EFFECTS OF DIFFERENT INSPIRATORY MUSCLE TRAINING INTENSITIES ON PHYSIOLOGICAL RESPONSE TO EXERCISE IN HEALTHY MEN

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Abstract

The aim of the study was to assess the influence of various types of isolated training of the inspiratory muscles (IMT) on changes the aerobic capacity and the values of selected indices of inspiratory muscle function of healthy men. The group of 28 students did not practise competitive sports but performed moderate physical activity divided into two groups: those undergoing IMT with gradually increasing inspiratory resistance (which corresponded to 58.6±12.1% PImax in the fourth week and to 79.9±14.1% PImax in the final week) and those undergoing training of low constant inspiratory resistance (38.0±11.3% PImax). In both groups, IMT lasted 9 weeks and involved 30 inspirations performed twice a day, 6 days a week. An intermittent incremental stress test performed to exhaustion on a bicycle ergometer before and after IMT was applied. Indices of inspiratory muscle function were measured before IMT, after 4 weeks of its implementation and after IMT completion. The results confirmed that various types of IMT in combination with a moderate endurance exercise training did not significantly increase aerobic capacity in healthy men. Both types of IMT have similarly improved PImax in non-training students. Although measurements of inspiratory muscle relaxation time, active and passive time, and inspiratory time may be helpful in assessing the reproducibility of the inspiratory pressure measurements used, they do not seem to be very useful in assessing IMT effects in healthy men.

Key words*: inspiratory muscle training, healthy men, indices of inspiratory muscle function, exercise response*

Introduction

The research data published in the last several years has confirmed that respiratory muscles, like other skeletal muscles, undergo fatigue during exercise (Boussana et al., 2002; Brown and Kilding, 2011; Janssens et al., 2013; Ohya et al., 2016; Ozkaplan et al., 2005). It is emphasized that respiratory muscle fatigue can reduce exercise capacity even in athletes with a high level of training (Romer et al., 2002a). In the studies on mechanisms influencing respiratory muscle fatigue, particular attention have been paid to the the relaxation phase of diaphragm by which, the muscle actively returns to its initial length and tension (Coirault et al., 1999; Sliwinski et al., 1996a; Sliwinski et al., 1996b). This phase plays an essential role in the perfusion of blood through the muscle. The mechanism responsible for slowing down relaxation after fatigue seems to reduce rate of calcium inflow into the sarcoplasmic reticulum and of the division of cross bridges. It is assumed that, this relaxation time of the inspiratory muscles increases proportionally to the degree of fatigue of the diaphragm (Coirault et al., 1999). Therefore, in our research special attention has been given to the evaluation of the relaxation time of the diaphragm and to more precise characteristics of indicators related to the functional state of the respiratory muscles. On the other hand, in order to reduce or delay the occurrence of respiratory muscle fatigue, a separate, the respiratory muscle training and in particular the inspiratory muscles (IMT) has been proposed (Inbar et al., 2000; Klusiewicz et al., 2008; Ohya et al., 2016; Volianitis et al., 2001; Wells et al., 2005). Earlier studies by Romer and McConnell (2003) showed that the specificity of IMT effects depending on the pressure-flow model used, progressive or constant load. In the subject literature, progressive inspiratory threshold loading during IMT has been applied in a large number of studies (HajGhanbari et al., 2013). Less frequently studied the effects of IMT with a constant intensity of 100 and 80% maximum inspiratory pressure were also compared (Gething et al., 2004a), and so were the effects of IMT with an intensity of 80% maximum inspiratory pressure and minimum inspiratory resistance (Gething et al., 2004b). It should be stressed as mentioned above that are only few comparative data for the effects of using IMT with progressive and constant inspiratory resistance. Additionally, from a practical point of view, the question arises as to whether the use of low, constant inspiratory resistance without the incremental threshold load technique should facilitate this type of training and may be important for optimal benefits for healthy students. Therefore, the main aim of the study was to assess the influence of various types of isolated training of the inspiratory muscles, progressive and constant load, on changes the aerobic capacity and the values of selected indices of inspiratory muscle function of healthy men.

