ and with the upper extremities 13.36 ±2.50 kJ. The result of VO_2max measurement for the lower limbs averaged 43.23 ±7.79 ml·kg^{-1} · min^{-1}, and for the upper limbs 37.19 ±5.26 ml·kg^{-1} · min^{-1}. HRmax recorded in the graded test for the lower limbs averaged 185 ±8.19 bpm and for the test for the lower limbs: 183 ±8.43 bpm. The time to reach VT2 averaged 11.50 ±3.09 min for the lower extremities and 8.32 ±2.99 min for the upper extremities. At the second ventilation threshold, the heart rate of contraction (HRVT2) was 168 ±8.42 bpm (LL) and 162 ±8.75 bpm (AA). The percentage of oxygen uptake at the second ventilation threshold (%VO_2max) was 77.68 ±9.61% (LL) and 71.88 ±11.65% (AA), respectively. As a result of exercise dehydration at 21°C and 31°C, there was a statistically significant reduction in body weight ($p<0.05$). However, there was no statistically significant difference between the BM values recorded after a series of exercise at 21°C and 31°C. PSI and CHSI values were statistically significantly higher for exercise performed at 31°C.

Conclusions: Different ambient thermal conditions do not affect the volume of work performed in pulsatile anaerobic exercise, which does not support the view represented by some researchers about the effect of ambient temperature on anaerobic capacity. The tested athletes tolerated the thermal load well and their subjective assessment of the strenuousness of the work, did not differ in the ambient temperatures used. The greater weight loss, and thus dehydration, observed in athletes after exercise at elevated ambient temperatures may be related to a widening of their capillary network in both muscle and skin, influenced by years of training, which also increases the body's water percentage which promotes sweat transpiration. In order to increase the body's tolerance to heat and exercise stress, it is reasonable in professional judokas to conduct training under various ambient thermal conditions.

Keywords: aerobic capacity • anaerobic performance • combat sports • thermoclimatic chamber

Conflict of interest: Authors have declared that no competing interest exists

Ethical approval: The study was approved by the Bioethics Committee at the Regional Chamber of Physicians in Krakow (Poland), no. 102/KBL/OIL/2011, and was financed under the statutory research of the AWF Krakow (Poland), project no. GRANT 7/BS/IFC/2011

Provenance & peer review: Not commissioned; externally peer-reviewed

Source of support: Departmental sources

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Combat sport – *noun* a sport in which one person fights another, e.g. wrestling, boxing and the martial arts [77].

Anaerobic performance – the ability to perform work using the energy of the body's anaerobic metabolism [19].

Aerobic capacity – maximum oxygen uptake (L/min), correlated with the performance of muscle work during intense exercise lasting from 5 to 15 minutes [17].

Heat stress – compilation of the effects of temperature and humidity stimuli on the human body, leading to heat management disorders such as

INTRODUCTION

The response of the human body to exercise depends on the type of physical activity, intensity, external conditions, duration as well as the number of muscles involved in the physical work, among other factors. Any form of exercise will induce an increase in metabolism, affecting improved oxygen transport due to increased blood flow. In addition, it will result in an increase in endogenous temperature as a result of heat generated by working muscles [1-3].

The exercise metabolism of a judoka during a tournament bout or a single training unit is based primarily on anaerobic processes. Under such conditions of physical stress, significant damage to muscle cells occurs, greater than in typically aerobic efforts. Among the strongest stimuli causing these changes are the mechanical and metabolic stresses associated with the physiological cost of exercise, which can be exacerbated when working at elevated ambient temperatures [4, 5].

The time structure of a judo fight in the tournament system consists of 4 to 6 five-minute fights, separated by a short break between them [6]. During combat, the endogenous heat produced increases the body's rectal temperature, which can have a significant impact on athletes' exercise capacity [7]. The increase in internal temperature may be exacerbated by the limited thermoregulatory capacity induced by the elevated ambient temperature. Such conditions impair most of the effective methods of heat removal from the body, thereby exacerbating heat stress [8]. This will be manifested by an increase in heart rate and heart minute volume [9].

Physical exertion undertaken under such conditions induces increased water loss with sweat, which can be associated with hypovolemia, resulting in a much greater burden on the cardiovascular system, increased glycogen consumption and central nervous system dysfunction [10]. Continuing to work under such conditions leads to water-electrolyte disorders, as well as thermal imbalance and intracorporeal homeostasis, compounding the physiological and biochemical changes associated with the physical work undertaken [11]. Available literature indicates that the decline in endurance performance progresses with the magnitude of the dehydration deficit and generally increases with increasing ambient temperature. Dehydration leads to significantly greater losses in physical endurance during exercise in warm and hot climates [11-13].

The magnitude of heat load during exercise is assessed using changes in rectal temperature (T_{re}), while the overall load on physiological mechanisms is illustrated by the physical strain index (PSI) [14] or the cumulative heat strain index (CHSI) [15].

The manifestation of adaptive responses as a result of the work undertaken at elevated ambient temperatures is a decrease in stroke volume and an anticipatory increase in heart rate to maintain cardiac minute capacity [16]. This is due to the movement of a larger volume of blood from the blood stores in the viscera to the skin area and a change in plasma volume. Intense sweating causes a decrease in the body's systemic water reserves, which is combined with a decrease in the volume of plasma and electrolytes, and consequently: blood volume. To counteract the negative effects of dehydration, fluids should be replenished during exercise, in such a way as not to allow the loss of more than 2% of body weight. This level of dehydration results in a 10-20% reduction in maximum aerobic capacity [17].

Taking into account the fact that numerous international judo competitions are held under different thermal conditions, which can affect the course of physiological and biochemical reactions and the course of the fight, it seems expedient to study the effect of a special fitness test conducted at two different ambient temperatures on the level of heat stress in judokas.

