

Application of Thermal Imaging and PWC₁₇₀ Test for the Evaluation of the Effects of a 30-Week Step Aerobics Training

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Abstract. The aim of this paper is to verify whether step aerobics training (SAT) has an impact on the temperature of deep muscles of the spine of young, healthy subjects and if there exists a relationship between the maximal oxygen uptake (VO₂max) and thermal results. The study was conducted in a group of 21 subjects of both sexes, aged 20.2 ± 0.38 . The step aerobics training sessions lasted 30 weeks, one training session per week, 60 minutes per session. Thermograms of the spine were taken with the use of an infrared thermographic camera. Instrumental measurements included BMI, vital capacity of the lungs, and maximal oxygen uptake (VO₂max). After a 30-week-long SAT, a statistically significant increase in the average temperature of the muscles of the thoracic and lumbar spine was observed in subjects of both sexes (1.2°C and 1.28°C , respectively, $p < 0.05$). At the same time, VO₂max increased from 42.98 ml/kg/min to 43.6 ml/kg/min in male subjects and from 40.4 ml/kg/min to 41.1 ml/kg/min in female subjects ($p > 0.05$). The relationship between VO₂max and temperature of the muscles of the thoracic and lumbar spine after the 30th SAT was not statistically significant ($r = -0.28$; $p = 0.226$; $r = -0.11$; $p = 0.634$, respectively). The study showed that a 30-week-long step aerobics training (SAT) had a positive impact on thermoregulation of apparently healthy male and female subjects aged 20. Furthermore, it can be safely assumed that thermography may be used as a non-invasive method of examination of the thermoregulation mechanism of SAT participants.

Introduction

The deep muscles of the spine are responsible for maintaining posture and movement. They also help to stabilize, rotate, flex, and extend the spinal column (Davies, 1990). During physical activity, as a result of muscle contraction, chemical energy is transformed into heat. This process increases

local metabolic activity and perfusion, leading to an increase in muscle temperature.

Step Aerobics Training (SAT) is one of the most popular collective forms of fitness and may have a positive impact on the human body and the person's abilities (Olex-Mierzejewska, 2002). It combines step-on and step-off movements with marching, dancing, and jumping exercises. During SAT, the participants step up and down a platform of adjustable height in a cycle of footsteps, creating a determined choreography (Zuzda & Latosiewicz, 2010). Various fitness forms have been shown to have the potential to develop a large number of components of physical fitness during training sessions (Akdur et al., 2007; Drobnik-Kozakiewicz et al., 2013; Forte et al., 2001; Hallage et al., 2010; Irez et al., 2014; Kravitz et al., 1993; Mori et al., 2006; Zuzda & Latosiewicz, 2013). These studies indicate that SAT has a positive impact on components of functional fitness, which was found to improve body muscle strength, balance, agility, and flexibility.

Thermography is a non-invasive method used to measure thermal radiation emitted by the body or its parts and it can be used to identify temperature changes caused by training. Although few studies applying infrared thermography have been devoted to sports performance and sports pathology diagnostics (Akimov et al., 2009; Coh & Širok, 2007; Hildebrandt et al., 2012; Novotny et al., 2015), there are some investigations that have confirmed beneficial health outcomes associated with SAT in adults (Drobnik-Kozakiewicz et al., 2013; Forte et al., 2001; Kravitz et al., 1993; Mori et al., 2006; Zuzda & Latosiewicz, 2013). These studies, however, did not evaluate SAT's effects on the temperature of the deep muscles of the spine. In fact, to the knowledge of the authors, no study has examined the effects of the training programme in question on the temperature of the subject's deep spine muscles.

For the reasons specified above, the authors designed this study with a twofold aim, i.e. to verify if SAT has an impact on temperature changes in the deep muscles of the spine of healthy subjects and, secondly, to verify if there is a relationship between the temperature of the muscles of the thoracic and lumbar spine and the aerobic capacity of persons participating in SAT.

