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SPECIAL TRAINING OF INSPIRATORY MUSCLES IN FITNESS ACTIVITIES AND EXERCISE CAPACITY IN YOUNG WOMEN

original paper
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ABSTRACT
Purpose. The aim of the study was to determine if an 8-week-long endurance fitness training with elastic belts would increase the strength-endurance of the inspiratory muscles and lung function characteristics, and to assess whether these changes were consistent with an increase in aerobic power and exercise capacity in healthy young women.
Methods. Twenty-two females aged 20–25 years were randomly allocated into 2 groups. The experimental group preformed 8-week-long exercises on stationary bikes with an elastic belt on the lower part of the chest. The control group underwent the same workout, without elastic belts. Vital capacity, forced vital capacity, maximal voluntary ventilation, maximal inspiratory and expiratory pressure, sustained maximal inspiratory pressure, physical activity status, and perceived exertion scores were measured. In the incremental exercise test, work capacity and maximal oxygen uptake were assessed. Tidal volume, minute ventilation (VE), oxygen uptake (VO_2), VE/VO_2, heart rate (HR), and VO_2/HR were continuously monitored. The cycle performance at the power of the ventilatory threshold was evaluated on the following day.
Results. The fitness training with elastic belts significantly improved the strength and strength-endurance of the inspiratory muscles, the functional cardio-respiratory capabilities, and aerobic work output. In the control group, the studied parameters were not significantly increased.
Conclusions. Applying elastic belts to fitness endurance exercises improves the strength and strength-endurance of inspiratory muscles, cardio-respiratory capabilities, and aerobic power, which additionally raises aerobic work output in fitness training of young women.
Key words: aerobic power, elastic belts, fitness training, inspiratory muscles training, young women

Introduction

Factors affecting exercise tolerance have been of interest for several decades. Reduced physical activity along with sedentary lifestyle lead to overloads in the motor system [1]. Among the limiting factors is diaphragmatic fatigue, which occurs during sustained exercise of high intensities (> 80% maximal oxygen consumption, VO_2max) [2]. However, there is no consensus about an optimal protocol to induce and assess the fatigability of the inspiratory muscles [3]. Although the ergogenic effect of respiratory muscle training (RMT) remains controversial [4–6], several recent well-controlled studies have shown that threshold inspiratory muscle training (IMT) [7–10], as well as voluntary normocapnic hyperpnoea training [10, 11] can improve exercise performance in healthy subjects. In general, the functional capacity of the healthy human respiratory system, including the lung, chest wall, and neural control systems, exceeds the demands placed upon it during heavy exercise. This is an impressive feat considering the major challenges the respiratory system must face during intense exercise. The high metabolic costs and subsequent increased work of breathing associated with this ventilatory increase can result in a number of limitations to the healthy respiratory system [12–14]. During high intensity physical exercises, the oxygen uptake (VO_2) by respiratory muscles significantly increases and equals approximately 10–15% of the overall oxygen consumption by the body [2, 12, 15]. This competition between the muscles of respiration and locomotion for a limited cardiac output and VO_2 peak may have dramatic consequences for exercise performance [3, 13].

An example of respiratory system limitations associated with high work of breathing is inspiratory flow restriction due to exercise-induced diaphragmatic fatigue in swimming [16–18]. It can lead to an inability to increase alveolar ventilation in the face of increasing metabolic demands, resulting in gas exchange impairment and diminished endurance exercise perfor-

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mance. Diaphragm fatigue has been shown after strenuous exercise and may be related to a mechanism which increases sympathetic vasoconstrictor outflow and reduces limb blood flow during prolonged exercise [19, 20]. These factors may potentially lead to diminished exercise performance owing to a competitive relationship between respiratory and locomotor muscles for blood flow [12–14]. It is the reason why RMT is widely applied to increase physical fitness in sport and health training. Evidence from previous studies suggests that high-intensity IMT may reduce dyspnoea perception in highly trained people and increase aerobic capacities in moderately trained healthy people [12].