The aim of our research was to obtain knowledge about the relationship between the results of a special fitness test conducted at two different ambient temperatures and the level of heat stress in judokas.

MATERIAL AND METHODS

Characteristics of the study group

The study included a group of 15 professional judo athletes aged 20.65 ±2.03 years with an average aerobic capacity level according to the American Heart Association [18] having current medical examinations and at least sports class I. During the study, the men did not use any stimulants, vitamins or other dietary supplements. The full cycle of the study was completed by a group of 10 athletes (five subjects were excluded from the study, the reason being injury 1 person or infection 4 judokas).

Participation in the research project was voluntary. The subjects gave written consent to participate in the project. In accordance with the requirements of the Declaration of Helsinki, the subjects were informed about the purpose of the research, the methodology used, possible side effects and the possibility of resigning from participation at any time without giving a reason. The study was performed at the Institute of Human Physiology, University of Physical Education (abbreviation of the name in Polish: AWF) in Krakow, and, in accordance with current standards, was conducted under the supervision of qualified medical personnel.

The project was approved by the Bioethics Committee at the Regional Chamber of Physicians in Krakow No. 102/KBL/OIL/2011, and was financed under the statutory research of the AWF Krakow Project No. GRANT 7/BS/IFC/2011.

Research protocol

The research protocol consisted of two main parts with separate tasks. Part one was the preliminary study (stage I, II and III), and part two was the main study (stage IV and V) (Figure 1). The performance tests were conducted during the

overheating, heat exhaustion, and life-threatening heat stroke [8].

Thermoclimatic chamber – a device enabling artificial induction of various environmental conditions (temperature and humidity control, as well as the ability to create climatic conditions that do not occur in the natural environment).

Training periodization – depending of the phase of periodization plan, the training emphasis will shift to develop specific characteristics and manage fatigue. A truly comprehensive plan includes dietary recommendation and psychological training. If the training plan is not completely integrated, the like hood that the athlete will achieve successful results is significantly decreased. The annual training should contain at least preparatory, competitive, and transition phases [78, p. 146].

Preliminary research	**Stage I** ▪ Biometric and physiological measurements **Stage II (LL)** ▪ Measurement of anaerobic capacity ▪ Measurement of aerobic capacity **Stage III (AA)** ▪ Measurement of anaerobic capacity ▪ Measurement of aerobic capacity
Main research	**Stage IV** ▪ Pulse physical effort at 21°C **Stage IV** ▪ Pulse physical effort at 31°C

Figure 1. Study protocol.

starting period and took place in a thermoclimatic chamber and an air-conditioned laboratory of the Department of Physiology and Biochemistry at the AWF in Krakow. Taking into account circadian rhythms, the tests were performed in the morning, no earlier than 2 h after a light meal.

Preliminary examination

Stage I

In Stage I, selected biometric indicators such as body mass (BM) and body height (BH) were measured. An eight-electrode electrical bioimpedance technique (JAWON MEDICAL IOI-353, certificate EC0197, Korea) was used to assess body structure and the following were estimated: lean body mass (LBM), percent body fat (PBF) and fat mass (MBF). Body height was determined using a Martin-type anthropometer (USA) with a measurement accuracy of 0.5 cm. Based on weight and height, the body mass index (BMI) was calculated. In addition, body surface area (BSA) and body surface area to body weight ratio (BSA – BM-1) were calculated.

For diagnostic purposes, the test athletes' blood pressure (BP) and heart rate (HR) were measured. Blood pressure at the level of the brachial artery was measured in the sitting position by the routine Korotkow method with an accuracy of 5 mmHg (0.67 kPa), using a mercury apparatus. The rate of heart contractions in laboratory tests was recorded using a Polar (Finland) 610S sporttester.

Stage II and III

Stage II involved the male subjects performing an exercise test assessing anaerobic and aerobic capacity with the lower limbs (LL). After seven days, the subjects proceeded to Stage III, in which they performed the same exercise tests again, but this time with the upper extremities (AA).

The Wingate test for lower limbs (LL) and upper limbs (AA) was used to assess anaerobic capacity indices. The core exercise was preceded by a 5-minute warm-up on a cycloergometer at an individually selected intensity of 50 ±2% VO_2max, with a pedaling rate (RPM) of 60 rev/min. During which three five-second accelerations were performed at 2, 4 and 5 minutes. After a 2-min break, a proper test was conducted, in which the subject performed 30 seconds of maximal exercise. The external resistance for the subject's lower extremities was 8.3% of body weight, and for the upper extremities was 4.5% of body weight [19]. The main part of the test was performed on Monark 875 E lower limb and 891E upper limb ergometers (Sweden).

During the test, the following indices were recorded: peak power (PP), mean power (MP), total work (TW), time to peak power (toPP), time to maintain maximum power (tmPP), and loss of power factor (IPF).

After a minimum of 2h after completing the Wingate Test, the subjects took a test to assess aerobic capacity.

To assess aerobic capacity, a direct method was used – a test with gradually increasing load performed on a cycloergometer to refusal to continue due to extreme fatigue. The test determined physiological indicators at the level of the second ventilation threshold (VT2) and at the maximum level (VO_2max). To determine VT2, changes in respiratory indices were analyzed as work intensity increased. The criteria for determining VT2 were as follows:

(a) the percentage of CO_2 in exhaled air reached a maximum value and then decreased;

(b) the respiratory equivalent for carbon dioxide reached a minimum value and then increased;

(c) a non-linear, large increase in lung ventilation was recorded after VT2 was exceeded.

The magnitude of VO_2max was considered to be the highest recorded [20].

The test effort was preceded by a two-minute warm-up, during which the subject pedaled at 60 rev/min at an intensity of 110W for the lower extremities (cycloergometer type ER 900 D – 72475 BIT2 from Jeager, Germany) and 60W for the upper extremities (ergometer from Monark type 891E, Sweden). Then, every 2 minutes, the power was increased by 20W (LL test) or 12W (AA test). The test was performed until refusal to continue further due to extreme fatigue.