Materials and Methods

The participants were voluntarily recruited from among the students of Bialystok University of Technology, Poland (BUT). The study was conducted in BUT's Laboratory of Exercise Science with the participation

of 21 young subjects (6 male and 15 female), whose average age was 20.2 ± 0.4 years. The inclusion criteria included general health status (to determine that the subjects would be capable of completing the training programme) and non-participation in any SAT course in the year preceding the study. All participants were examined by a medical doctor pre-training and post-training. Subjects were excluded if they were obese ($\text{BMI} > 30.0 \text{ kg/m}^2$) or had any other medical disorder that might adversely affect their dexterity.

Before the first SAT session, each participant completed medical history forms, the Physical Activity Readiness Questionnaire (PAR-Q+), and the International Physical Activity Questionnaire (IPAQ-SF). Subjects participated in the study after they granted their informed consent in accordance with Declaration of Helsinki, following the approval of the local Ethical Committee.

Each subject's body weight and height were measured using a professional scale and a WPT 100/200 OW stadiometer (RADWAG Wagi Elektroniczne, Poland). BMI was automatically calculated using the software provided by the manufacturer. Systolic and diastolic blood pressure was measured pre- and post-training using an electronic blood pressure monitor (Panasonic, EW 3106).

PAR-Q+ was used to provide information relevant to the safety of starting an exercise training and to identify known diseases and risk factors for cardiovascular diseases or orthopaedic injury (Bredin et al., 2013). The short version of the International Physical Activity Questionnaire (IPAQ-SF) was used to assess the subjects' physical activity level (Biernat et al., 2007). Physical activity level was expressed in minutes per week of Metabolic Equivalent of Task (MET).

Maximal oxygen uptake ($\text{VO}_{2\text{max}}$) was measured by applying the Physical Working Capacity 170 cycle test (PWC_{170}) (Górski, 2006). The PWC_{170} test was conducted on the Monark Ergomedic 828E bicycle ergometer (Monark Ergometric Company, Sweden); the load was increased every 2 minutes until the subject reached a heart rate (HR) of 170 BPM. HR was monitored continuously with the use of a telemetry system by the same company. The $\text{VO}_{2\text{max}}$ was determined using the following equation:

$$\text{VO}_{2\text{max}} = 1.7 \cdot \text{PWC}_{170} + 1240$$

where: $\text{VO}_{2\text{max}}$ = maximal oxygen uptake; PWC_{170} = physical working capacity.

Vital capacity (VC) of the lungs was measured with the use of a mechanical spirometer (Barens, Poland) and expressed in millilitres (Górski, 2006). Each measurement was taken twice and averaged.

Thermograms were taken in the standing position at normal breathing in a room with a constant temperature of 21–22°C. A thermographic camera (CEDIP Titanium 560M IR, USA) was used. The integrated resolution of the camera was 640×512 pixels, with an accuracy of up to 1°C of absolute temperature and emissivity values of 0.98. The camera was placed perpendicularly to the scanned surface. The temperature of the region of the deep muscles of the spine was recorded before and after the first training and before and after the 30th training. Paravertebral areas Th1–Th12 were subject to automatic processing and calculation. Examples of thermograms of selected areas, i.e. Th1–Th12 and L1–L5, are presented in Figure 1.

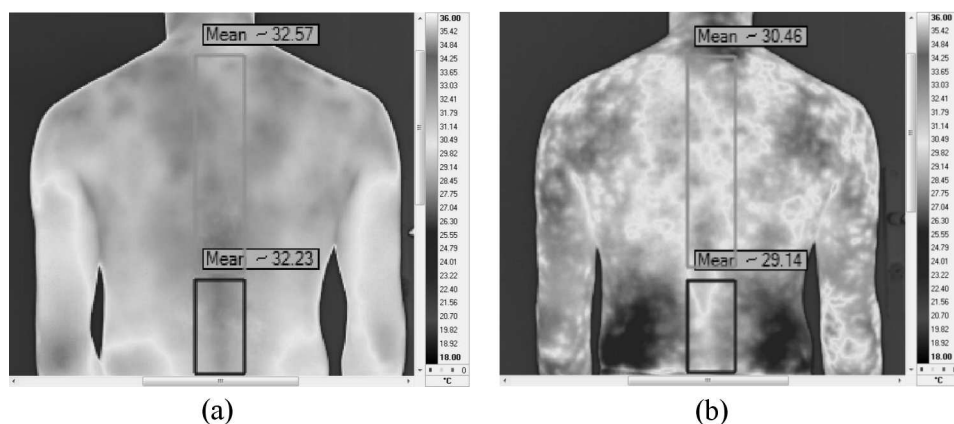


Figure 1. Thermograms with zones Th1–Th12 and L1–L5 marked: before SAT (a) and after SAT (b)