Now, IMT is based on the usage of a flow resistance respiratory device. It is usually applied at rest, separately of physical exercises [3]. All these devices (e.g. PowerLung, POWERbreathe, Ultrabreathe, Expand-A-Lung, Breathslim, DIY Breathing Device) improve the strength of the inspiratory (and sometimes expiratory) muscles. This is indeed the most important (but superficial) result of such breathing exercisers (breathing trainers). It creates a possibility to improve the endurance of respiratory muscles. The conflicting findings are likely to be due to variations in the type of the training applied to the inspiratory muscles (strength or endurance training), the mode of training (whether the workload is fixed through a full inspiratory volume), the intensity, duration, and frequency of training. There are only a few studies of sex differences in IMT. Furthermore, the high ventilatory requirements of endurance exercises and the inherent anatomical characteristics of females could make these groups more susceptible to inspiratory flow limitation. The structural and functional differences of the respiratory system may provide insight into why some women may be more prone to respiratory limitations as compared with men [21–23]. We supposed that training programs with additional inspiratory muscle work during endurance exercise in healthy females might result in a decrease of respiratory muscle fatigue and respiratory limitation of endurance capacities. IMT by means of elastic belts possibly will be applied in exercise typical of women fitness training. This type of IMT has not been investigated.

The aim of the study was to assess the additional benefits of increased inspiratory muscles work due to elastic belt resistance in endurance fitness training of young females. The key objectives of the analysis were: (1) to determine whether an 8-week fitness endurance training with elastic belts would increase the strength-endurance of the inspiratory muscles and lung function characteristics, (2) to assess if these changes were consistent with the increase in aerobic power and exercise capacity in healthy women.

Material and methods

Setting and participants

The study was conducted in a university-based human movement laboratory. The total of 26 healthy female university students volunteered to take part in the investigation. The age of the women was 21.8 (20–25) years (*SD*, 1.7). This was a single-centre controlled study in which the participants were randomly allocated to 2 groups. In the experimental group, the exercises on stationary bikes included elastic belt application on the lower part of the chest. The control group performed the same workout without elastic belts. The planned training program was completed by 11 females of the experimental (age, 21.9 years) and 11 females of the control group (age, 21.7 years). All participants were non-smokers and had no evidence of pulmonary pathology or any known metabolic or endocrine disorder. Prior to the study, all the students' height (in cm, with the accuracy of 1.5 mm) and weight (in kg, with the accuracy of 0.1 kg) were determined. The participants were measured wearing lightweight clothing and no shoes. The percentage of body fat was estimated with

Table 1. Biological characteristic of the participants

Characteristics	Experimental group	Control group
Body mass (kg)	64.62 ± 9.48	65.21 ± 7.57
BMI ($kg \cdot m^{-2}$)	22.51 ± 1.98	23.36 ± 2.68
Fat (kg)	18.55 ± 6.89	18.89 ± 6.02
Fat (%)	26.31 ± 6.12	26.05 ± 5.35
FFM (kg)	46.51 ± 3.13	45.92 ± 2.19
VC (l)	4.17 ± 0.29	4.16 ± 0.32
FVC (l at BTPS)	3.93 ± 0.52	3.75 ± 0.42
FEV1 (l at BTPS)	3.18 ± 0.4	3.20 ± 0.50
PEF ($l \cdot s^{-1}$)	6.28 ± 1.43	6.21 ± 1.29
MVV ($l \cdot min^{-1}$)	130.4 ± 11.2	128.2 ± 9.4
MIP (–cm H_2O)	96.45 ± 14.7	90.64 ± 19.75
MEP (cm H_2O)	121.55 ± 8.38	121.15 ± 13.7
SMIP (PTU)	446 ± 104	435 ± 119
VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$)	35.52 ± 5.20	33.86 ± 4.57
Pmax ($W \cdot kg^{-1}$)	3.19 ± 0.45	3.16 ± 0.42
PAS (MET)	41 ± 8.2	39 ± 7.9
BSRPE	9.1 ± 2.2	9.0 ± 1.9

BMI – body mass index, FFM – fat free mass, VC – vital capacity, FVC – forced vital capacity, BTPS conditions – body temperature, ambient pressure, saturated with water vapour, FEV1 – forced expiratory volume in 1 s, PEF – peak expiratory flow, MVV – maximal voluntary ventilation, MIP – maximal inspiratory pressure, MEP – maximal expiratory pressure, SMIP – sustained maximal inspiratory pressure, PTU – pressure time unit, VO_2max – maximal oxygen uptake, Pmax – maximal power, PAS – physical activity status, MET – metabolic equivalent of task, BSRPE – Borg scale for rating of perceived exertion scores in the incremental tests skinfold callipers (0–48-mm model) at four sites: biceps, triceps, subscapular region, and supra-iliac crest. Three measurements for each site were taken, with the mean used for body fat determination with formulas for women [24]. The characteristics of the participants are presented in Table 1.