Although in last systematic review Shei (2018) documented that studies for the most part have confirmed the efficacy of respiratory muscle training for enhancing physical capacity in a different endurance-based sports, it is not obvious whether training developing the strength of the respiratory muscles is always effective in improving exercise capacity healthy people. In addition, it is not clear which type of IMT is of sufficient magnitude to increase an aerobic capacity of healthy men, students of physical education, which simultaneously practicing only moderate training programme.

Methods

Participants

Twenty-eight healthy, non-smoking students from the University of Physical Education took part in the study. The students did not practise competitive sports, but they performed moderate physical activity as part of the curriculum of their studies. The basic characteristics of the subjects are presented in Table 1. The students were divided randomly into two groups: those undergoing IMT with gradually increasing inspiratory load (Progressive Load) and those performing training with constant inspiratory load (Constant Load). It was assumed that the average values of the maximal oxygen consumption (VO_2max) obtained in a test on a bicycle ergometer and maximal inspiratory pressure (PImax) would not differ significantly between the two groups. In case of a difference in the mean VO_2max or PImax values between the groups, the composition of the groups was changed by selecting students with higher or lower values of the discussed index. Differences in this context could have had an impact on the effects of IMT. The study was conducted according to the Declaration of Helsinki (1975) and was approved by the Research Ethics Committee of (***deleted for blind copy***).

Test procedures

As in the research of other authors (Romer and McConnell, 2003) the IMT lasted 9 weeks and included the following measurements for each student carried out in the order given:

- initial anthropometric and inspiratory muscle function measurements and exercise test,
- periodic inspiratory muscle function measurements after 4 weeks of IMT,
- final inspiratory muscle function measurements and exercise test.
  None of the students had prior experience with spirometry or IMT.

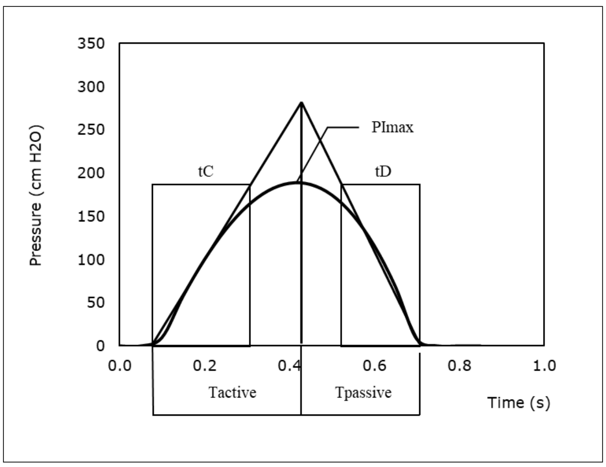
Anthropometric measurements

The anthropometric data recorded included the body height and weight of the subjects. The amounts of body fat and fat-free mass were assessed by means of a bioimpedance (BIA) body fat analyzer (Tanita BC-418 MA, Japan).

Inspiratory muscle function measurements

The subjects were made familiar with the methods and procedure used in the study, and all the measurements were performed by the same technician. Inspiratory muscle function measurements were carried out according to ATS/ERS recommendations (Am J Respir Crit Care Med, 2002). Maximal inspiratory mouth pressure (PImax) was measured using a procedure described by several authors; this was a simple, reproducible, and non-invasive method of evaluating the strength of the inspiratory muscles (Klusiewicz et al., 2008; Romer and McConnell, 2004). A minimum of 10 and a maximum of 15 inspiratory manoeuvres were performed. The three highest values, which varied by no more than 5%, were established as the maximum. The initial position of the inspiratory muscles was controlled by having the subjects expire up to the residual volume (RV) before the measurement. All of the measurements were performed in a standing position. The subjects were verbally motivated to exert maximal effort. The measurement points which were used are shown in Figure 1.