Thermograms were taken at the following four time periods: during the first session after 10 minutes of warm up, after finishing the first session, during the last session after 10 minutes of warm up, and after finishing the last session. Thermograms were analysed with the use of the original 5.80.005 software (Altair Engineering, Inc., USA).

The step aerobics training was conducted according to valid collective forms of fitness within a training methodology (Davies, 1990; Olex-Mierzejewska, 2002). The training sessions took place during a period of 30 weeks. The subjects participated in one training session per week, 60 minutes per session, each consisting of a warm-up (10 minutes), the main part involving a choreographed sequence, and a cool-down with breathing and stretching

exercises (10 minutes). All sessions were supervised by the same instructor and conducted under standardized conditions as regards artificial light, a constant air temperature of 21–22°C, and relative humidity (50%).

The means and standard deviations were calculated for basic data describing the characteristics of the population. The non-parametric Wilcoxon signed-rank test of a pair of samples (Novotny et al., 2015) was used to evaluate the differences between two related samples, either repeated or matched. The variables for the Wilcoxon test have multiple possible scores, with the focus on whether the mean of the variables differs significantly. The linear Pearson correlation coefficient (r) was used to determine the relationship between VO₂max and the temperature of the muscles of the thoracic and lumbar spine. A value of $p < 0.05$ was considered as statistically significant. Statistica 12.5 (Stat Soft Polska, Poland) software was used to perform the analysis.

Results

The mean age of all the subjects at the beginning of the study was 20.2 ± 0.4 years. Detailed characteristics of the participants are shown in Tables 1 and 2, for male and female subjects respectively.

The initial level of physical activity reported by males was lower than activity reported following the 30-week-long SAT (2958.1 MET·minutes/week; 3633.5 MET·minutes/week; $p = 0.116$). The dominant type of activity reported by male participants pre-training was intensive effort. The difference in this kind of activity between pre-training and post-training was not statistically significant (3578.2 MET·minutes/week *vs* 4195.4 MET·minutes/week, respectively, $p = 0.285$).

The total level of physical activity pre-training among female participants was lower when compared with the level of physical activity post-training (2400.9 MET·minutes/week; 3031.7 MET·minutes/week; $p = 0.030$). The dominant type of activity reported by female participants pre-training was moderate effort. The difference in this kind of activity between pre-training and post-training was statistically significant (1785.8 MET·minutes/week *vs* 2035.8 MET·minutes/week, respectively, $p = 0.012$).

Aerobic capacity is the maximum amount of physiological work that an individual can do as measured by oxygen consumption (Górski, 2006). In this study, the average maximal oxygen uptake (VO₂max) for male subjects increased from 42.98 ± 6.3 ml/kg/min to 43.6 ± 6.4 ml/kg/min, which was not statistically significant ($p > 0.05$). Average vital capacity in-

Table 1. Male characteristics pre-training and after 30 weeks of SAT (n = 6)

Subject's characteristic	Pre-training Mean ($\pm SD$)	Post-training Mean ($\pm SD$)	p
BMI (kg/m ²)	24.4 \pm 3.7	23.8 \pm 3.4	0.120
Waist circumference (cm)	86.3 \pm 8.8	86.0 \pm 8.7	0.470
Systolic blood pressure (mm Hg)	127.0 \pm 3.4	126.3 \pm 4.1	0.920
Diastolic blood pressure (mm Hg)	77.7 \pm 4.5	76.0 \pm 5.2	0.110
Vital capacity of lungs (ml)	5166.7 \pm 492.6	5233.3 \pm 546.5	0.200
VO2max (ml/kg/min)	42.98 \pm 6.3	43.6 \pm 6.4	0.250