All the participants were informed of the nature of the study and provided their full written consent prior to the study. Each participant's physical activity level was assessed before the training program with the use of a questionnaire [25]. Activity scores were calculated over a 24-hour period and expressed in metabolic equivalents of task (1 MET, 3.5 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$). Following the completion of the recall questionnaire, the participants were encouraged not to change their physical activity patterns during the study period. Within this time, the participants were defined as being recreationally active when participating in at least 3 hours per week of sporting activity of an intensity sufficient to elevate their heart rate (HR) to 80% of the age-predicted maximum.

Training exercise and inspiratory muscle training

The program of fitness training was implemented on stationary bikes in the Academic fitness club in Gdansk, Poland, and was typically developed. The contents and intensity modalities of exercise were usual for young women fitness endurance training [26]. The experimental and control groups realized the same program of endurance training at variable intensity, in the range of 120–185 beats per min. The level of workload was assessed by HR monitoring in each participant (Polar Team System program, Polar Precision 3.0, the averaging mode for 5 s), and the data were preserved for all training sessions. On this basis, the average HR was calculated for the entire period of training. The main parts of the sessions were performed in the high area of exercise intensity (HR, 160–179 beats/min). In the experimental group, for the duration of the training session, elastic belts with regulated tension were applied on the lower part of the chest (tightened with the force of 2.5 kg at functional residual capacity [FRC]). During the exercise, the belts forced the inspiratory muscles (first of all, diaphragm) to perform increased work. The elastic belts, with the width of 220 mm, were made of two components: polyurethane (the carrier cover) and a flexible tape (the knitted substrate). Components made of an adhesive tape served to fasten the belts. The force with which the strips were fastened was based on the analysis of subjective sensations and comfort during exercise in the preliminary study [27]. The belts were individually matched to the size of the chest and assigned to the participants with the use of a dynamometer. The ratings of perceived exertion (measured with a modified 0–10 Borg scale [28]) were recorded for all training sessions (after the session) to assess the perceived exercise program intensity. The experimental training was conducted 3 times a week for 8 weeks. The duration of each session was 60 min.

Lung and respiratory muscle function measurements

At the beginning, as well as after 8 weeks of training, lung function measurements of vital capacity (VC), forced vital capacity (FVC), forced expiratory volume in 1 s (FEV_1), peak expiratory flow (PEF), and maximal voluntary ventilation (MVV) were performed by a 12-second test with the COSMED spirometer technique ($K4b^2$). All participants were asked to refrain from vigorous exercise for at least 24 hours prior to the tests. During all measurements, the participants were seated and a single experienced technician performed the recordings. All lung function measurements were expressed in litres under BTPS conditions (body temperature, ambient pressure, saturated with water vapour). Maximal inspiratory pressure (MIP), maximal expiratory pressure (MEP), and sustained maximal inspiratory pressure (SMIP) were determined with an electronic manometer and a computer connected by a serial interface to a laptop computer (Micromedical). During the inspiratory manoeuver, the manometer set the maximum flow, proportional to the pressure achieved [8]. The MIP and MEP indicated the maximum pressure (cm H_2O) developed in the first second of inspiration and represented measures of inspiratory muscle strength. The SMIP was the integrated area under the pressure-time curve, measured in pressure time units (PTU) [29], and represented a measure of inspiratory muscle strength-endurance. Pressure generation set the maximum flow of 450 ml $\cdot s^{-1}$ and allowed continuous measurement of pressure over the full inspiratory effort from residual volume to total lung capacity (TLC) until no further pressure could be generated. The published data demonstrated reproducibility coefficients of 0.87–0.90 for MIP measurements and 0.94–0.99 for SMIP [30].

Aerobic capacity and power output measurements

At the beginning and after 8 weeks, an incremental exercise test was performed on a cycle ergometer (Ergomedic 828 E) to measure the work capacity and VO_2max. At the time of scheduling, all participants were instructed to avoid caffeine and refrain from eating and participating in vigorous activity for at least 3 hours before the tests. On 2 separate days, they implemented an incremental test and cycle performance at the power of the ventilatory threshold (VT). The incremental test started after 5 min of 1.5 $W \cdot kg^{-1}$ body weight workload, at the rate of 50 rev $\cdot min^{-1}$. In the main phase of the test, the workload was increased by further 25 W each minute.