In incremental test, oxygen uptake (VO_2), heart rate (HR), respiratory exchange ratio (RER), pulmonary ventilation (VE), carbon dioxide output (VCO_2), fractional concentrations of expired CO_2 (%FECO2) and O_2 (%FEO_2), ventilatory equivalent ratio for oxygen (VE/VO_2) and carbon dioxide (VE/VCO_2) were measured breath by breath using an erospirometer (MetaLyzer 3R, Cortex, Germany).

The test was conducted at an ambient temperature of 21 ±0.5°C and a relative humidity of 40 ±3%. Thermoclimatic conditions were controlled with a Harvia thermohygrometer (Finland) and an Ellab electrothermometer (Denmark) with a measurement accuracy of ±3% and ±0.5°C, and air movement was controlled with a Hill cathermometer.

Main study

Stage IV and V

In the main study, half of the male subjects performed 5 restrictive pulse exercise sequences on a foot cycloergometer (cycloergometer 827E, from Monark, Sweden) and hand cycloergometer (cycloergometer 881E, from Monark, Sweden) in a thermoclimatic chamber at 21±0.5°C (stage IV) and the other half at 31 ±0.5°C (stage V), relative humidity 50% ±5%. After the seven days necessary to extinguish the possible effects of physical exertion, the subjects re-joined stages IV and V. This time, the first group of subjects performed the exercise at 31 ±0.5°C and the second half at 21 ±0.5°C. The interval effort was characterized by pulsatile, alternating, time-varying loading of the upper and lower extremities during anaerobic exercise series punctuated by 15-minute rest intervals (Table1).

The pulse effort at both temperatures was preceded by a 30-minute acclimatization to the thermal conditions, followed by a 5-minute warm-up with an individually selected load of 50 ±1% of VO_2max, at a pedalling rate of 60 rev/min with three 5-second maximum accelerations at the 2nd, 4th and 5th minute. During each pulse test sequence, the load was the same at 8.3% of the subject's body weight for LL and 4.5% of body weight for AA, respectively.

Table 1. Characteristics of a single series of pulsatile efforts (seconds).

Interval effort															
first				second				third				fourth			
LL	Int	AA	Int	LL	Int	AA	Int	LL	Int	AA	Int	LL	Int	AA	Int
15	30	15	30	30	60	30	60	20	45	20	45	15	30	15	30

Note: **AA** upper limbs; **LL** lover limbs; **Int** interval

During the individual sequences of the pulse test, based on a modified version of the Wingate test for the lower and upper extremities, the basic indicators of the Wingate test were analysed. The sum of work globally performed in all five sequences of the pulse test (∑TW) and the sum of work performed with the upper ($\sum TW_{AA}$) and lower limbs ($\sum TW_{LL}$) were also calculated. The total duration of the experiment assuming five sequences of pulsatile efforts and four 15-minute intervals was 96 min. and 20 sec (Figure 2).

Throughout the test, heart rate (HR) and the degree of strenuous work were recorded in each of the 5 sequences of the pulse test using the 20-point Borg scale: 6, 7 points on the scale indicate extremely light work; 8, 9 – very light work; 10, 11 – fairly light work; 12, 13 – fairly heavy work; 14, 15 heavy work, 16, 17 – very heavy work; 18, 19, 20 – extremely heavy work [21].

Rectal temperature (Tre) was recorded continuously. Before and after the end of the test after drying the skin coverings, the body weight was measured and the degree of body dehydration (ΔBM) was calculated on this basis. In addition, at the beginning and after 5 series of the pulse test and at 1-, 24 – and 48 hours, the following biochemical determinations were made from blood samples: hematocrit count (HCT) and plasma volume changes (%ΔPV) were calculated. Blood pressure (BP) and skin temperature (Tsk) were also measured before and after the test.

Rectal temperature (Tre) was measured with an electro thermometer type MRV-A from Ellab (Denmark), and skin temperature was measured with an apparatus type MHS-A from the same company, with a measurement accuracy of 0.05°C. The thermocouples for measuring rectal temperature at a depth of 15 cm were each time sheathed in a disposable sterile sheath according to the manufacturer's instructions. Before each test, the sensors were sterilized in an autoclave at 120°C and then disinfected chemically. Each participant in the experiment used the same sensor throughout the study.

The weighted average skin temperature was calculated from the formula of Hardy and DuBois [22]:

$$T_{\overline{sk}} = 0.07 \text{ forehead} + 0.35 \text{ chest} + 0.14 \text{ arm} + 0.05 \text{ palm} + 0.19 \text{ thigh} + 0.13 \text{ lower thigh} + 0.007 \text{ foot}.$$

Indexes based on heart rate and rectal temperature measurements were used to determine the effect of heat load during exercise. The PSI index (physical strain index) [14] depicting the physiological load expressed on a 10-point numerical scale, expressed by the formula:

$$PSI = 5 \cdot (T_{ret} - T_{re0}) \cdot (39.5 - T_{re0})^{-1} + 5 \cdot (HR_t - HR_0) \cdot (180 - HR_0)^{-1}$$

where: Tre0 – rectal temperature at time t0; Tret – rectal temperature at a given time; HR0 – heart rate at time t0; HRt – heart rate in a given time;

