The effect of prolonged thermal stress on the physiological parameters of young, sedentary men and the correlations with somatic features and body composition parameters

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Title page

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Abstract

Little is known about the effect of prolonged thermal stress on the physiological parameters of young and sedentary men. The aim of the study was to determine the effect of prolonged thermal stress on the physiological parameters of young men and the correlations with somatic features and body composition parameters. Forty-two sedentary men aged 20.24±1.68 years were exposed to 10-, 12- and 14-minute sauna sessions (temperature: 90-91^{o}C; relative humidity: 14-16 %). The participants' body composition parameters were determined pre-sauna exposure, and their body mass and blood pressure were measured pre and post-sauna treatment. Physiological parameters were monitored during each sauna session. Heart rate, energy expenditure, oxygen uptake, excess post-exercise oxygen consumption, respiratory rate, and blood pressure differed significantly between 10-, 12- and 14-minute sauna sessions. The increase in physiological parameters during sauna sessions (10, 12 and 14 minutes, respectively) was not significantly correlated with somatic features or body composition parameters. The only exception were the values of blood pressure (systolic and diastolic), which were significantly correlated with body mass, body mass index, body surface area, waist-hip ratio and the initial values of blood pressure pre-sauna exposure. Every additional two minutes of exposure to thermal stress induces significant changes in the physiological parameters of young and sedentary men. Whilst changes in physiological parameters following heat exposure are not significantly correlated with somatic features or body composition parameters, excluding blood pressure. Given the marked physiological changes observed in this study, it is recommended that sauna bathing of longer durations be investigated in order to elucidate the thermal stress response among varying body types.

Introduction

In recent decades, sauna has emerged as a popular physiotherapeutic and wellness treatment, not only in sports, but also in recreational fitness activities (Podstawski et al., 2013). This type of physical activity is particularly popular in Scandinavia, and across the life span. Sauna bathing is colloquially known for its health enhancing benefits, with a large proportion of, particularly, Scandinavians' utilizing sauna baths at least once a week for the purpose of health improvement (Kukkonen-Harjula and Kauppinen, 2006). Studies concerning the popularity of sauna in Poland, albeit only in university students, have reported that although sauna treatment exerts a positive influence on students' well-being, its' usage remains relatively sporadic (Podstawski et al., 2013). Moreover, sauna is more often used by students (women and men) of higher socioeconomic status and within densely populated areas, where access to such places is easier (Podstawski et al., 2015; Podstawski et al., 2016).

There are many indications for sauna therapy, and most studies investigating the benefits of, and indeed contraindications, to sauna bathing have been conducted in Finland, since the late 1970s (Kukkonen-Harjula and Kauppinen, 2006; Kosunen et al., 1976; Luurila, 1980; Eisalo A, Luurila, 1988; Helamaa and Aikas, 1988; Kauppinen, 1989a, b, c; Kauppinen and Voori, 1986; Leppäluoto et al., 1986; Vuori, 1987; 1988; Hannuksela and Ellahham, 2001; Koljonen, 2009).

In a sauna, exposure to high temperature and low humidity exerts physiological effects on bodily systems and organs; activating thermoregulatory mechanisms which induce reactive changes in the body (Podstawski et al., 2014; Podstawski et al., 2016b). The exposure to heating (heating phase) and cooling (cooling phase), respectively, stimulates different processes in the human body. During the heating phase, the cardiovascular system is exposed to thermal stress, causing vasodilation, increased blood perfusion, and tachycardia, which stimulates perspiration (Podstawski et al., 2014; Podstawski et al., 2016b). The heart rate (HR) of sauna bathers has been shown to double in response to heat, whilst cardiac output can increase by 70% relative to rest values, and peripheral vascular resistance decrease by approximately 40% (Podstawski et al., 2014; Podstawski et al., 2016b). An increase in diastolic blood pressure and mean arterial pressure is also observed, whereas systolic blood pressure remains relatively invariant (Kukkonen-Harjula and Kauppinen, 2006, Kauppinen, 1989a). The physiology of the cardiac conduction system is modified as an artefact of the temperature in the sauna. Skin temperature ranges from 40ºC, during the heating phase, to 33ºC, during the cooling phase after immersion in cold water.