Table 2. Female characteristics pre-training and after 30 weeks of SAT (n = 15)

Subject's characteristic	Pre-training Mean ($\pm SD$)	Post-training Mean ($\pm SD$)	p
BMI (kg/m ²)	21.0 \pm 2.5	20.8 \pm 2.5	0.190
Waist circumference (cm)	73.8 \pm 7.3	74.1 \pm 7.0	0.210
Systolic blood pressure (mm Hg)	119.5 \pm 7.5	121.3 \pm 6.9	0.120
Diastolic blood pressure (mm Hg)	72.3 \pm 6.5	71.6 \pm 6.9	0.350
Vital capacity of lungs (ml)	3873.3 \pm 510.6	4020 \pm 538.8	0.008
VO2max (ml/kg/min)	40.4 \pm 4.9	41.1 \pm 4.8	0.230

creased from 5167 \pm 492 ml to 5233 \pm 546 ml which was not statistically significant ($p > 0.05$). In male subjects, systolic blood pressure fell from 127 \pm 3.4 mm Hg to 126 \pm 4.1 mm Hg, which was not statistically significant ($p > 0.05$), whereas diastolic blood pressure fell from 77 \pm 4.5 mm Hg to 76 \pm 5.2 mm Hg, which was not statistically significant ($p > 0.05$).

In females, average VO2max increased from 40.4 \pm 4.9 ml/kg/min to 41.1 \pm 4.8 ml/kg/min, which was not statistically significant ($p > 0.05$). Average vital capacity increased from 3873 \pm 510 ml to 4020 \pm 538 ml which was statistically significant ($p = 0.008$). In female subjects, systolic blood pressure increased from 119 \pm 7.5 mm Hg to 121 \pm 6.97 mm Hg, which was not statistically significant ($p > 0.05$) and diastolic blood pressure fell from 72 \pm 6.5 mmHg to 71 \pm 6.9 mmHg, which was not statistically significant ($p > 0.05$).

After the 30-week-long SAT, the mean temperature of thoracic muscles increased by 1.2 \pm 0.09°C (Table 3). The difference was statistically significant (30.34 \pm 0.85°C *vs* 31.54 \pm 0.94°C, $p = 0.001$). In the same time period,

Table 3. Descriptive statistics of differences in the temperature of deep spine muscles (Th1–Th12 and L1–L5) pre-training and after week 30 of SAT (n = 21)

Gender	Region of the spine	Pre-training			After 30-week-long SAT			p
		Min	Max	Mean ($\pm SD$)	Min	Max	Mean ($\pm SD$)	
All Subjects (21)	Th1–Th12	28.66	31.77	30.34 \pm 0.85	29.6	33.69	31.54 \pm 0.94	0.001
	L1–L5	28.21	31.63	29.94 \pm 1.062	29.51	33.35	31.22 \pm 0.96	0.000
Male (6)	Th1–Th12	29.52	31.31	30.48 \pm 0.65	30.94	33.69	32.11 \pm 1.07	0.028
	L1–L5	29.8	31.63	30.23 \pm 1.21	31.46	32.71	31.96 \pm 0.48	0.028
Female (15)	Th1–Th12	28.66	31.77	30.28 \pm 0.94	29.6	32.53	31.31 \pm 0.95	0.011
	L1–L5	29.82	31.54	29.82 \pm 1.02	29.51	33.35	30.92 \pm 0.96	0.004

Table 4. Descriptive statistics of differences in the temperature of deep spine muscles (Th1–Th12 and L1–L5) before the 1st vs after the 1st SAT, and before the 30th vs after the 30th SAT (n = 21)