Figure 1. Curve for changes in inspiratory pressure during vigorous inspiration with measuring points (PImax – maximum inspiratory pressure, tC – diaphragm strain time C-climb, tD – diaphragm relaxation time, Tactive – active time, Tpassive – passive time



The following data were recorded:

– active time (Tactive) – the segment of the time axis between the point of intersection of the tangents projected onto the time axis and the intersection of the tangent for the rising part of the curve with the time axis,

– passive time (Tpassive) – the segment of the time axis between the point of intersection of the tangents projected onto the time axis and the intersection of the tangent for the falling part of the curve with the time axis,

– inspiratory time (Tin),

– diaphragm strain time C-climb (tC) – the time it takes for the negative pressure to climb (build-up) from its lowest value (zero) of PI (Inspiratory pressure) to the highest value (PImax),

- diaphragm relaxation time (tD) – the time it takes for the negative pressure to fall from its highest value (PImax) to zero (PIo),

The relaxation time of the inspiratory muscles is the time taken for the negative pressure to drop from its highest value (PImax) to zero (PIo). The PImax and PIo points were calculated based on the tangent for the middle segment (50-80%) of the relaxation time curve. It is worth emphasizing that our previous research (Klusiewicz et al., 2014) has confirmed the reproducibility of the method that was used to measure the indices of inspiratory muscle function mentioned above (we found no statistically significant differences between repeated measurements, as well as observing significant correlations and a total error rate of 11 to 24% for all of the indices of inspiratory muscle function examined).

The measurements were performed using a spirometer which was compatible with Lungtest 1000 software (MES, Cracow, Poland). The apparatus transmitted the pressure from the measurement site (the mouthpiece) to the pressure sensors.

Exercise test

The subjects performed an intermittent incremental stress test consisting of several trials lasting 3 minutes, with 1-minute breaks between the trials, on the Corival bicycle ergometer (Lode B.V., Netherlands). The power used in the initial trial was 50 W, and it was increased by 50 W in each successive trial to exhaustion.

Lactate concentrations (LA) were measured in the blood collected from the fingertip at rest, immediately after the subjects completed each trial and 3 minutes after the entire test was performed, using the Super GL2 device (Dr Müller, Germany). Respiratory exchange parameters were recorded continuously in a breath-by-breath (BxB) mode using a Cortex 3B MetaLyzer (Cortex Biophysik, Germany) over the entire duration of the test. Heart rate (HR) was recorded by means of a Polar S610i heart rate monitor (Electro Oy, Finland).

Maximal oxygen uptake was defined as the highest amount of oxygen consumed by the athlete's organism during 30 s of the test. The maximal intensity exercise necessary for estimation of VO_2max was defined by the following criteria: the VO_2 plateauing with increasing workload, the post-exercise blood lactate concentration >8 mmol/l, the Respiratory Exchange Ratio (RER) >1.1, and the attainment of the age-adjusted maximal heart rate expressed as HRmax = 220 – age of the subject. If at least two of the above criteria were met during the exercise, the attained effort and oxygen uptake were regarded as maximal.

The value of the anaerobic threshold (AT4) was determined by interpolation for a blood lactate concentration of 4 mmol/l.

Inspiratory muscle training

The IMT consisted of 30 inspirations performed twice a day, 6 days a week, using the POWERbreathe® medium resistance muscle training device (IMT Technologies, Birmingham, UK). The main principle was to overcome a certain inspiratory resistance and perform free expiration. The inspirations were full-volume, fast, and strong while the expirations were long and slow. A single training session did not last longer than 5 min.

In Progressive Load and Constant Load IMT groups, the first week of training the resistance was set to the "0" position using the resistance knob (23 cmH_2O). The inspiratory resistance was low, because it was aimed at making it possible for the students to learn the correct breathing technique. In the Progressive Load IMT group in the following 8 weeks, gradually increasing resistance was applied in consecutive weeks, so that only 30 manoeuvres could be completed as described by the manufacturer. Inspiratory resistance was increased individually as students progressed, and the criterion for the magnitude of resistance was the ability to perform 30 maximum inspirations. In the fourth and ninth week of IMT the inspiratory resistances were 84±20 cmH_2O (58.5±12.1% PImax) and 126±32 cmH_2O (79.9±14.1% PImax), respectively. In the Constant Load IMT group in the following 8 weeks, a constant resistance value of "1" position using the resistance knob (39 cmH_2O, 38.0±11.3% PImax) was applied.