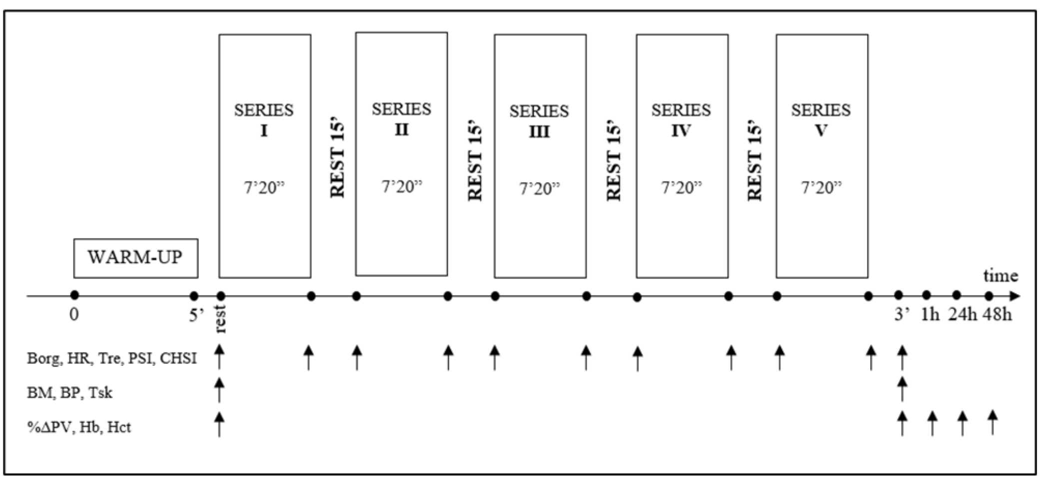

Figure 2. Diagram of the main part of the study with indication of measurement points (**Borg** the Borg scale; **HR** heart rate; **Tre** rectal temperature; **PSI** physical strain index; **CHSI** cumulative heat strain index; **BM** body weight; **BP** blood pressure; **Tsk** skin temperature; **%ΔPV** plasma volume changes; **Hb** haemoglobine; **Hct** hematocrit count)

PSI index illustrates the physiological load expressed on a numerical scale from 0-10 where: 0-2 points is very low or no load; 3, 4 – low, 5, 6 – moderate; 7, 8 – high; 9, 10 – very high.

The CHSI, proposed by Frank et al. [15] takes into account not only the baseline and end values, but also the change in HR and Tre relative to time. For this purpose, changes in Tre are recorded continuously. HR is recorded at minute intervals.

Post-exercise Tre values were corrected for changes in plasma volume. Plasma volume changes (%ΔPV) were estimated using the formula of Dilla and Costil [23] modified by Harisson et al. [24]:

$$\%\Delta PV = 100\{(Hb_1/Hb_2)\cdot[100-(Hct_2 \cdot 0.874)]/[100-(Hct_1 \cdot 0.874)]-1\}$$

where: Hb_1 i Hct_1 are the baseline values of haemoglobin concentration and hematocrit number, and Hb_2 i Hct_2 is the values of these indicators after the effort.

In whole blood collected, the hematocrit (Hct) and haemoglobin (Hb.) were determined. The Hct used to calculate changes in plasma volume was determined by the micromethod using a Unipan centrifuge type MPW – 212H (Poland). The concentration of Hb (g/dL-1) in venous blood was determined with use of Drabkin method.

Statistical analysis

Statistical analysis was performed using Statistica 9.0 software. The Shapiro-Wilk test was used to assess the normality of the distribution of the continuous variable. Changes in indicators under the influence of applied pulsatile exercise, after confirming the normality of their distribution, were evaluated using multivariate analysis of variance and Tuckey's test (post-hoc test) or Student's t-test. Person's linear correlation coefficient was used to estimate the strength and direction of the relationship between the study variables. In addition, basic measures of descriptive statistics were used: arithmetic mean ($\bar{x}$), standard deviation (SD or ±). A test probability of $p<0.05$ was taken as significant.

RESULTS

Preliminary studies

Somatic indices

The average BH of the men was 178.0 ±6.31cm with an average BM of 76.26 ±12.57 kg. The average body surface area of the judokas studied was 1.88 ±0.17 m^2. The BMI was within the reference values. The male subjects were of very similar age (Table 2).

Anaerobic test – Wingate (LL, AA)

In the Wingate test with the lower extremities, the maximum anaerobic power (RPP) was 12.12 ±0.87 $W \cdot kg^{-1}$, and with the upper extremities

Table 2. General characteristics of the studied men.

Index [unit]	$\bar{x}$	SD
Age [years]	20.65	2.03
Seniority [years]	10.36	1.50
BM [kg]	76.26	12.57
BH [cm]	178.00	6.31
PBF [%]	16.03	2.44
LBM [kg]	64.00	10.42
BSA · BM [$cm^2 \cdot kg^{-1}$]	0.02494	0.00165
BSA [m^2]	1.88	0.17
BMI [kg/m^2]	23.95	2.58
BPS [mmHg]	117.73	4.67
BPD [mmHg]	76.82	4.62

Note: **BM** body mass; **BH** body height; **PBF** percentage body fat; **LBM** lean body mass; **BSA·BM** body surface area to body weight ratio; **BSA** body surface area; **BMI** body mass index; **BPS** systolic blood pressure; **BPD** diastolic blood pressure.

Table 3. Level of selected indices characterizing anaerobic capacity for lower (LL) and upper limbs (AA).

Index [unit]	LL		AA	
	$\bar{x}$	SD	$\bar{x}$	SD
PP [W]	933.00	216.13	536.09	107.73
RPP [W · kg^{-1}]	12.12	0.87	7.00	0.56
TW [kJ]	21.85	4.26	13.36	2.50
TW [J · kg^{-1}]	285.27	17.73	173.55	13.50
IPF [W · kg^{-1} · s^{-1}]	0.26	0.05	0.13	0.03
toPP [s]	4.43	0.88	5.61	1.08
tmPP [s]	3.25	0.76	4.15	1.06

Note: **PP** peak power; **RPP** relative peak power; **TW** total work; **IPF** power factor; **toPP** time to obtain peak power; **tmPP** time of maintaining peak power

it was 7.00 ±0.56 W · kg^{-1}. Total work (TW) in the test with the lower extremities was 21.85 ±4.26 kJ and with the upper extremities 13.36 ±2.50 kJ (Table 3).