Gender	Region of the spine	Before 1 st vs after 1 st SAT			Before 30 th vs after 30 th SAT			p
		Min	Max	Mean ($\pm SD$)	Min	Max	Mean ($\pm SD$)	
All Subjects (21)	Th1–Th12	– 5.27	0.02	2.9 \pm 1.31	– 3.86	0.24	1.66 \pm 1.03	0.003
	L1–L5	– 5.39	1.18	2.6 \pm 1.37	– 3.54	2.11	1.599 \pm 1.53	0.019
Male (6)	Th1–Th12	– 4.1	– 0.95	2.59 \pm 1.24	– 2.06	0.2	1.33 \pm 0.83	0.046
	L1–L5	– 3.72	1.18	1.9 \pm 1.87	– 3.51	0.29	1.54 \pm 1.46	0.075
Female (15)	Th1–Th12	– 5.27	0.02	3.03 \pm 1.36	– 3.86	0.24	1.797 \pm 1.09	0.017
	L1–L5	– 5.39	– 1.62	2.93 \pm 1.07	– 1.62	2.11	1.62 \pm 1.6	0.009

the mean temperature of lumbar muscles increased by $1.28 \pm 0.1^\circ\text{C}$. The difference was statistically significant ($29.94 \pm 1.06^\circ\text{C}$ vs $31.22 \pm 0.96^\circ\text{C}$, $p = 0.0003$). The difference in the mean temperature of thoracic muscles was $1.63 \pm 0.42^\circ\text{C}$ ($p = 0.028$) for men and $1.03 \pm 0.01^\circ\text{C}$ for women ($p = 0.110$). For lumbar muscles, this difference in the mean temperature was $1.73 \pm 0.73^\circ\text{C}$ for men ($p = 0.030$) and $1.1 \pm 0.06^\circ\text{C}$ for women ($p = 0.004$).

Table 4 shows temperature differences between the 1st and the 30th SAT. Smaller increases in temperature were observed for thoracic muscles ($2.9 \pm 1.31^\circ\text{C}$ vs $1.66 \pm 1.03^\circ\text{C}$, $p = 0.003$) than for lumbar muscles ($2.6 \pm 1.37^\circ\text{C}$ vs $1.599 \pm 1.33^\circ\text{C}$, $p = 0.019$) during the 30th SAT.

The performed research showed a positive and statistically significant ($r = 0.28$; $p = 0.022$) correlation between aerobic capacity and the temperature of lumbar muscles pre-training in all subjects. For muscles of the thoracic spine, the correlation was not statistically significant ($r = 0.22$; $p = 0.334$). No relationship between aerobic capacity and the temperature of the thoracic spine has been found; nor between aerobic capacity and the temperature of lumbar muscles immediately after a 30-week-long SAT (Figure 2).

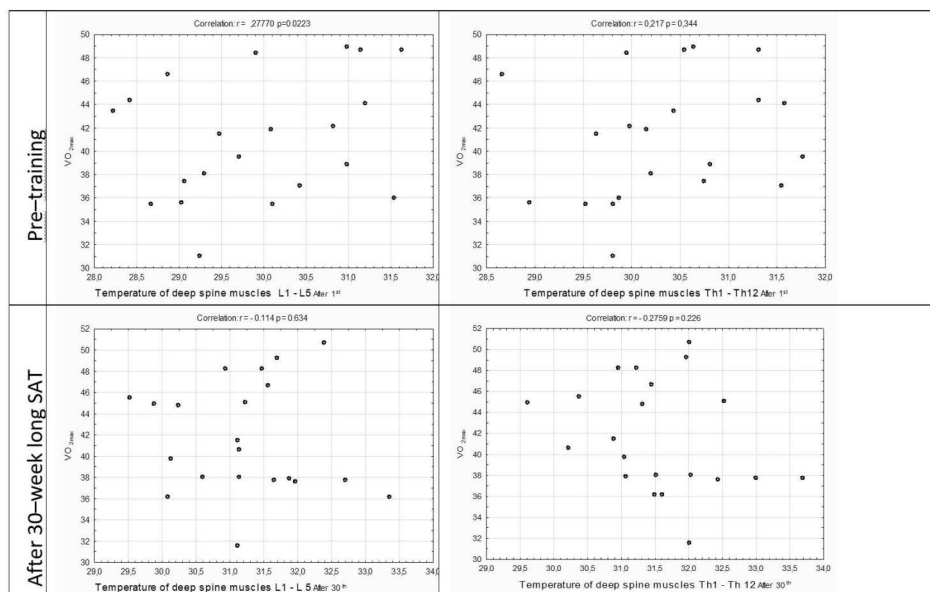


Figure 2. Relationship between the temperature of deep spine muscles L1– L5 and Th1–Th12 vs $\text{VO}_{2\text{max}}$ index pre-training and after 30-week-long SAT ($n = 21$)