The body must dispose of sauna-induced heat to prevent an excessive rise in body temperature (hyperthermia). The above can be achieved with the involvement of several mechanisms, where the evaporation of sweat from skin surface plays the most important role (Brouns, 1991).

The exposure to high temperature in a sauna activates various bodily systems, including the endocrine system, which promotes the secretion of adrenalin (Kukkonen-Harjula and Kauppinen, 2006; Leppäluoto et al., 1986; Leppäluoto et al., 1991; Jezová et al., 1994; Pilch et al., 2003; Pilch et al., 2008; Pilch et al., 2010), adrenocorticotropic hormone (ACTH), cortisol and prolactin as the body becomes acclimatized to high temperature (Pilch et al., 2005). The endocrine system is activated to retain more water in the body and maintain thermal equilibrium, whilst perspiration decreases sodium serum levels in the body (Kauppinen, 1989a, b). Sauna use is also shown to decrease total cholesterol and low-density lipoprotein levels, and it increases the concentration of high-density lipoproteins (Pilch et al., 2010). There is evidence to indicate that sauna bathing can be effectively incorporated into depuration (purification or cleansing) protocols for the treatment of lifestyle diseases (Crinnion, 2011). Scoon et al. (2007) and Ernst et al. (1986) demonstrated that a 3-week course of post-exercise sauna bathing enhanced endurance running performance, attributing this to increased blood volume. Blood volume increases when blood is released from other organs, including the kidneys, and when more erythropoietin is released into the blood stream (Pagel et al., 1988); which, in turn, increases peripheral blood flow, promotes blood flow to the working muscles, and, consequently, improves endurance capacity (Ridge and Pyke, 1986; Luetkemeier and Thomas, 1994).

It is generally acknowledged that regular sauna visits can improve physical and mental well-being as well as vascular and cardiac functions (Beever, 2010; Biro et al., 2003). Sauna benefits have previously been studied in the general population as well as in persons suffering from exercise-induced muscle pain, soreness, myocardial ischemia and heart failure (Laukkanen et al., 2018; Blum & Blum, 2007; Miyamoto et al., 2005). Further, sauna baths facilitate the treatment of locomotory manifest inflammation, nonspecific ailments of the upper respiratory system (Imamura et al., 2001, Tei et al., 1995; Tei et al., 1996), and sport-induced injuries (Biro et al., 2016; Kihara et al., 2002). Regular exposure to sauna bathing purportedly relieves pain associated with injuries of the musculoskeletal system and improves mobility of joints in patients suffering from rheumatism (Oosterveld et al., 2009).

The effect of prolonged thermal stress on physiological parameters and their relationship with somatic features and body composition parameters are hitherto unexplored in sedentary individuals sporadically using sauna. Therefore, the aim of this study was to evaluate the effect of prolonged thermal stress on physiological parameters, and to investigate their relationship with somatic features and body composition parameters in young men with low, habitual levels of physical activity (PA).

Materials and Methods

Participants

Forty-two male university students aged 19-24 (20.24±1.68 years) volunteered to participate in the study. The participants were informed about the purpose of the study during obligatory physical education (PE) classes at the University of Warmia and Mazury in Olsztyn. The participants attended only mandatory PE classes (90 min per week), they did not participate in any extra-curricular PA programs and had used sauna baths sporadically before the study. The evaluated participants did not take any medication or nutritional supplements, were in good health, had no history of diseases affecting biochemical and biomechanical factors. None of the evaluated participants had respiratory or circulatory ailments. Participants' PA levels were evaluated using the Polish short version of the standardized and validated International Physical Activity Questionnaire (IPAQ) (Biernat et al., 2007). The IPAQ was used only to select a homogenous sample of male students, and the results were presented only in terms of Metabolic Equivalent of Task (MET) units indicative of the participants' PA levels. The participants declared the number of minutes dedicated to PA (minimum 10 minutes) during an average week preceding the study. The energy expenditure associated with weekly PA levels was expressed in terms of Metabolic Equivalent of Task (MET) units, where the MET is the ratio of the work metabolic rate to the resting metabolic rate, and 1 MET denotes the amount of oxygen consumed in 1 minute, which is estimated at 3.5 mL/kg/min. Based on the frequency, intensity and duration of PA declared by the surveyed students, the respondents were classified into groups characterized by low (L < 600 METs-min/week), moderate (M < 1,500 METs-min/week) and high (H ≥ 1,500 METs-min/week) levels of activity. Only male students with low levels of PA (energy expenditure of up to 600 METs per week) and a sedentary lifestyle were chosen for the study. Prior to research commencing, written and informed was attained from all participants. This research was conducted in agreement with the guidelines and policies of the University of Warmia and Mazury in Olsztyn (UWM), Poland, ethics committee, and in accordance with the Declaration of Helsinki.