During the 9 weeks of IMT, its correct implementation was supervised 5 days a week by trained instructors and the realization of the IMT was recorded by the students in specially prepared training diary. The completion of the established

IMT in Progressive Load and Constant Load groups were respectively 83±11 and 85±13%.

Physical fitness training

The students participating in the research took part in the practical training programme included in the curriculum of the University of Physical Education, in the volume of 4 to 7 hours of moderate physical activity per week. The activities offered had a varied character and included team games, athletic competitions, gymnastics, and swimming.

Statistical calculations

The statistical analysis started with checking the assumptions for the analysis of variance (ANOVA). Basic somatic characteristics of the groups were compared using one-way analysis of variance, while the values for the other indicators were analysed by means of two-way analysis of variance (2 x 2 and 2 x 3 ANOVA; group x term). The significance of differences between the means was evaluated using the Tukey test for post-hoc comparisons. Statistical significance was set at P<0.05. Calculations and statistical analyses were performed with the use of Statistica software v. 13.1 (StatSoft).

Results

The IMT groups (Progressive Load and Constant Load) examined did not differ statistically significantly in terms of basic morphological characteristics, PImax, or VO_2max in the baseline measurement, as shown in Table 1.

Table 1. Basic morphological characteristics, maximum inspiratory pressure (PImax), and maximal oxygen uptake (VO_2max) in groups of students undergoing 9-week respiratory muscle training with graded inspiratory resistance (Progressive Load) and with constant inspiratory resistance (Constant Load) (mean ± SD)

Variable/Group	Progressive Load (n=14)	Constant Load (n=14)
Age (years)	21.4±1.7	22.0±2.2 ^{ns}
Body height (cm)	181±5	181±5 ^{ns}
Body weight (kg)	75.1±8.9	74.3±8.4 ^{ns}
BMI (kg/m^2)	23.0±2.0	22.7±1.9 ^{ns}
Fat mass (%)	12.4±3.6	11.1±4.2 ^{ns}
PImax (cmH_2O)	122±23	112±34 ^{ns}
VO_2max (ml/kg/min)	44.8±6.5	47.3±7.1 ^{ns}

^{ns} – no statistically significant intergroup differences.

In both groups, after 4 weeks of IMT, a statistically significant increase in PImax was observed, representing 19-20% of the baseline value (Table 2). The following 5 weeks of the training did not significantly improve value in either group compared to the 4th week. Moreover, there were no statistically significant differences between the groups in the subsequent periods of the study. Other indices of inspiratory muscle function (Tactive, Tpassive, tD, and Tin) did not differ significantly between measurements or groups, as presented in Figures 2 and 3.

Table 2. Changes in maximum inspiratory pressure (PImax) in baseline measurement (0), after 4 weeks, and after 9 weeks in two groups of students undergoing 9-week respiratory muscle training (IMT) with graded inspiratory resistance (Progressive Load) or with constant inspiratory resistance (Constant Load) (mean ± SD)

	PImax (cm H_2O)		PImax (difference, %)		
Week No.	Progressive Load	Constant Load	Weeks of IMT	Progressive Load	Constant Load
Baseline (0)	122±23	112±34	0-4	19.9±19.0	19.2±16.6
4 wk. of IMT	143±23^{A}	130±30^{A}	4-9	10.6±19.1	−0.8±8.3
9 wk. of IMT	155±33^{A}	129±31^{A}	0-9	30.4±33.1	18.5±18.4
Time effects: F=24.42; P<0.0001					

(difference, %) – percent difference with respect to baseline level, ^{A}– different from baseline level (P<0.05).