Discussion

The temperature of various parts of the body is an important parameter in the evaluation of human adaptation to different environmental conditions and muscle activities (Akimov et al., 2009; Chudecka & Lubkowska, 2012; Fernández-Cuevas et al., 2015; Kenney & Munce, 2003; Novotny et al., 2015; Torii et al., 1992; Zontak et al., 1998). Thermography is a non-invasive technique that can reveal and visualize differences in temperature distribution on the skin surface of an individual (Torii et al., 1992; Zontak et al., 1998).

It is known that one of the immediate responses of the vascular system to physical exercise is redistribution of blood flow and reduction of blood inflow to the skin. On the other hand, the decrease in skin temperature during and after exercise is due to the prolonged act of sweating. In this study, a statistically significant decrease in muscle temperature after the first SAT was noted, both for thoracic spine muscles ($2.9 \pm 1.31^{\circ}\text{C}$, $p < 0.05$) and lumbar muscles ($2.6 \pm 1.37^{\circ}\text{C}$, $p < 0.05$). Similarly, after the last (30th) SAT, a statistically significant reduction of the temperature of thoracic spine muscles ($1.66 \pm 1.03^{\circ}\text{C}$, $p < 0.05$) and lumbar muscles ($1.6 \pm 1.53^{\circ}\text{C}$, $p < 0.05$) was found. The obtained results are consistent with those of other researchers using similar methods (Chudecka & Lubkowska, 2012; Novotny et al., 2015). Merla et al. (2010) recorded drops in total body surface temperature of 15 runners after exercise interruption. The temperature values were on average 3–5 degrees Centigrade lower than baseline temperature. The thighs and forearms exhibited the earliest response.

SAT, similarly to other exercise programs, increases arterial diameter, improves whole body vasodilatory function and causes a decrease in vasomotor tone (Kondo et al., 2009). A SAT session results in sweating, which eliminates endogenous heat and, consequently, leads to an observed decrease in skin surface temperature. Therefore, it can be indirectly concluded that the efficiency of the thermoregulatory mechanisms of SAT participants allows them to continue physical exercise without a significant increase in their internal temperature, which could be a factor limiting physical performance of SAT participants. In the present study, lower increases in temperature were observed during the 30th SAT for thoracic muscles (2.90°C *vs* 1.66°C , $p < 0.05$) in comparison with lumbar muscles (2.60°C *vs* 1.60°C , $p < 0.05$). Fit people have a lower rise in rectal temperature during exercise than unfit people, due to adaptation to effort, i.e. they remove endogenic heat more efficiently. A higher physical efficiency is a facilitating factor in a properly functioning thermoregulatory mechanism and thereby the effective ex-

change of heat generated during the effort (Smorawiński, 1991; Chudecka & Lubkowska, 2010).

The results of this study show that the temperature of thoracic and lumbar spine muscles was slightly higher in male participants than in females, except temperatures in those regions before the 1st SAT, where the temperature was lower in male participants as compared to females ($33.07 \pm 0.79^{\circ}\text{C}$ vs $33.31 \pm 0.76^{\circ}\text{C}$ and $32.13 \pm 1.28^{\circ}\text{C}$ vs $32.75 \pm 0.91^{\circ}\text{C}$). Fernández-Cuevas et al. (2015) state that gender may influence the results of an infrared thermography examination of the subcutaneous fat, the metabolic rate, and female menstrual cycle. Chudecka and Lubkowska (2015) also found higher upper body skin temperature in women. Zaproudina (2012), on the other hand, indicated non-significant gender-related differences in skin temperature. Christensen et al. (2012) analysed gender differences in facial skin temperature and found a higher facial skin temperature in males. It seems that more infrared thermography examinations in order to test gender differences in skin temperature are necessary.