The participants were instructed to continue until they could no longer pedal owing to volitional exhaustion. The cycle performance at the power of VT ($W \cdot kg^{-1}$) (continued to volitional exhaustion) was measured on the following day. All participants, therefore, exercised to a self-determined maximum. The tidal volume (V_T), minute ventilation (VE), VO_2, ventilatory equivalent for O_2 (VE/VO_2), VO_2/HR, and HR were continuously monitored; 15 s averaging was applied (Quark b2, COSMED). The accuracy of the incremental load was achieved by use of processors which checked the actual workload. The incremental loads for each participant were programmed manually. The same resistance was added in the increments before and after the programs of training by the technician administering the test, and was adjusted for each participant. Ratings of perceived exertion were recorded to assess the perceived exercise at the end of the incremental test. Work capacity was defined as power output (energy expended, in watts) at the end of the protocol.

Statistical analyses

Between-group baseline characteristics, anthropometric data (mass, height, body fat, body mass index), lung function data, aerobic capacity, and power output were compared with the cross-sectional ANOVA method. Prior to all analyses, normality of the data was assessed by the one-sample Kolmogorov-Smirnov test. The 2-way repeated measures ANOVA was used to identify differences before and after training between and within groups for inspiratory pressure data, lung function, work capacity, and power output. For all significant data, unplanned, pair-wise multiple comparisons were made with the Tukey critical difference test. Differences were considered significant at $p < 0.05$. All presented values are means ± standard deviations. The statistical calculations were performed with the use of Statistica software, version 8.

Ethical issues

The study was approved by the Gdansk University of Physical Education and Sport Bioethical Committee. The experiment was conducted in accordance with the ethical standards established in the Declaration of Helsinki.

Results

The evaluation of the fitness training program intensity based on averaging HR for the entire period of training is presented in Table 2.

The cross-sectional ANOVA method showed no significant differences between the groups for mean HR ($F = 0.28$, $p = 0.7576$), for HR peak ($F = 0.31$, $p = 0.7343$), or for Borg scale for rating of perceived exertion (BSRPE) scores ($F = 0.21$, $p = 0.2776$).

No significant changes in body composition in the experimental or control group compared with baseline were observed after completion of the training (Table 3).

The results showed that in the experimental group, the use of elastic belts caused a significant increase in FEV1, PEF, MVV, MIP, MEP, and SMIP as compared with the baseline values. In the control group, only PEF was improved (Table 4).

The comparison of the groups after training showed significant differences in the values of MVV, MIP, and SMIP. In the control group, only PEF values changed significantly after the training. The results of the incremental test showed a significant increase in aerobic power and maximal power output in the experimental group. Additionally, effects of the training in the group using elastic belts on V_T, peaks of lung ventilation, and the relation of VO_2 to HR were observed (Table 5).

Table 2. The mean and peak heart rate for the whole training program, and the mean rating of perceived exertion scores for the 60-minute sessions

Characteristics	Experimental group	Control group
HR, mean ($beat \cdot min^{-1}$)	148.4 ± 11.86	146.8 ± 11.18
HR, peak ($beat \cdot min^{-1}$)	178.42 ± 7.47	177.65 ± 7.67
BSRPE	7.9 ± 1.4	7.6 ± 1.2

HR – heart rate, BSRPE – Borg scale for rating of perceived exertion scores in the incremental tests

Table 3. Characteristics of body composition in the experimental and control groups before and after endurance fitness training

Characteristics	Before training		After training	
	experimental group	control group	experimental group	control group
Body mass (kg)	64.62 ± 9.48	65.21 ± 7.57	64.90 ± 9.42	64.7 ± 8.01
BMI ($kg \cdot m^{-2}$)	22.51 ± 1.98	23.36 ± 2.68	22.68 ± 2.03	23.56 ± 3.10
Fat (kg)	18.55 ± 6.89	18.89 ± 6.02	18.52 ± 6.67	18.74 ± 6.13
Fat (%)	26.31 ± 6.12	26.05 ± 5.35	27.52 ± 6.81	28.42 ± 6.11
FFM (kg)	46.51 ± 3.13	45.92 ± 2.19	46.65 ± 3.16	46.05 ± 2.44

BMI – body mass index, FFM – fat free mass

Table 4. Characteristics of lung function in the experimental and control groups before and after endurance fitness training