Aerobic test (LL, AA)

The result of VO_2max measurement for the lower limbs averaged 43.23 ±7.79 ml · kg^{-1} · min^{-1}, l · min^{-1}, and for the upper limbs 37.19 ±5.26 ml · kg^{-1} · min^{-1}, l · min^{-1}. HRmax recorded in the graded test for the lower limbs averaged 185 ±8.19 bpm , and for the test for the lower limbs: 183 ±8.43 bpm. The time to reach VT2 averaged 11.50 ±3.09 min for the lower extremities and 8.32 ±2.99 min for the upper extremities. At the second ventilation threshold, the heart rate of contraction (HR_{VT2}) was 168 ±8.42 bpm (LL) and 162 ±8.75 bpm (AA). The percentage of oxygen uptake at the second ventilation threshold (%VO_{2max}) was 77.68 ±9.61% (LL) and 71.88 ±11.65% (AA), respectively. Detailed changes in physiological indices under the graded test are shown in Table 4.

Table 4. Level of selected indices characterizing aerobic capacity for lower (LL) and upper limbs (AA).

Index [unit]	LL		AA	
	$\bar{x}$	SD	$\bar{x}$	SD
		maximum values		
DE [min]	17.86	3.36	15.18	1.76
MWL [W]	273	33.25	141	10.49
VO_2max [l min^{-1}]	3.28	0.63	2.91	0.43
VO_2max [ml kg^{-1} · min^{-1}]	43.23	7.79	37.19	5.26
HRmax [bpm]	185	8.19	183	8.43
$V_E$max [l · min^{-1}]	131	36.30	114	21.94
FRmax [odd min^{-1}]	53.36	9.63	49.18	8.28
TVmax [L]	2.60	0.52	2.44	0.41
TW_{VO2max} [kJ]	204	55.03	93	15.02

Index [unit]	LL		AA	
	$\bar{x}$	SD	$\bar{x}$	SD
		values for vt2		
tVT2 [min]	11.50	3.09	8.32	2.99
HR_{VT2} [bpm]	168	8.42	162	8.75
WL_{VT2} [W]	204.55	31.10	100.36	16.34
HRmax [%]	90.70	5.49	88.54	4.75
VO_2max [%]	77.68	9.61	71.88	11.65
TW [kJ]$\downarrow_{VT2}$	110.21	43.14	45.91	18.83
TW [kJ]$\uparrow_{VT2}$	94.25	38.87	50.68	13.62

Note: **DE** duration of incremental exercise; **MWL** maximum work load; **VO_2max** maximum oxygen uptake; **HR_{max}** maximum heart rate; **VEmax** maximum minute ventilation; **FRmax** maximum respiratory rate; **TVma**x maximum tidal volume; **TW_{VO2max}** total work in the incremental test; **tVT2** time to reach the second ventilatory threshold; **HR_{VT2}** heart rate at the ventilatory threshold; **WL_{VT2}** power output at the threshold; **TW $\downarrow_{VT2}$** work done up to the threshold; **TW $\uparrow_{VT2}$** work done above the threshold

Results of the main tests

The tested athletes, during five series of pulsed efforts, performed work (∑TW) of 2895.21 kJ (at 21°C ambient temperature) and 2928 kJ (at 31°C). There were no statistically significant differences between ∑TW at the two temperatures (Table 5).

The initial average body weight of the judokas tested at 21°C was 74.68 kg, and at 31°C: 74.87 kg. After performing pulsatile exercise, the values were 73.70 kg and 73.31 kg, respectively. As a result of exercise dehydration at 21°C and 31°C, there was a statistically significant reduction in body weight ($p<0.05$). However, there was no statistically significant difference between the BM values recorded after a series of exercise at 21°C and 31°C (Figure 3).

Physical exertion performed at both room and elevated ambient temperatures led to a statistically significant increase in Tre ($p<0.05$). In the former case, the increment (ΔTre) was 0.71°C,

Table 5. Total work and its sum in upper limb ($\sum TW_{AA}$) and lower limb ($\sum TW_{LL}$) tests in individual series of pulse exercise and the global value of its sum (∑TW) in pulse exercise performed at 21°C and 31°C.

Series	21°C			31°C		
	TW_{LL} [kJ]	TW_{AA} [kJ]	∑TW [kJ]	TW_{LL} [kJ]	TW_{AA} [kJ]	∑TW [kJ]
I	386.60	220.63	607.23	386.91	224.36	611.27
II	367.74	212.39	580.13	375.57	214.65	590.22
III	352.42	212.33	564.75	365.22	207.35	572.57
IV	350.30	218.09	568.39	367.58	213.30	580.88
V	349.70	225.01	574.71	358.41	214.65	573.06
∑	**1806.76**	**1088.45**	**2895.21**	**1853.69**	**1074.31**	**2928.00**

Note: **TW_{LL}** total work lover limbs; **TW_{AA}** total work upper limbs; **∑TW** total work done while in the latter it was 0.86°C. No statistically significant difference was noted between Tre values recorded after a series of efforts at 21°C and 31°C (Figure 4).

The mean value of skin temperature recorded before the series of pulsatile exercise at 21°C and 31°C were, respectively: 30.33 ±0.72°C and 31.40 ±0.72°C; after exercise, the values were 31.07 ±0.46°C and 31.64 ±0.38°C, respectively. Statistical analysis indicated that the results differed significantly. The effect of temperature was indicated only for room temperature (21°C). It was also indicated that the baseline results obtained were significantly different (p = 0.030), with the same level of confidence the post-exercise results differed.

PSI and CHSI values were statistically significantly higher for exercise performed at 31°C (Table 6).

The degree of inconvenience of work at the two tested ambient temperatures as assessed by the Borg scale did not differ statistically significantly (Figure 5).