Instruments and procedures

The participants received comprehensive information about sauna rules preceding the study. They were instructed to drink at least one litre (L) of water on the day before the test and 0.5 L of water 2 hours before the test. During the studies every participant visited the dry sauna three times during PE classes, on the same day and in the same location, at two-week intervals. The time frame of the study was designed to avoid significant changes in somatic features and body composition parameters. During each of the three sessions, the participants remained in the sauna (temperature: 90-92^{o}C; relative humidity: 14-16 %) in a seated position for 10, 12 and 14 minutes. After each session, the participants cooled down in the neutral compartment with a temperature of 18-20°C. Every cool-down break lasted 5 minutes, during which the participants took a shower set to a temperature of 14-15°C. They could also cool down in a paddling pool (pool width: 100 cm; pool depth: 130 cm; water temperature: +10^{o}C). Temperature and humidity inside the sauna room and water in the shower were measured by means of the VOLTCRAFT hygrometer BL-20 TRH + FM-200, and the accuracy of temperature parameters was verified using a laser thermometer (STALGAST 620711).

Body height was measured to the nearest 0.1 mm with a stadiometer, and nude body mass was measured to the nearest 0.1 kg with a calibrated WB-150 medical scale (ZPU Tryb Wag, Poland) prior to the first sauna session. Blood pressure (BP) was determined with an automatic digital blood pressure monitor (Omron M6 Comfort, Japan) immediately before the first session and during every cool-down break in the neutral compartment. Somatic features, including body mass, body mass index (BMI), body surface area (BSA) and the waist-hip ratio (WHR), and body composition parameters, including body mass, total body water (TBW), protein and mineral content, body fat mass (BFM), fat-free mass (FFM), skeletal muscle mass (SMM), percent body fat (PBF), InBody score, target weight, visceral fat level (VFL), basal metabolic rate (BMR) and degree of obesity, were determined by bioelectrical impedance (Gibson et al., 2008) with the InBody 720 body composition analyzer. Due to high temperature in the sauna, physiological parameters, including heart rate ($HR_{min, avg, max}$), recovery time, peak training effect (PTE), energy expenditure, oxygen uptake ($VO_{2\ avg, max}$), excess post-exercise oxygen consumption ($EPOC_{avg, peak}$), respiratory rate ($_{avg, max}$) and physical effort (easy, moderate, difficult, very difficult, maximal), were measured indirectly with Suunto Ambit3 Peak heart rate monitors which are widely used in studies of the type (Scoon et al., 2007). Every pulsometer was calibrated to male sex, year of birth, body mass and PA level before sauna exposure.

Statistical analysis

Measurement results were processed statistically in the Statistica PL v. 13.5 application with the use of descriptive statistics. The arithmetic means of the parameters measured after each sauna session were determined by one-way (univariate) analysis of variance (ANOVA). The Least Significant Difference (LSD) post-hoc test was performed when the F value was statistically significant. The above test is particularly recommended for planned repetitive experiments or longitudinal data with equal group size. The direction and strength of the relationships between interval features were determined by calculating Pearson's correlation coefficient (*r*). Statistical significance was accepted at $P \leq 0.05$.