Characteristics	Before training		After training	
	experimental group	control group	experimental group	control group
FVC (l at BTPS)	3.93 ± 0.52	3.75 ± 0.42	4.23 ± 0.71	3.94 ± 0.38
FEV1 (l at BTPS)	3.18 ± 0.4*	3.20 ± 0.50	3.35 ± 0.41*	3.30 ± 0.30
PEF ($l \cdot s^{-1}$)	6.28 ± 1.43*	6.21 ± 1.29**	7.31 ± 0.76*	7.23 ± 0.71**
MVV ($l \cdot min^{-1}$)	130.4 ± 11.2*	128.2 ± 9.4	143.6 ± 11.1*	134.9 ± 12.6
MIP (–cm H_2O)	96.4 ± 14.7*	90.6 ± 19.7	111.1 ± 15.7*	98.1 ± 20.3
MEP (cm H_2O)	121.5 ± 18.4*	121.1 ± 13.7	132.0 ± 21.4*	128.0 ± 13.3
SMIP (PTU)	446.1 ± 104*	435.3 ± 119	634.7 ± 127*	502.1 ± 117

FVC – forced vital capacity, BTPS conditions – body temperature, ambient pressure, saturated with water vapour, FEV1 – forced expiratory volume in 1 s, PEF – peak expiratory flow, MVV – maximal voluntary ventilation, MIP – maximal inspiratory pressure, MEP – maximal expiratory pressure, SMIP – sustained maximal inspiratory pressure, PTU – pressure time unit
* – significant differences before vs. after training ($p < 0.05$), ** – significant differences before vs. after training ($p < 0.01$)

Table 5. Characteristics of aerobic capacity and work output in the incremental maximal test before vs. after the 8-week endurance fitness training with (experimental group) and without (control group) increasing inspiratory muscles work with the use of elastic belts

Characteristics	Before training		After training	
	experimental group	control group	experimental group	control group
BFmax ($breath \cdot min^{-1}$)	42.90 ± 8.18	42.13 ± 6.9	42.11 ± 8.04	42.35 ± 6.37
V_{Tpeak} (l)	1.99 ± 0.43*	1.88 ± 0.27	2.24 ± 0.34*	1.95 ± 0.36
VEmax ($l \cdot min^{-1}$)	84.5 ± 17.7*	79.4 ± 8.5	94.2 ± 14.8*	82.1 ± 13.2
VE/VO_2max	36.71 ± 1.92	33.81 ± 5.43	35.20 ± 4.70	32.99 ± 5.22
VO_2/HRmax	12.58 ± 2.42*	11.94 ± 1.20	13.82 ± 2.20*	12.15 ± 1.13
HRmax ($beat \cdot min^{-1}$)	187.2 ± 4.4	185.0 ± 3.4	188.1 ± 5.4	187.4 ± 2.2
VO_2max ($ml \cdot min^{-1}$)	2283 ± 382*	2192 ± 273	2531 ± 416*	2276 ± 230
VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$)	35.52 ± 5.2*	33.86 ± 4.57	39.36 ± 5.76*	35.51 ± 4.41
Pmax (W)	204.5 ± 31.2*	204.5 ± 24.5	234.0 ± 28*	209.0 ± 20.2
Pmax ($W \cdot kg^{-1}$)	3.19 ± 0.45*	3.16 ± 0.42	3.65 ± 0.44*	3.34 ± 0.63
Power VT (W)	131.8 ± 22.6*	138.6 ± 20.5	159.1 ± 23.1*	147.7 ± 17.5
Power VT ($W \cdot kg^{-1}$)	2.06 ± 0.35*	2.14 ± 0.32	2.47 ± 0.33*	2.33 ± 0.43
Performance at VT (min)	21.0 ± 6.1*	22.1 ± 6.9*	33.8 ± 9.9*	28.2 ± 8.7*

BFmax – maximum breathing frequency, V_T – tidal volume, VE – minute ventilation, VO_2 – oxygen uptake, HR – heart rate, Pmax – maximal power, VT – ventilatory threshold * – significant differences before vs. after training ($p < 0.05$)

Table 6. Statistical characteristics (test – F, and probability – p) of differences (in the function test and probability test) in the aerobic capacity and work output in the incremental maximal test between the groups before and after endurance fitness training; differences are significant at $p < 0.05$

