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INSPIRATORY MUSCLE TRAINING INCREASES TIDAL VOLUME DURING INCREMENTAL EXERCISE WITH REDUCED BREATHING – A PILOT STUDY

VADBA ZA MOČ VDIŠNIH MIŠIC POVEČA DIHALNI VOLUMEN MED VEČSTOPENJSKO OBREMENITVIJO Z NIŽJO FREKVENCO DIHANJA – PILOTSKA RAZISKAVA

ABSTRACT

The purpose of this study was to investigate the influence of inspiratory muscle training (IMT) on tidal volume (V_T or inspiratory volume) during incremental exercise where breathing frequency is restricted. 21 healthy subjects (9 males, 12 females) were divided into two groups: experimental (Group E) and control (Group C). Group E performed 30 dynamic inspiratory efforts twice daily against a pressure-threshold load of ~50% maximal inspiratory pressure. A spring-loaded threshold inspiratory muscle trainer was used for this IMT. Group C received no IMT. Prior to and following a 6 week intervention both groups performed incremental cycle ergometry until volitional exhaustion with reduced breathing frequency (RBF), which was defined as 10 breaths per minute. After training, the inspiratory muscle strength in Group E (+35 ± 16%; $p<0.01$) and submaximal and maximal V_T was higher (+13 ± 14%; $p<0.01$) during incremental cycle ergometry with RBF compared with pre-training. The latter adaptation was the reason for the extended time to exhaustion (17 ± 15%; $p<0.01$) following training. V_T and time to exhaustion were unchanged in Group C. It could be concluded that IMT increased V_T during incremental exercise where breathing frequency was restricted. However, future research is needed to establish the efficacy of this training as a supplement to regular exercise training with or without RBF.

Keywords: inspiratory muscles, training, reduced breathing, incremental exercise, swimming

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IZVLEČEK

Namen raziskave je bil ugotoviti učinek šest tedenske vadbe za moč vdišnih mišic na dihalni volumen med večstopenjskim obremenilnim testom z nižjo frekvenco dihanja. Enaindvajset merjencev (devet fantov in dvanajst deklet) je bilo razdeljenih v dve skupini: poskusno (skupina E) in referenčno (skupina C). Skupina E je dvakrat dnevno vadila s 30 dinamičnimi vdihi in izdihi s pomočjo dihalnega trenažerja, pri čemer je bil upor vdiha približno 50% največjega vdišnega pritiska. Skupina C opisane vadbe ni opravljala. Pred vadbo in po njej sta obe skupini opravili večstopenjski obremenilni test na kolesarskem ergometru z nižjo frekvenco dihanja. Le-ta je bila določena z 10 vdihi na minuto. Skupina E je z vadbo povečala moč vdišnih mišic (+35 ± 16%; p<0.01) in dihalni volumen (+13 ± 14%; p<0.01) med večstopenjskim obremenilnim testom z nižjo frekvenco dihanja. Slednje je omogočilo tudi daljše opravljanje tega testa (čas trajanja se je z vadbo podaljšal za 17 ± 15%; p<0.01). Pri skupini C opisanih sprememb ni bilo. Glede na dobljene rezultate lahko zaključimo, da vadba za moč vdišnih mišic poveča dihalni volumen med večstopenjskim obremenilnim testom z nižjo frekvenco dihanja. Kljub vsemu pa verjamemo, da nam bodo verodostojnejše in uporabnejše podatke dale bodoče raziskave, ki bodo ugotovile učinek tovrstne vadbe kot dodatek običajni vadbi z nižjo frekvenco dihanja ali brez nje.

Ključne besede: vdišne mišice, vadba, zmanjšano dihanje, večstopenjska obremenitev, plavanje

INTRODUCTION

Perhaps the best example in sport of where breathing frequency is naturally reduced is during front crawl swimming. While performing the front crawl swimmers may use different breathing patterns. They usually take a breath every second stroke cycle (Maglischo, 2003). However, they can reduce their breathing frequency by taking a breath every fourth, fifth, sixth or eighth stroke cycle. During such exercise, breathing (and specifically inspiration) must be coordinated with stroke mechanics and as a result the tidal volume (V_T or inspiratory volume) is elevated to compensate for the reduced breathing frequency (RBF) (Dicker, Lofthus, Thornton, & Brooks, 1980). However, as V_T increases it requires progressively stronger inspiratory muscle force to expand the lungs, which requires greater effort and results in breathing discomfort. Further, the time for inhalation during swimming is quite short. Cardelli, Lerda, & Cholet (2000) demonstrated that the duration of inhalation lasted less than 0.5 seconds during 800m front crawl swimming at a lower velocity i.e. 1.28 m/s. Swimmers must therefore inhale quickly to ensure high lung volumes during swimming with RBF. Therefore, it could be suggested that this breathing pattern during swimming could pose a great challenge for the respiratory muscles. Indeed, it was recently shown that a reduced breathing frequency induced a larger magnitude of inspiratory muscle fatigue during 200m of maximal swimming (Jakoljevic & McConnell, 2009).