Results

Descriptive statistics of participants height, weight and BMI are detailed in Table 1. 76% of the participants exceeded a BMI of 25 kg/m^2, ranging from 19.34 – 40.23 kg/m^2. The waist-hip ratio (0.90) approximated the upper limit of the healthy range (WHR>0.95) and was not indicative of android obesity (WHR ≥1), with relatively high values of VFL (7.88 kg) and high degree of obesity (122.43). According to the percent body fat scale (Cafri et al., 2004), the evaluated participants (PBF=21.88%) belonged to the ‘potential risk’ group (19.0-24.0%), which was confirmed by their BFM values (19.62 kg). The target weight (79.20 kg) calculated for the participants with an average body mass of 86.72 kg indicates that the students should lose 7.52 kg of BFM to achieve a healthy body mass. High BFM values were accompanied by relatively high values of SMM and FMM (38.23 and 67.10 kg, respectively), whereas the average values of systolic (SBP) and diastolic blood pressure (DBP) were within the norm (126.62 and 81.67, respectively). The average PA level was 509.17±74.3 MET.

*****Table 1 here*****

Heart rate increased with prolonged sauna use (10, 12 and 14 min) (Table 2). The values of HR_{min}, HR_{avg}, and HR_{max} differed significantly ($p<0.001$) between 10- and 12-minute sessions and between 12- and 14-minute sessions, whereas significant differences between 12- and 14-minute sessions were observed only for the values of HR_{max}. As a result, the recommended recovery time increased significantly ($p<0.001$) to 0.17 h after a 10-min session, 0.86 h after a 12-minute session, and 1.29 h after a 14-minute session. The volunteers expended an average of 72.86 kCal after a 10-minute session, 104.21 kCal after a 12-minute session, and 125.24 kCal after a 14-minute session ($p<0.001$). The average values of VO_{2avg} and VO_{2max} differed significantly between 10- and 12-minute sessions and between 10-minute and 14-minute sessions ($p<0.001$), whereas significant differences between 12- and 14-minute sessions were noted only in the values of VO_{2max} ($p<0.009$). The same trend was observed in the values of $EPOC_{avg}$ and $EPOC_{peak}$ ($p<0.001$), excluding the difference in the values of $EPOC_{peak}$ (0.008) between 12- and 14-minute sessions. Prolonged sauna bathing significantly increased respiratory rates $_{avg,\ max}$ between 10- and 12-minute sessions and between 10- and 14-minute sessions ($p<0.001$). There was no significant difference observed in respiratory rate between 12- and 14-minute sauna sessions. The average values of SBP and DBP were within the norm in all cases (10-, 12- and 14-minute sessions), and the maximum values were determined at 145, 150 and 143 mmHg, respectively. Significant changes in SBP and DBP were noted only between 10- and 12-minute sessions ($p<0.043$ and $p<0.039$, respectively). During the 10-minute session, the most frequent HR readouts were within the easy effort range (469.6 s), with instances noted in the moderate effort range (128.8 s). The number of HR readouts within the moderate effort range (341.4 s) was higher than within the easy effort range (304.5 s) during the 12-minute session, whereas the reverse was noted during the 14-minute session (easy effort - 365.7 s; moderate effort - 348.2 s). However, the differences observed in both cases (12- and 14-minute sessions) were smaller than during the 10-minute session. HR readouts indicative of maximal effort were not noted in any of the studied sessions, and readouts indicative of very difficult effort were not observed during the 10-minute session (Table 2).

*****Table 2 here*****

The correlations between the increment in physiological parameters during each sauna session and body composition parameters relating to adipose tissue (body mass, BMI, BSA, WHR, PBF, BFM, FFM, VFL and obesity degree) were also analyzed. Significant correlations were not determined, which suggests that the noted increase in physiological parameters (Table 2) was not linked with body composition.

Comparable results were obtained in an analysis of the correlations between anthropometric features and physiological parameters (Table 3), where a significant positive correlation was found only with blood pressure (SBP, DBP), regardless of the length of stay in the sauna. It should be noted that the correlations with systolic blood pressure were stronger than the correlations with diastolic blood pressure in all cases. The length of stay in the sauna did not differentiate the values of the correlation coefficient.