Indices	Statistic characteristics of differences between experimental and control groups			
	Before training		After training	
	F	P	F	P
BFmax	0.00	0.9714	0.01	0.9136
V_{Tmax}	0.73	0.4025	3.48	0.0491*
VEpeak	0.73	0.4022	4.07	0.0502
VE/VO_2max	2.79	0.1100	1.09	0.3085
VO_2/HRmax	0.60	0.4475	5.00	0.0369*
HRmax	1.65	0.2138	0.13	0.7202
VO_2max	0.41	0.5292	4.14	0.0414*
VO_2max	0.63	0.4365	4.10	0.0436*
Pmax	0.00	1.0000	5.76	0.0362*
Pmax ($W \cdot kg^{-1}$)	0.02	0.8781	4.79	0.0354*
Power VT (W)	4.32	0.4674	4.69	0.0485*
Power VT ($W \cdot kg^{-1}$)	2.67	0.5873	4.76	0.0392*
Performance at VT	1.67	0.7653	5.76	0.0167*

F – function test, P – probability test, BFmax – maximum breathing frequency, V_T – tidal volume, VE – minute ventilation, VO_2 – oxygen uptake, HR – heart rate, Pmax – maximal power, VT – ventilatory threshold
* – significant differences before vs. after training ($p < 0.05$)

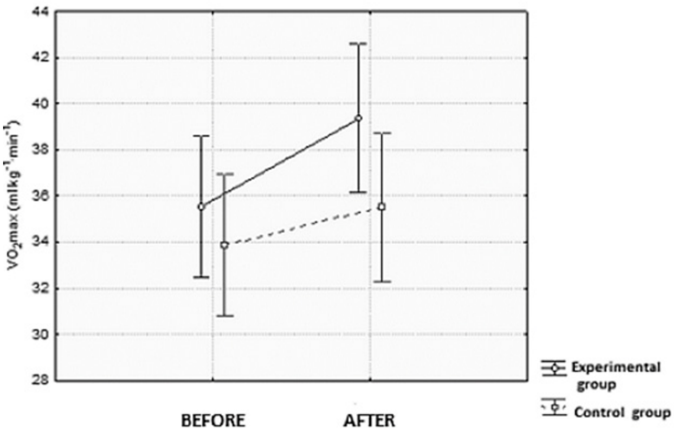

Figure 1. The changes of VO_2max (ml · kg^{-1} · min^{-1}) in the incremental test during the training in the experimental and control groups

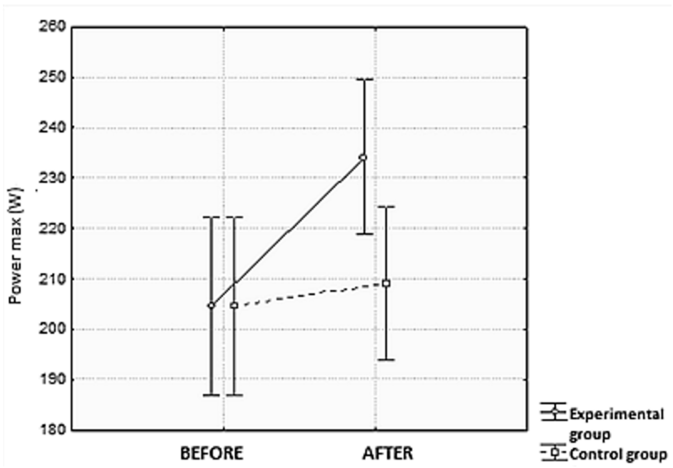

Figure 2. The changes of maximal power in the incremental test during the training in the experimental and control groups

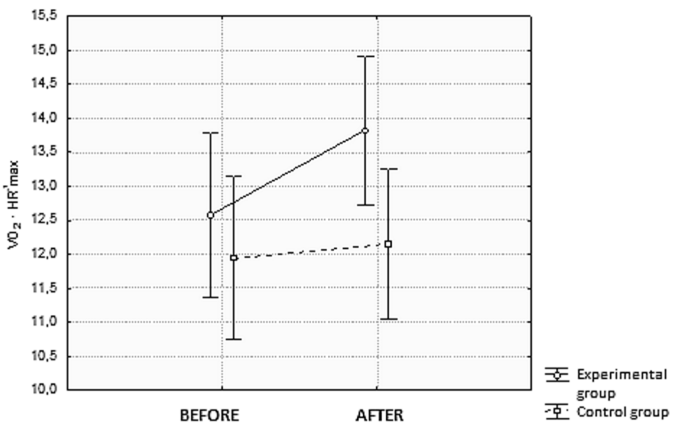

Figure 3. The changes of VO_2/HRmax index in the incremental test during the training in the experimental and control groups

Table 6 summarizes the statistical characteristics of differences between the groups in the function test (F) and probability (*p*) among the studied women before and after training.