Figure 3. Body weight (BM) values before and after a series of pulsed efforts at different ambient temperatures. *Note*: significant differences (p<0.05) between individual measurements: *21°C; #31°C

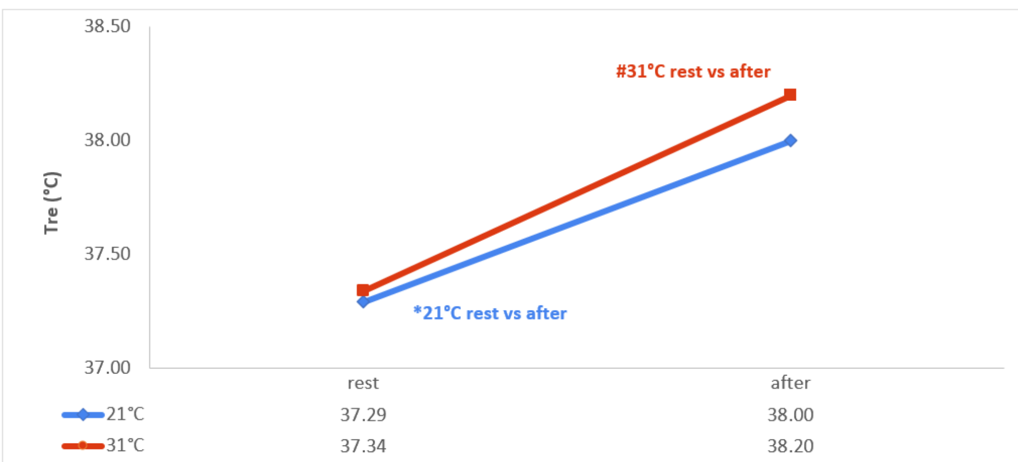

Figure 4. Rectal temperature (Tre) values before and after a series of pulsatile efforts at different ambient temperatures. *Note*: significant differences (p<0.05) between individual measurements: *21°C; #31°C

Table 6. Changes in heat stress indices PSI and CHSI (pts.) under a series of pulsatile exercise performed at ambient temperatures of 21°C and 31°C

Index [points]	$\bar{x}$		SD		t	p
	21°C	31°C	21°C	31°C		
PSI	6.49	6.93	0.50	0.52	–5.77	<0.05
CHSI	268.30	407.50	124.58	121.33	–3.82	<0.05

Note: **PSI** physical strain index; **CHSI** cumulative heat strain index

Changes in plasma volume (ΔPV%) were not significantly different between 21°C and 31°C. Due to the large SD values, no significant differences were indicated between consecutive time points (Figure 6).

The initial mean systolic blood pressure of the judokas tested at 21°C was 121.50 ±9.44 mmHg and at 31°C was 119.5 ±8.96 mmHg; at the end of the pulsatile exercise, the values were 114.5 ±12.35 mmHg and 121.5 ±9.44 mmHg, respectively. Statistical analysis indicated no significant differences.

Diastolic blood pressure was 77.00 ±6.75 mmHg and 78.50 ±5.30 mmHg (for 21 and 31°C, respectively) in the judokas at baseline, and changed after exercise to 71.00 ±8.76 mmHg and 67.00 ±9.19 mmHg, respectively. There were statistically significant differences (p<0.05) in BPD only for exercise at 31°C (Figure 7).

DISCUSSION

Understanding the effect of high temperature on the body's recovery capacity will enable more effective periodization of the training process (see glossary) for sporting events performed at high ambient temperatures, so as to optimize the body's potential for exhaustive work. The search for and development of new training models is still a priority for combat sports coaches [25, 26].

The exertional nature of judo athletes during sports competition forces them to have comprehensive physical preparation for effective combat [27]. Existing laboratory tests, assessing physical performance, allow to determine the efficiency of energy-glycolytic, phosphagenic and aerobic processes. This provides trainers with the opportunity to compare the exercise capacity of athletes, monitor the dynamics and direction of changes in the training macrocycle [6, 28]. Due to the technical limitations of the aforementioned laboratory

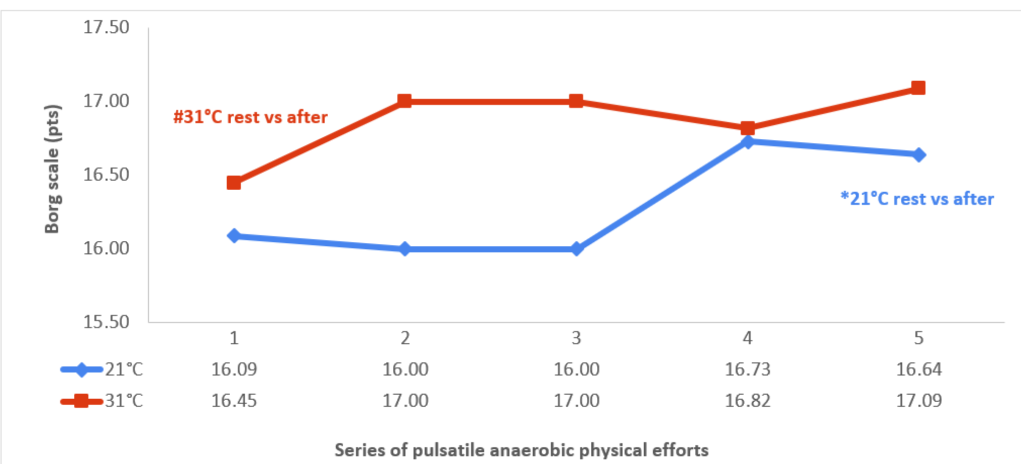

Figure 5. Degree of work annoyance (points) according to the Borg scale in individual measurements at 21°C and 31°C. *Note:* significant differences (p<0.05) between individual measurements: *21°C; #31°C