*****Table 3 here*****

Discussion

The results of this study provide novel and valuable insights into physiological parameters of young men with a sedentary lifestyle sporadically using sauna. Prolonged sauna bathing significantly increased all HR values between 10- vs. 12- and 14-minute sessions, and HR_{max} values between 12- and 14-minute sessions, respectively. During successive sessions, the values of HR_{avg} were determined at 97.38, 108.31 and 108.81 bpm, respectively, indicative of easy physical effort (< 107 bpm) during the 10-minute sauna session and of moderate effort

(107 – 124 bpm) during 12- and 14-minute sessions. The values of HR_{max} were determined at 130 (difficult effort), 148 and 149 bpm (very difficult effort) during 10-, 12- and 14-minute sessions, respectively.

In young people who regularly use the sauna, HR increases to around 100-110 bpm, and can exceed 140-150 bpm with a rise in ambient temperature (Luuira, 1980; Kaupinen and Vuori, 1986; Leppäluoto et al., 1986; Leppäluoto et al., 1991; Tei et al., 1995; Hasan and Karvonen, 1967; Sohar, 1976; Lamintausta et al., 1976). Greater HR increases are also noted in individuals who do not visit a sauna on a regular basis, which can be attributed to the absence of adaptation to high temperature (Leppäluoto et al., 1986). The rise in HR values is also affected by other factors, including the duration of the sauna session, the bathers' age, sex and physical fitness level (Sawicka et al., 2007). An increase in HR to around 120 bpm is regarded as a beneficial adaptive response, whereas an increase in excess of 140 bpm is asserted to have adverse consequences because it is associated with higher cardiac demand and diastole shortening (Sawicka et al., 2007). In the present study, such deleteriously high values of HR_{max} were noted during 12- and 14-minute sessions, notwithstanding, the increase in the values of $HR_{min, avg, max, max-min}$ was not correlated with the length of stay in the sauna. The number of HR readouts within the difficult effort range (125 – 141 bpm) increased significantly with prolonged exposure to thermal stress. During 10-, 12- and 14-minute sessions, the highest number of HR readouts was noted within the easy (< 107 bpm) and moderate effort range (107-124 bpm).

The average HR values measured immediately before sauna exposure were relatively high at 82.67 bpm, which is suggested to be an acute adaptation to minor thermic stress (Podstawski et al., 2013; Podstawski et al., 2016a). The average HR values (82.7 bpm) pre-sauna exposure in men, who did not train professionally and visited a sauna sporadically, were also elevated and significantly higher than in men with average and high training levels (71.8 bpm and 68 bpm, respectively), who were regular sauna users (Chorąży and Kwaśny, 2005). During a 30-minute stay in the sauna (3 sessions of 10 minutes each with 5-minute breaks; temperature: 83°C; humidity: 12-14%), Chorąży and Kwaśna (2005) noted that the HR values of sedentary men increased to 119.9 bpm, whereas in the participants with average and high training levels, the analyzed parameter was determined at 107 and 83.6 bpm, respectively. Pilch et al. (2005) compared the HR values of 10 professional swimmers and 10 untrained students (aged 20-23 years). Following three 15-minute sauna sessions with 5-minute breaks (temperature: 92.3°C, humidity: 27.4%), the participants' HR values increased from 74 and 80 bpm to 133 and 144 bpm, respectively, after the third session.

Notwithstanding, the aforementioned, cited studies are difficult to compare with our results because they involved prolonged sauna sessions (30-45 minutes), were conducted under different conditions and on participants with different characteristics. Moreover, the noted HR values were not significantly correlated with anthropometric features and body composition parameters. These findings suggest that sauna use (temperature: 90-92ºC; relative humidity: 14-16 %) for 10 to 14 minutes is significantly correlated with the duration of thermal stress, but not with somatic features or body composition parameters. In our study, we noted that exposure to thermal stress also exerted a significant effect on the remaining physiological parameters, including energy expenditure, $VO_{2\ avg, max}$, $EPOC_{avg, peak}$ and respiratory rate $_{avg, max}$. The changes in the above parameters, in successive sauna sessions, were not significantly correlated with somatic features or body composition parameters. Whereas physiological parameters increased significantly with prolonged exposure to thermal stress in the analyzed time intervals. According to Kauppinen (1989c), physiological processes reach peak levels after approximately 15 minutes of sauna bathing, therefore, it is conceivable that sauna sessions of 10 to 14 minutes in duration could have been too short to elicit such a response.