Because the continuing 8 weeks of training demonstrated a statistically significant interaction effect for maximum VO_2 and maximum power, it supported the faster growth rates during the training. The rate of increase in VEpeak, VO_2max (Figure 1), maximal power (Figure 2), and VO_2/HRmax (Figure 3) during the training was significantly higher in the group with elastic belts than in the control group.

Discussion

Our study demonstrated that fitness training with elastic belts significantly improved pulmonary capacity (FEV_1, PEF, MVV, MIP, MEP, SMIP, V_{Tmax}, and VEpeak) in relation to the baseline. In the control group, only the values of PEF changed significantly as compared with those before training. The pulmonary capacity would increase aerobic capacity and power output after training in the group that applied elastic belts. This growth was significantly higher than the increase observed in the control group, in which it turned out statistically not significant. These results may indicate that increasing the inspiratory muscle work by elastic belts as an addition to fitness endurance exercises improves strength and strength-endurance of inspiratory muscles and the functional cardio-respiratory capabilities (VO_2max, VEpeak, VO_2/HR, VT), which causes an increase in aerobic work output (maximal power and endurance at VT) in fitness training. In the participants who did not use elastic belts in physical training, typical of young women fitness in content and intensity, the aerobic power and maximum power of work were not significantly increased. The maintaining of the power exercise at VT by the women in the control group increased significantly lesser.

Although previous studies have shown that the pulmonary system is unaffected by whole-body exercise, evidence now suggests that a regimen of high-intensity exercise can be a factor limiting maximal endurance working capacity. In healthy people and in athletes, the inability to sustain high levels of ventilation can restrict maximal aerobic capacity [7, 12, 31]. It has been shown that IMT without the addition of systemic exercise may result in quantitative outcomes [9, 10, 17, 32]. The total mechanical work done during breathing is the sum of all elastic and non-elastic work components. This resistance is composed of work that must be carried out against lung elastic recoil, chest wall recoil, and surface tension. In previous studies, IMT was represented by the non-elastic component referred to the effort required to overcome airway resistance. However, no research concerning increased elastic resistance additive to chest wall recoil has been conducted. In this study, elastic work was increased by elastic belts. The IMT device is based on using flow inspiratory resistance. It is typically applied at rest, without physical exercises, and improves the strength of the inspiratory (and sometimes expiratory) muscles. This is indeed the main (but superficial) result of such breathing exercises. Recently published data referring to IMT intensities of 80% of peak pressure have shown an increase not only in the lung volume and diaphragm thickness, but also in the sustained maximal inspiratory pressure [8, 29]. The work capacity growth was related to the rise in the sustained maximal inspiratory pressure. This creates a possibility to improve the endurance of respiratory muscles and exercise capacity [29].

A problem arises that respiratory muscle fatigue induces hyperventilation, limiting cycle performance at the anaerobic threshold. The endurance of respiratory muscles can be related to reduced blood lactate concentration and performance at the anaerobic threshold [33, 34]. It may be improved remarkably even in special training forms. The subjects trained the respiratory muscles for 4 weeks by breathing 85–160 $1 \cdot min^{-1}$ (in normocapnia) for 30 min daily; this increased breathing endurance from 6.1 min to about 40 min. Cycle endurance at the anaerobic threshold (77% VO_2max) was improved from 22.8 min to 31.5 min, while VO_2max and the anaerobic threshold remained essentially the same [7]. The effects of IMT with flow resistance devices in cycle endurance athletes were connected with improving the time of sustained exercise intensity at the anaerobic threshold, while VO_2max and the anaerobic threshold (VO_2 in % VO_2max) remained basically unchanged [7, 8, 31]. Some studies show that IMT leads to an increase of aerobic power in hypoxic situations only [3]. This suggests that the effects of IMT may grow with the rise of IMT intensity. Increasing the time and intensity of the additional loading of inspiratory muscles is the major factor of endurance improvement. The simplest way to achieve this is to apply additional resistance of the chest wall recoil using an elastic belt. In our study, when elastic belts were involved during exercise, an increase occurred not only in work output, but in aerobic power and respiratory threshold as well. After training with elastic belts, VEpeak in the incremental exercise was increased, although VE for a given exercise intensity was reduced. Cycle performance at the power of VT ($W \cdot kg^{-1}$) was prolonged (161.1% vs. baseline). In the control group, the increase equalled 127.6%. The rise in aerobic power in our study will possibly be related to a remarkable growth of respiratory muscles endurance and the facilitated effect of the elastic belt for expiration. Additionally, the rise of the lactate kinetics removal during high intensity physical exercise will possibly be essential [33, 34]. The explanation may be also related to a reduction of vascular conductance and blood flow to the exercising legs. This was bound with accumulation of metabolites in the inspiratory and expiratory muscles. Respiratory muscles fatigue activates unmyelinated type IV phrenic afferents [19], which in turn increases sympathetic vasoconstrictor activity via the supra-spinal reflex (metaboreflex). This reduces the whole body exercise performance and the chance to reach the individual peak of VO_2. In some types of physical activity and sports (e.g. swimming), an increase in respiratory muscles work is observed.