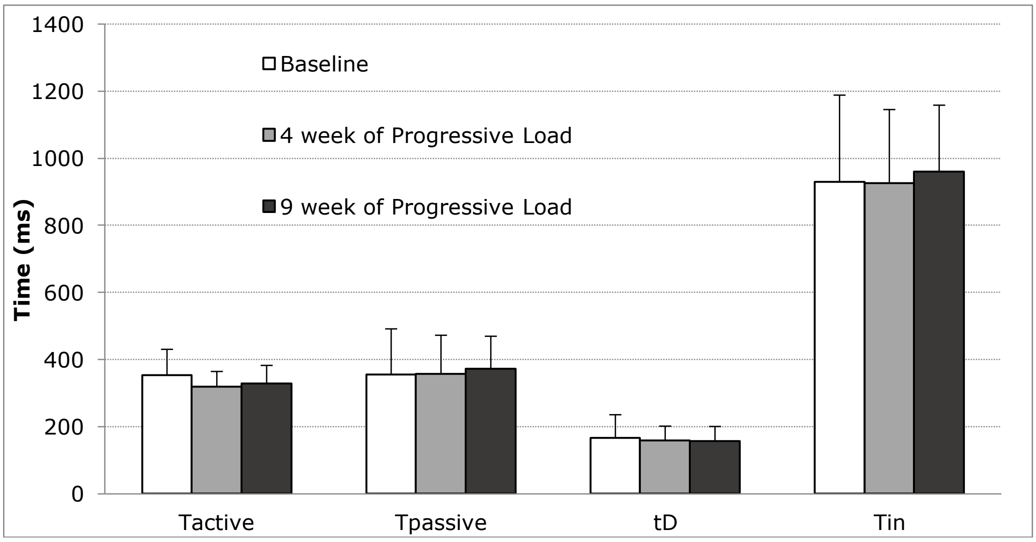


Figure 2. Changes in active time (Tactive), passive time (Tpassive), diaphragm relaxation time (tD), and inspiratory time (Tin) during 9-week training of inspiratory muscles with graded inspiratory resistance (Progressive Load) in the group of students (n=14); Time effects - no statically significant

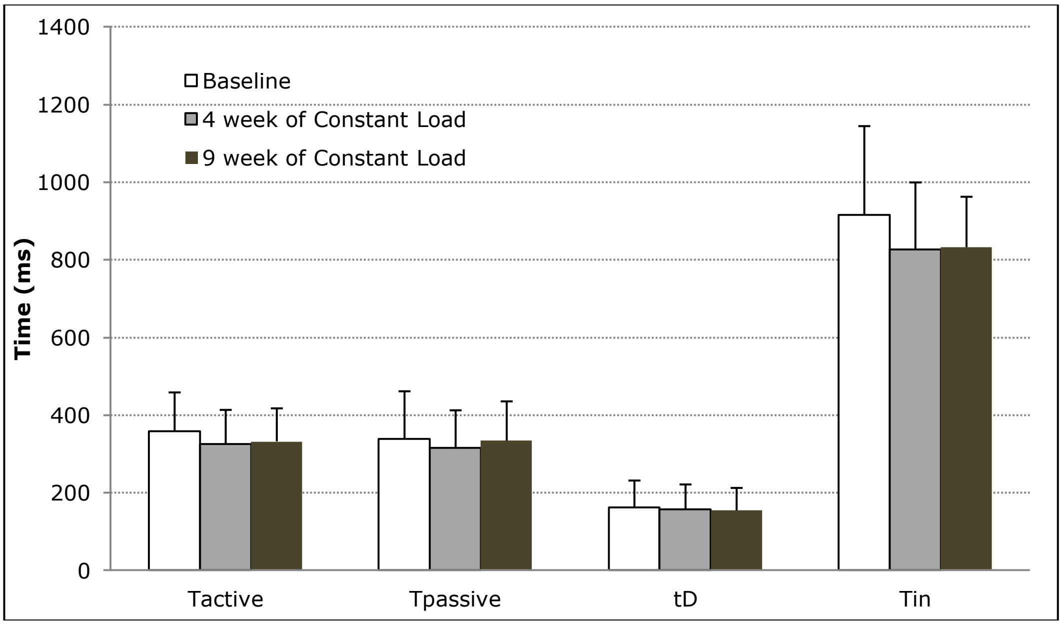


Figure 3. Changes in active time (Tactive), passive time (Tpassive), diaphragm relaxation time (tD), and inspiratory time (Tin) during 9-week training of inspiratory muscles with constant inspiratory resistance (Constant Load) in the group of students (n=14)); Time effects - no statically significant

The various types of IMT applied did not significantly improve test duration, test work, peak power, VO_2max and power at AT4 in the final measurement (9 weeks) compared to the baseline measurement, as shown in Table 3.