Blood pressure (SDP and DBP) values differed from the remaining physiological parameters. Significant differences in SBP and DBP were noted only between 10- and 12-minute sauna sessions (128.86/83.10 and 132.81/86.14, respectively). In men, with various training levels (high, average and men who did not train professionally), SBP values increased (from 125.7 to 133, 121.5 to 129.6, and 113.4 to 119.4 mmHg, respectively) and DBP values decreased (from 73.47 to 69.4, 75.6 to 73.5, and 71.4 to 70.1 mmHg, respectively) during sauna bathing (Chorąży and Kwaśny, 2005). In Pilch et al. (2014), three 15-minute sauna sessions separated by 5-minute breaks (temperature: 9.23°C, humidity: up to 27.4%) resulted in increased SBP values (122.6 to 142.6 mmHg) and decreased DBP values (78.7 to 63.7 mmHg) in 10 healthy males aged 25-28 years. Following 30 minutes of bathing in a dry sauna (65°C), Blatteau et al. (2008) reported that SBP values decreased significantly (112±10 mmHg, p=0.013), whereas DBP values remained unchanged; conversely, Saikhun et al. (1998) noted increases in SBP following 30 minutes of 80-90°C sauna exposure.

Compared with aforementioned studies, sauna conditions and participant parameters differed from those evaluated in the present study, therefore, the noted changes in BP values are difficult to compare. The increase in BP values (SBP and DBP) during successive sauna sessions was not significantly correlated with somatic features or body composition parameters, but significant correlations were noted during successive sauna sessions (10, 12 and 14 minutes). The analyzed parameters were also strongly correlated with the initial BP values measured directly before sauna exposure. Therefore, SBP and DBP values may be determined by somatic features and body composition parameters during sauna sessions lasting 10 to 14 minutes. Recent studies have highlighted that deleterious cardiovascular adaptations during sauna sessions are most prevalent in men characterized by the highest degree of obesity and the largest body size (Podstawski et al., 2019). However, future work must consider whether sauna bouts of 10-14-minutes are sufficient to elucidate differences between people with varying somatic and body composition indicators, and as such, physiological responses to further prolonged sauna bathing should be investigated.

Empirical data on the effect of sauna exposure on BP is incongruent, and varies dependent on the applied measurement method, sauna type, duration of exposure which elicits the evaporation effect as well as sauna users' adaptation to high temperature. Varied results were reported in studies where the sphygmomanometer was used, including a minor increase (Kosunen et al., 1976; Leppäluoto et al., 1986), no change (Luuira, 1980; Eisalo A, Luurila, 1988; Sawicka et al., 2007; Paolone et al., 1980; Rismann et al., 2002), decrease in SBP (Kihara et al., 2002; Miyamoto et al., 2005; Kiss, 1994; Gianetti, 1999), as well as a decrease in DBP to a lesser degree (Luuira, 1980; Kauppinen, 1989a; Leppäluoto et al., 1986; Kauppinen and Voori, 1986; Tei et al., 1995; Hasan and Karvonen, 1967; Kihara et al., 2002; Imamura et al., 2001; Tei et al., 1996). In the present study, BP values were highest at 150/101 mmHg during the 12-minute sauna session, which is indicative of stage 1 hypertension (Frese et al., 2011). Overweight and obese men and women are characterized by relatively higher values of SBP and DBP than their normal weight counterparts (Pichler et al., 2015); whilst blood pressure often elevates to levels that are dangerous for health and mortality (Mertens and Van Gaal, 2000). For this reason, individuals with hypertension, and indeed other co-morbidities, are advised to bathe in a sauna at lower temperature (45-50°C) and lower humidity (Sawicka et al., 2007). Further highlighting the necessity of conducting further studies, utilizing longer sauna bouts (16-, 18-, 20-minute-sesions); which is concordant with the observations made by Kauppinen (1989a), who assert that total activation of physiological processes (e.g perspiration) only occurs after 15 minutes of sauna use.