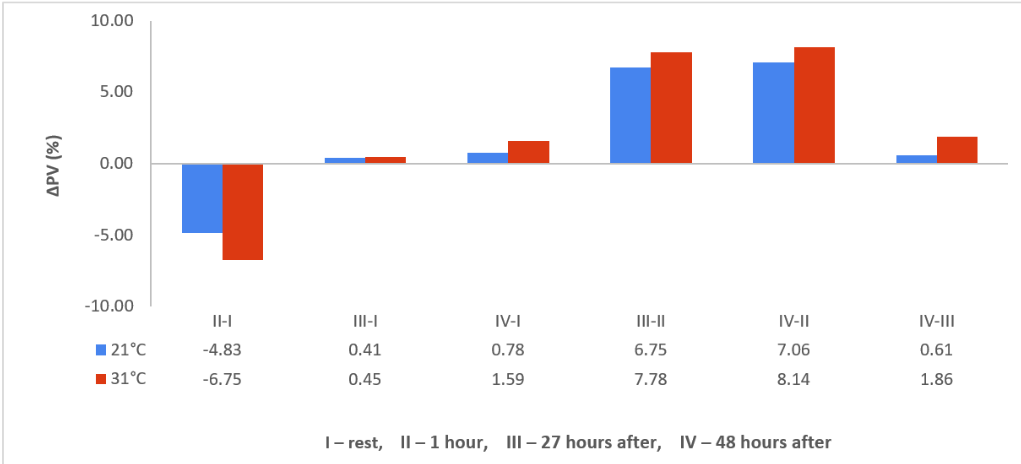

Figure 6. Comparison of changes in plasma volume (ΔPV%) in individual measurements between athletes performing pulse exercise series at different ambient temperatures.

Figure 7. Mean values of diastolic blood pressure, (BPD; mmHg) recorded before and after a series of pulsatile efforts at 21°C and 31°C.
Note: significant differences ($p<0.05$) between individual measurements: *21°C; #31°C

tests, they are generally performed at room temperature, where the athlete's body is charged only with endogenous heat. In the available literature, there is little information about the exercise physiological and biochemical responses of the body when performing such tests at elevated ambient temperatures. Under such conditions, the athlete's body must cope with accumulated heat of exogenous and endogenous origin.

In judokas, exercise tests are not highly specific due to the fact that they are most often performed on foot ergometers. In the present study, an alternating work variant was used using a cycloergometer for the lower (LL) and upper (AA) extremities. The sequence of anaerobic interval workouts included both the time structure of a single judo bout and tournament bouts. Such an effort, although it does not reflect the actual loading of the body as in a fight on the mat, is largely similar to it. Applied to the athletes, the series of pulsatile anaerobic efforts on the foot and hand ergometer attempted to mimic single and tournament judo bouts in terms of time and intensity [6, 28].

The mean values of total work performed with the lower limbs (TWLL) and upper limbs (TWAA) and the mean values of total work performed with the lower and upper limbs (TTW) showed no statistically significant differences between the individual series, separately at 21°C and 31°C, and between 21°C and 31°C, separately in the individual series. This pattern of results indicates that the series of pulsatile efforts at room and elevated ambient temperatures affect the fatigue processes in the body of the tested athletes to the same extent. This is manifested by a statistically insignificant difference in the sum of total work performed at 21°C and 31°C, amounting to only 1.12%. Tracking changes in phosphagenic and glycolytic power in repeated anaerobic exercise enables analysis of energy metabolism under combat conditions, as pointed out in their study by Lech et al. [6, 28] showing a high correlation between maximum power and the amount of work performed and the effectiveness during the fight. The results of our own study of a series of pulsatile efforts present important information about the anaerobic endurance capacity of judokas, as well as information about the course of fatigue accumulation processes and the rate of restitution of the subjects.

The influence of the thermal factor on physical performance is very significant both in a positive and negative sense [29]. Physical exercise, including exercise undertaken at elevated ambient temperatures, is accompanied by an increased rate of metabolic processes and endogenous heat production [30, 31]. Prolonged heat stress leads to increasing dehydration of the body, as seen in our study, where body weight loss was considered a measure of dehydration, which was greater in athletes performing exercise at 31°C. After a series of pulsatile efforts at 21°C, body weight decreased by an average of 0.980kg (1.31%), and at 31°C by 1.560kg (2.08%). The change in body weight, recorded in our own study, induced by exercise at elevated ambient temperatures was probably related to the loss of body water due to increased sweat production. In its wake, there may have been a change in the effective molality of body fluids and an increased transfer of water from the intracellular space to the extracellular space and then to the sweat glands. This mechanism is also confirmed by other studies [30, 32]. It is worth noting that even a small loss of water, on the order of 2% of body weight, can reduce exercise tolerance [17] and negatively affect the body's cognitive function and regenerative abilities [33, 34]. The loss of electrolytes as well as the decrease in the volume of body fluids associated with intense sweating leads to an increase in physiological stress and, consequently, to an even greater increase in the body's heat load [35].

The increase in rectal temperature occurs with the production of endogenous heat, which is induced by undertaking physical labour. This increase can be exacerbated by the limited thermoregulatory capacity caused by the increased ambient temperature. Such conditions impair most of the effective ways of removing heat from the body. The results of our own research confirm other studies [36, 7], in which the authors proved that Tre increases with exercise duration and can reach values above 38°C and even 40°C. In our study, Tre among the tested athletes increased by an average of 0.71°C during a series of pulsatile efforts performed at 21°C, and by 0.86°C at 31°C. The increase in internal temperature in both cases led to the activation of thermoregulatory mechanisms, which led to the loss of water resources of the body.