One of the purposes of SAT is to improve maximal oxygen uptake in healthy subjects (Akdur et al., 2007; Irez et al., 2014). Olson et al. (1995) established that a four-minute aerobic dance test provides a valid and reliable sub-maximal protocol for estimating VO₂max in apparently healthy 18 to 40 years old females. In a study by Drobnik-Kozakiewicz et al. (2013), female subjects performed SAT at 70% of their maximum HR intensity, achieving an increase of VO₂max. The values of VO₂max in this particular study increased from 42.04 ml/kg/min to 45.71 ml/kg/min. Other studies also confirm the increase of VO₂max after SAT, including two studies confirming that SAT can develop cardiovascular efficiency in both younger and older females, suggesting that SAT can be beneficial in females of all ages (Akdur et al., 2007; Irez et al., 2014; Kravitz et al., 1993). On the contrary, in the male group examined in the present study, VO₂max increased by 0.62 ml/kg/min (42.98 ± 6.3 ml/kg/min vs 43.6 ± 6.4 ml/kg/min), which was not statistically significant ($p < 0.05$). In females, VO₂max increased by 0.7 ml/kg/min (40.4 ± 4.9 ml/kg/min vs 41.1 ± 4.8 ml/kg/min), which was not statistically significant ($p > 0.05$).

The results show a statistically significant difference ($p < 0.05$) in vital capacity (VC) of lungs, pre-training and post-training, for female subjects, the value increased by 147 ± 28.2 ml (3873 ± 510.6 vs 4020 ± 538.8 ml). In the same period, VC of males raised by as little as 67 ml (5166 ± 492.6 vs 5233 ± 546.5 ml), which was statistically insignificant ($p > 0.05$). This result is in agreement with a study by Badaam et al. (2013), who found

that training groups showed improvement in vital capacity. They compared Sprint Interval Training and traditional aerobic exercise with respect to changes in vital capacity in males. They concluded that SAT is more beneficial than traditional aerobic exercise with respect to improvement in Forced Vital Capacity (0.48 ± 0.17 vs 0.31 ± 0.1 l; $p = 0.09$) and in Maximum Voluntary Ventilation (27.77 ± 7.03 vs 21.5 ± 11.6 ; $p = 0.290$). They suggested that Sprint Interval Training can be used as a health promotion strategy. In accordance with our study, the data from Dunham and Harms (2012) also suggest that high-intensity interval training is effective in improving aerobic capacity and performance.

The presented results show a positive correlation between aerobic capacity and the temperature of lumbar muscles pre-training in subjects ($r = 0.28$; $p = 0.022$), but the correlation between aerobic capacity and the temperature of thoracic spine muscles was not statistically significant ($r = 0.21$; $p = 0.334$). The outcome of our study shows a negative correlation between aerobic capacity and skin temperature of thoracic and lumbar muscles immediately after a 30-week-long SAT. The relationship between $VO_{2\max}$ and temperature of the muscles of the thoracic and lumbar spine was not statistically significant.

The aim of two studies conducted by Chudecka and Lubkowska (2010) was to evaluate temperature changes and analyse the impact of physiological factors of dynamic temperature changes in selected body parts of 16 handball players and 12 professional basketball players (Chudecka & Lubkowska, 2011) submitted to endurance physical activity (PA) lasting 90 minutes. They found a significant positive correlation between maximal oxygen uptake changes in skin temperature after PA. They concluded that efficiency was greater in the subjects with higher maximal oxygen uptake (larger temperature loss immediately after training) while thermography may be used as a non-invasive method allowing to examine the thermoregulation mechanism of these subjects. A higher general physical and functional capacity enables better body thermoregulation during excessive heat release and maintains thermal tolerance after physical activity.

The limitation of this study was the small group of participants and possibly the chance factor. Further investigation should be done to evaluate the impact of SAT on other muscle groups to prove the effectiveness of SAT and to have it incorporated in health promotion recommendations. It would also be worthwhile to investigate the temperature of muscles of the spine after regular SAT for one or two years.

Conclusions

1. A thirty-weeks-long step aerobics training (SAT) had a positive effect on thermoregulation of apparently healthy male and female subjects aged 20.
2. Thermography may be used as a non-invasive method allowing to examine the thermoregulation mechanism of SAT participants.

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