Conclusion

Every additional two minutes of exposure to thermal stress induces significant changes in the physiological parameters of young and sedentary men. However, changes in physiological parameters following heat exposure are not significantly related with somatic features or body composition parameters, with the exception of blood pressure. Given the marked physiological changes observed in this study, it is recommended that sauna bathing of longer durations be investigated in order to elucidate the thermal stress response among varying body types.

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Conflict of interest
The authors declare that they have no actual or perceived conflicts of interest.

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Table 1. Descriptive statistics of the studied anthropometric features and physiological parameters (N=42) before the first sauna session.

Parameter	**Mean**	**SD**	**min-max**	**As**
Body mass [kg]	86.72	14.84	55.90-137.70	1.36
Body height [cm]	179.48	6.37	166.0-194.0	-0.10
BMI (Body Mass Index) [kg/m^2]	26.88	3.95	19.34-40.23	0.80
BSA (Body Surface Area) [m^2]	2.08	0.19	1.63-2.69	0.98
WHR (Waist-Hip Ratio)	0.90	0.09	0.75-1.20	0.93
TBW (Total Body Water) [L]	49.11	6.13	32.90-64.00	-0.05
Proteins [kg]	13.33	1.68	8.90-17.20	-0.09
Minerals [kg]	4.65	0.62	3.24-6.25	-0.08
SMM (Skeletal Muscle Mass) [kg]	38.23	5.07	24.70-50.00	-0.11
SBP (Systolic Blood Pressure) [mmHg]	126.62	9.20	106-140	-0.66
DBP (Diastolic Blood Pressure) [mmHg]	81.67	5.91	69-92	-0.28
PBF (Percent Body Fat) [%]	21.88	7.11	10.20-46.30	0.81
BFM (Body Fat Mass) [kg]	19.62	9.90	7.50-63.80	2.41
FFM (Fat Free Mass) [kg]	67.10	8.41	45.00-87.50	-0.06
VFL (Visceral Fat Level) [kg]	7.88	4.52	2.00-28.00	2.37
Obesity Degree	122.43	18.01	88-183	0.75
InBody score	78.50	10.12	39-95	-1.24
Target weight	79.20	9.01	63-103	0.38
BMR (metabolism) [kcal]	1819.33	181.35	1342-2260	-0.06
PA levels in METS [3.5 mL/kg/min]	509.17	74.26	390 - 596	-0.42

Table 2. A comparison of the average values of physiological parameters (N = 42) depending on the length of stay in the sauna (ns – non-significant differences, *) - values close to significance.