The assessment of the character of physical training impact in this case may contribute to understanding the effects of combined physical activity and increased work of the respiratory muscles. The anomalous respiratory characteristics of competitive swimmers have been suggested to be due to the extraordinarily advanced respiratory muscle work [35]. All swimmers, not only elite individuals, appear to be a special group of athletes with lung function greater than predicted and better than in other endurance athletes [18, 36].

We suggested that the inspiratory muscles work increased by elastic resistance belts with simultaneous endurance exercises (as is created by water resistance in swimming) resulted in growing pulmonary potential, aerobic power, and working capacities in the studied young women. There are no studies related to using an inspiratory training device of that type. The additional increase of respiratory muscle work by the elastic belts is created by a rise in the resistance of the chest wall elastic structures, but not by inelastic resistance occurring in respiratory pathways, as it takes place in flow resistance devices. The degree of inspiratory muscle strength increase due to the application of the elastic belts resistance in the 8-week physical exercise was similar to that observed in an 8-week training owing to the flow resistance high intensity IMT [8]. Inspiratory muscle strength and endurance increased largely, approximating the peak of lung ventilation, deep inspiration, and working output in the maximum test on a bicycle ergometer. This contributes to an increase effect of respiratory pump on venous return and maximal cardiac output. The gradient of the negative pressure of the pleural cavity can be increased from approximately 3 cm H_2O at eupnoea to 8 cm H_2O by deep inspiration at 70% of individual vital capacity [37].

An increase in the inspiratory muscle strength-endurance improves V_T and significantly facilitates the return of the blood toward the right atrium in high intensity fatiguing exercise. As a result, conditions are created for increasing the maximal cardiac output, which mainly determines the growth of aerobic power; however, the role of this mechanism after RMT needs further research. It is noteworthy that the intensity of physical activity, estimated by the average HR and peak response for all training sessions, was not statistically significant in the experimental or the control group. The same applies to the perceived exertion. This suggests that the additional work of the inspiratory muscles induced by elastic resistance does not significantly affect the whole intensity of training sessions of this type. However, it should be noted that these data are difficult to compare, since flow resistance before and after training (measured with the use of the POWERbreathe device) and the inspiratory muscles work increased by the elastic resistance constitute rather independent impacts, especially that the latter influence (the belts) was applied during the whole exercise entity.

Conclusion

The application importance of the data is connected with the need to increase the efficiency of health-related training and to obtain its individual efficiency within an optimal amount of time. It becomes obvious that with the use of traditional means of fitness technology, it is necessary to intensify and differentiate the training stimuli. The combination of fitness training with increased inspiratory muscle work constitutes one of the crucial components in this aspect. There are many flow resistance IMT devices being developed in sports which allow to deepen the training effects for the physical working capacities. Among the professional devices described in literature applied in RMT, elastic belts with regulated tension on the lower part of the chest are advantageous in the simplicity of their practical implementation and in their natural relations with physical activity. The nature of the training effect caused by additional elastic resistance for working inspiratory muscles was similar to that with flow resistance devices. The effect of the IMT on performance and aerobic capacity in women training as shown by this study seems large. The high ventilatory requirements in endurance exercise and the inherent anatomical characteristics of females could make these groups more susceptible to expiratory flow limitation. However, detailed studies are needed to determine the additional resistance force and duration of exposure which would be most favourable to achieve the effects described for IMT. Hopefully, these findings will provide a stimulus for further, insightful investigations into the cardiopulmonary consequences of respiratory muscle work increase during fitness training exercise.

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