Weight loss was caused by dehydration of the body of the judokas under study induced by physical exercise, as well as thermal stimulus of exogenous origin and reduction of plasma volume. In the study, subjects performed sedentary exercise at two different ambient temperatures, where a series of pulsatile efforts led to negligible changes in plasma volume. Noteworthy is the fact that physical work performed at 31°C led to a greater degradation of plasma water resources (by 1.92%) compared to exercise performed at 21°C. After 24 hours, water resources were close to resting levels. As noted in other studies, the magnitude of the reduction in plasma volume is somewhat of an exponent of adaptation to exercise especially under thermally unfavourable environmental conditions, and is indicative of the efficiency of heat elimination from the athletes' bodies [32, 13].

Physical exertion, which can be considered a specific form of stress, affects almost all systems in the human body. A very sensitive indicator for determining the degree of physiological stress is the PSI index [14] and CHSI [15] based on heart rate and rectal temperature. In our study, the PSI and CHSI values were statistically significantly higher for exercise performed at 31°C. Due to the above fact, it is so important to assess physiological load in the context of determining physiological endurance and protection against excessive thermal stimulus on the body, as has also been shown in other studies [15, 37].

Workload as expressed by an objective index does not always correlate with the subjective feelings of a person exposed to increased temperature and exertion. Therefore, the present study also used a subjective assessment of feelings of workload [21]. During physical exertion at the analysed ambient temperatures, the athletes studied indicated similar feelings of workload. This indicates that the thermal environment did not modify subjective feelings of strenuousness with physical work.

It is worth noting that dehydration begins to interfere with aerobic capacity when skin temperature exceeds 27°C, and each successive increase in skin temperature of 1°C further reduces capacity by almost 2% [12]. In our study, the mean value of skin temperature recorded before the series of pulsatile exercise at 21°C and 31°C were, respectively: 30.33 ±0.72°C and 31.40 ±0.72°C, while after exercise the values were 31.07 ±0.46°C and 31.64 ±0.38°C, respectively. Lower values of weighted average skin temperature were observed in the conditions of feeling comfortable by the judokas studied than in the conditions of feeling hot. Which confirms other reports that air temperature influences the value of skin temperature, and the lower values obtained for greater physical exertion are the result of the thermoregulatory system [38, 39].

Accompanying water loss, a reduction in plasma volume can be important for maintaining normal cardiovascular function and preserving proper blood flow. The reduction in plasma volume induces a significant increase in blood viscosity, forcing the heart to work harder to pump sufficient amounts of blood [40]. In our study, the initial mean value of diastolic blood pressure of the judokas studied at 21°C and 31°C was higher than the final value. In addition, statistically significant differences were shown for the mean value of diastolic blood pressure at 31°C in the judokas studied. This was probably due to a decrease in plasma volume. As a result, there was a decrease in blood pressure. Other findings confirm that a decrease in plasma volume results in a decrease in blood flow to contracting muscles, resulting in altered muscle cell metabolism and impaired thermoregulation, especially in hot environments [13, 41, 42].

Based on the results, it can be assumed that physical exercise under different thermal conditions of the external environment activates the response of the body to a different degree, with the direction of changes depending on the external thermal factor. In order to increase the tolerance of the body to thermal and exercise stress, it is reasonable in professional judokas to conduct training under different thermal conditions of the environment.

Although one of the tools used in this experiment (Borg's Perceived Exertion And Pain Scales [21]) concerns the mental sphere, the knowledge obtained is mainly related to the somatic aspect of the health of people practicing judo. Moreover, the recommendations from this work are also dedicated to the effectiveness of judo training from the perspective of professional sports. It will not be an exaggeration to say that this aspect (somatic health of judo athletes in relation to the effectiveness of sports selection and training) is dominated in the global scientific space by the number of reports from experimental studies and longitudinal observations. For example: changes in general physical fitness [43-45] and/or physical capacity [6, 28, 27, 46, 47] under the influence of many years of training of juvenile and adult judo practitioners. Only as a side note, we note a significant number of publications regarding trends in tactical and technical solutions during tournament fights, which are determined either by changes in regulations or modifications in training (these phenomena are interconnected) [e.g. 48-50].

However, sticking to the aspects of health in relation to the selection and effects of sports training, we separately emphasize the phenomenon of body balance, because not all of the recommended tests take into account this coordination ability. Therefore, the results of research in which the authors use various tests and associate the results not only with the effectiveness of judo fighting are inspiring [51-63].

However, in our opinion, what is most worth emphasizing is the fact that the deceased, distinguished members of the Editorial Board of *Archives of Budo* focused on promoting judo in a sustainable way, in accordance with the message of Jigoro Kano [63, 64] and his universal conclusion that the most important thing is 'judo in the mind' [65-67]. The promoters of this dimension of judo included Ewaryst Jaskólski (1932-2007) [68] and Josef Herzog (1928-2016) [69]. Waldemar Sikorski (1937-2022), on the other hand, consistently implemented the maxim 'science to practice judo' in his coaching and scientific life [70]. This direction of thinking is extended by its continuators, especially the 'scientific school of Ewaryst Jaskólski' [68], to other combat sports qualified to the philosophy and practice of budo [71-73]. This is a very important scientific activity from the perspective of the expansion of neo gladiatorialism [74-76].

CONCLUSIONS

Different ambient thermal conditions do not affect the volume of work performed in pulsatile anaerobic exercise, which does not support the view represented by some researchers about the effect of ambient temperature on anaerobic capacity. The tested athletes tolerated the thermal load well and their subjective assessment of the strenuousness of the work, did not differ in the ambient temperatures used. The greater weight loss, and thus dehydration, observed in athletes after exercise at elevated ambient temperatures may be related to a widening of their capillary network in both muscle and skin, influenced by years of training, which also increases the body's water percentage which promotes sweat transpiration.

In order to increase the body's tolerance to heat and exercise stress, it is reasonable in professional judokas to conduct training under various ambient thermal conditions.

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Cite this article as: Pałka T, Rydzik Ł, Witkowski K et al. Heat stress levels in judokas during a special performance test conducted at two different ambient temperatures. Arch Budo 2023; 19: 165-181