Table 3. Values of selected exercise indicators in the intermittent incremental stress test in the baseline measurement (0) and after 9 weeks in two groups of students undergoing 9-week inspiratory muscle training with graded inspiratory resistance (Progressive Load) or with constant inspiratory resistance (Constant Load) (mean ± SD). ANOVA revealed no significant time and group effects

Variable/Group	Week No.	Progressive Load (n=14)	Constant Load (n=14)
Test duration	0	16:00±2:10	16:13±2:11
(min:s)	9	15:53±2:19	16:49±2:35
Work	0	2.07±0.49	2.14±0.46
(kJ/kg)	9	2.06±0.54	2.28±0.53
Peak power	0	3.84±0.55	3.87±0.51
(W/kg)	9	3.75±0.69	4.04±0.53
VEmax	0	120±26	109±19
(l/min)	9	123±28	124±19
VO_2max	0	44.8±6.5	47.3±7.1
(ml/kg/min)	9	45.4±5.7	48.3±6.6
Power at AT4	0	2.10±0.51	2.17±0.41
(W/kg)	9	2.02±0.38	2.13±0.31
LA	0	12.7±1.8	12.4±2.4
(mmol/l)	9	13.7±2.8	13.4±1.7

VEmax – maximal pulmonary ventilation, VO_2max – maximal oxygen uptake, Power at AT4 – power at anaerobic threshold.

Discussion

The most important conclusion of the study was to point out that after 9 weeks of IMT accompanied by parallel regular, physical fitness training, no significant differences were found in the improvement of aerobic capacity between groups undergoing various types of IMT. In the case of the Progressive Load group, test duration was practically the same before and after the 9-week training (the difference was only 7 s), whereas in the case of the Constant Load group, this indicator was increased by 30 s (Table 3). In both groups high post-exercise LA concentration before and after IMT was found, confirming the high engagement of the subjects in performing the exercise with maximum intensity.

The demonstrated changes in exercise capacity after various types of IMT did not differ significantly between the study groups, which was consistent with the observations of previous authors who found no significant differences between Progressive Load and Constant Load IMT groups (Illi et al., 2012). According to these authors, the intermittent incremental test, applied in our work, was ranked – along with the constant load tests – among the most diagnostic in assessing IMT effects.

Based on literature data, tests with submaximal intensity indicated a higher improvement in results after IMT (from +24 to 50%) compared to efforts of high intensity simulating competitive effort (from +1.8 to 3.5%). For highly trained athletes, the improvement of exercise indicators after this type of training was found to be relatively lower, but the modality of performing the test – for example, rowing, pedalling, or swimming – was not significant (Sheel, 2002; Illi et al., 2012). On the other hand, it should be stressed that the characteristics of the study groups (healthy young students with no competitive training) had a significant impact on the changes observed in physical fitness after IMT. In addition, it is worth mentioning that not all authors examining different groups of competitors reported a positive effect of IMT on exercise capacity (Bell and Game, 2013; Driller and Paton, 2012; Forbes et al., 2011; Riganas et al., 2008; Wiliams et al., 2002).

At present, various hypotheses explaining the physiological mechanisms through which IMT can improve exercise capacity are being proposed. IMT can increase the activity of oxidizing enzymes and change the proportions of muscle fibres and the size of the respiratory muscles (according to HajGhanbari et al., 2013). These adaptations lead to an improvement in the aerobic capacity of the respiratory muscles by increasing both oxygen metabolism and supply. This can be one of the factors delaying the onset of fatigue and reducing competitive blood flow between the respiratory and limb muscles during exercise. Ultimately, IMT can also attenuate the metabolic response of the respiratory muscles and alleviate the feeling of exercise dyspnea by improving the subjective assessment of effort (according to HajGhanbari et al., 2013). In addition, with a certain amount of effort, IMT reduces blood lactate levels (McConnell and Sharpe, 2005; Romer et al., 2002b) and decreased exercise heart rate (Gething et al. 2004a). It should be added that the changes described above have been observed during dynamic efforts. More recent review on factors influencing the improvement of exercise performance after respiratory muscle training mention reorganization of motor recruitment pattern (adoption of "diaphragm-sparing" strategy and reduced phrenic motoneuron recruitment, increased activation of accessory respiratory muscles, reduction of cortical activation in premotor, motor and sensory cortical areas and reduction of dyspnea), improved ventilator efficiency and reduced cytokine release (Shei, 2018).