Parameter	**Length of stay in the sauna [minutes]**									**Difference**		**LSD** (*post-hoc*)		
	10			**12**			**14**							
	Mean	**SD**	**min-max**	**Mean**	**SD**	**min-max**	**Mean**	**SD**	**min-max**	***F***	***p***	**10-12**	**10-14**	**12-14**
HR_{min} [bpm]	82.67	8.33	67-103	89.29	9.10	58-104	87.93	9.08	69-108	6.57	0.002	<0.001	0.007	ns
HR_{avg} [bpm]	97.38	7.15	84-111	108.31	6.62	96-127	108.81	8.30	96-128	32.10	<0.001	<0.001	<0.001	ns
HR_{max} [bpm]	114.76	9.22	92-130	126.79	8.51	105-148	132.93	8.28	117-149	47.60	<0.001	<0.001	<0.001	0.002
Recovery time [h]	0.17	0.38	0-1	0.86	0.52	0-3	1.29	0.64	0-3	49.09	<0.001	<0.001	<0.001	<0.001
PTE-Peak Training Effect	1.21	0.11	1.0-1.5	1.56	0.29	1.2-2.2	1.68	0.30	1.2-2.3	44.70	<0.001	<0.001	<0.001	0.020
Energy expenditure [kcal]	72.86	12.68	52-94	104.21	12.74	71-131	125.24	17.25	96-167	141.03	<0.001	<0.001	<0.001	<0.001
VO_{2avg} [mL/kg/min]	14.29	2.41	10-20	18.29	2.56	13-25	18.50	3.29	12-25	30.65	<0.001	<0.001	<0.001	ns
VO_{2max} [mL/kg/min]	20.21	3.71	13-26	24.79	2.84	18-32	26.60	2.69	21-32	46.94	<0.001	<0.001	<0.001	0.009
$EPOC_{avg}$ [mL/kg]	1.71	0.71	1-4	3.67	1.96	1-13	4.37	2.75	2-13	19.94	<0.001	<0.001	<0.001	ns
$EPOC_{max}$ [mL/kg]	3.83	1.45	2-8	8.60	4.07	3-27	11.02	5.63	5-28	33.44	<0.001	<0.001	<0.001	0.008
Respiratory $rate_{avg}$ [brpm]	17.17	1.40	15-20	18.64	1.45	16-23	18.57	1.35	17-22	14.93	<0.001	<0.001	<0.001	ns
Respiratory $rate_{max}$ [brpm]	22.69	1.37	20-25	24.52	2.62	16-35	25.43	2.38	22-33	17.05	<0.001	<0.001	<0.001	ns
SBP (Systolic Blood Pressure) [mmHg]	128.86	8.80	110-145	132.81	9.65	108-150	131.67	8.04	115-143	2.22	ns *)	0.043	ns	ns
DBP (Diastolic Blood Pressure) [mmHg]	83.10	6.60	72-96	86.14	7.49	72-102	85.98	5.92	74-98	2.75	ns *)	0.039	ns	ns
Exercise intensity														
Easy <107 [bpm]	469.6	128.1	152-600	304.5	177.1	1-720	365.7	203.2	0-776	9.86	<0.001	<0.001	0.007	ns
Moderate 107-124 [bpm]	128.8	127.7	0-447	341.4	141.0	0-635	348.2	129.7	62-624	37.08	<0.001	<0.001	<0.001	ns
Difficult 125-141 [bpm]	1.6	5.0	0-25	73.2	98.0	0-490	120.9	149.7	0-548	14.19	<0.001	0.002	<0.001	0.036
Very difficult 142-159 [bpm]	0.0	0.0	0-0	0.9	5.7	0-37	5.2	20.5	0-103	2.15	ns	ns	ns	ns
Maximal ≥ 160 [bpm]	All values are zero													

Table 3. Correlations between anthropometric features and blood pressure depending on the length of stay in the sauna (ns – non-significant correlations).

Parameter	Length of stay in the sauna [min]	Blood pressure	
		SBP	DBP
Body mass [kg]	10	0.53	0.33
	12	0.46	0.33
	14	0.50	0.40
BMI (Body Mass Index) [kg/m^2]	10	ns	ns
	12	0.63	0.49
	14	0.60	0.50
BSA (Body Surface Area) [m^2]	10	0.46	ns
	12	0.38	ns
	14	0.46	0.34
WHR (Waist-Hip Ratio)	10	0.68	0.50
	12	0.61	0.50
	14	0.61	0.51
SBP (Systolic Blood Pressure) before sauna [mmHg]	10	0.91	0.62
	12	0.85	0.65
	14	0.83	0.64
DBP (Diastolic Blood Pressure) before sauna [mmHg]	10	0.84	0.81
	12	0.78	0.77
	14	0.67	0.70
PBF (Percent Body Fat) [%]	10	0.66	0.51
	12	0.61	0.49
	14	0.57	0.49
BFM (Body Fat Mass) [kg]	10	0.58	0.42
	12	0.52	0.41
	14	0.52	0.47
VFL (Visceral Fat Level) [kg]	10	0.59	0.42
	12	0.53	0.42
	14	0.52	0.46
Obesity Degree	10	0.71	0.49
	12	0.63	0.49
	14	0.60	0.51