Another issue discussed in the paper was a detailed analysis of inspiratory muscle function indicators related to the measurement of the strength of the respiratory muscles. The question arises as to whether other indicators of inspiratory muscle function are also affected by IMT. The results obtained did not confirm this hypothesis as we found no significant effect of IMT on the values of active and passive time, diaphragm relaxation time, or inhalation time (Figs. 2 and 3). It seems that in healthy individuals, this type of analysis is of limited usefulness in the assessment of IMT effects (Klusiewicz et al., 2014).

The effects of IMT will be dependent on the correct determination of the main training load, including inspiratory resistance, frequency and duration of training units, their arrangement in the training cycle, and so on. With respect to only inspiratory resistance, a wide range of 50 to 80% of maximum inspiratory pressure was used in research studies; the duration of IMT (3 to 12 weeks) and training protocols varied as well. Additionally, the research was conducted with the use of various types of devices for this type of training; different laboratory tests were used to assess exercise capacity; the groups examined had a varied level of training and were generally few; and in some cases, there was no control group (HajGhanbari et al., Illi et al., 2012; 2013; Sheel, 2002). According to the manufacturer of breathing trainers, effective inspiratory resistance during this type of training should exceed 30% of the individual PImax value. The meta-analysis on IMT assumes a load of less than 15% of the maximum inspiratory pressure as fictitious resistance (sham group) (HajGhanbari et al. 2013). In the current study, in the both IMT groups, the first week of training was implemented with 22.4±6.6% PImax, in order to learn the correct execution of the IMT. In the next 8 weeks, in the Constant Load IMT group the training was applied at the constant value of 38.0±11.3% PImax. Inspiratory resistance in this group was therefore higher than fictitious resistance, but close to the minimum level of effectiveness and thus easy to implement. We expected that this type of IMT would have low efficacy, because in many studies conducted so far, the training started with resistance equal to 50% PImax, which was then increased in the following weeks, and the need to maintain resistance at the level of 50-80% PImax was mentioned (HajGhanbari et al. 2013).

The current study found a significant improvement in PImax in the first 4 weeks of training regardless of the type of IMT. The improvement in PImax in the first 4 weeks was 19.9±19.0% for Progressive Load IMT and 19.2±16.6% for Constant Loud IMT. There was no significant improvement in PImax in the following weeks. The total improvement of PImax during the whole training in the Progressive Load IMT group was 30.4±33.1%, and it was 18.5±18.4% in the Constant Load IMT group. According to Romer and McConnell (2003) most of the pressure-flow power adaptations were expressed fully by the sixth week of IMT. The above-described PImax increase in the IMT model with graded resistance was similar to the one obtained in previous studies of leading Polish rowers (34±19%) (Klusiewicz et al. 2008) and lower than that recorded in British female rowers (45.3±29.7%) (Volianitis et al. 2001). These differences could be related, inter alia, to the use of IMT with a longer duration in the female rowers (11 weeks) compared to the students (9 weeks).

Conclusion

In conclusion, the most important finding of the study was that isolated 9-week IMT applied in combination with moderate physical activity did not increase aerobic capacity in healthy men. Progressive Load and Constant Load program of IMT have similarly improved PImax. Although measurements of diaphragm relaxation time as well as active, passive, and inspiratory time may be helpful in assessing the repeatability of the inspiratory pressure measurements performed, they do not seem to be very useful in assessing IMT effects in healthy men.

Acknowledgments

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