In the 1970s, Leith and Bradley (1976) demonstrated that the strength of respiratory muscles can be improved by inspiratory muscle training (IMT). It is now well documented that IMT enhances the performance of athletes across a range of endurance sports (Griffiths & McConnell, 2007; Romer, McConnell, & Jones, 2002; Voliantis et al., 2001), as well as during repeated sprinting (Romer, McConnell, & Jones, 2002). Recent evidence suggests that IMT has a small positive effect on swimming performance in trained swimmers in events shorter than 400 m (Kilding, Brown, & McConnell, 2010). Given the unique challenge for the respiratory muscles, it is surprising that so far no studies have examined the influence of IMT on exercise with RBF. Therefore, the purpose of this study was to investigate the influence of IMT on V_T during incremental exercise where breathing frequency is restricted. Considering suggestions from previous studies, we hypothesise that IMT will increase V_T during incremental exercise where breathing frequency is restricted. Due to the technical limitations of measuring respiratory parameters during swimming, the influence of IMT on subjects' performance in reduced breathing conditions was investigated during cycle ergometry in the present study. During such exercise the breathing frequency can be modified and respiratory parameters measured with greater ease.

MATERIALS AND METHODS

Subjects

Nine males (age: 27 ± 3 years, height: 1.80 ± 0.07 m, body mass: 80 ± 13 kg) and twelve females (age: 24 ± 1 years, height: 1.67 ± 0.03 m, body mass: 61 ± 5 kg)volunteered to participate in this study. None of the subjects were smokers and none had any respiratory diseases. The subjects were fully informed of the purpose and possible risks of the study before giving their written consent to participate. The study was approved by the National Ethics Committee of the Republic of Slovenia.

Testing protocol

The subjects completed the following tests in the same order in pre- and post-training: 1) tests of pulmonary function; 2) tests of respiratory muscle strength; and 3) an incremental cycle ergometry with RBF. All testing took place in controlled environmental laboratory conditions (21°C, 40–60% RH, 970–980 mbar) and at the same time of day. The subjects were asked to maintain their usual eating habits and avoid consuming food 2 hours before the testing. Post-training testing began 2 days after the last training session.

Pulmonary function. A pneumotachograph spirometer (Vicatest P2a, Mijnhardt, Netherlands) was used to measure resting flow-volume profiles. The following variables were derived: vital capacity (VC), forced vital capacity (FVC) and forced expiratory volume in one second ($FEV_{1.0}$). Pulmonary function measurements were made according to European Respiratory Society recommendations (Miller et al., 2005).

Respiratory muscle strength was assessed by measuring the maximal inspiratory mouth pressure (MIP) at residual volume and maximal expiratory mouth pressure (MEP) at total lung capacity. Both parameters were measured using a portable hand-held mouth pressure meter (MicroRMP, MicroMedical Ltd, Kent, UK) in the standing position. The assessment of maximal pressures required a sharp, forceful effort maintained for a minimum of 2 s. All subjects became well habituated with the procedure during two separate familiarisation sessions. They received visual feed-back of the pressure achieved during each effort by viewing the digital display on the hand-held device in order to maximise their inspiratory and expiratory effort. MIP and MEP measurements were taken repeatedly until a stable baseline of each parameter was achieved. The criteria for determining MIP and MEP stability was successive efforts within 5%. The highest value recorded was included in the subsequent analysis.

Incremental exercise test with RBF was performed on an electromagnetically braked cycle ergometer (Ergometrics 900, Ergoline, Windhagen, Germany) with a pedal cadence of 60 rpm. RBF was defined as 10 breaths per minute and was regulated by a breathing metronome. The breathing metronome was composed of a gas service solenoid valve (24 VDC, Jakša, Ljubljana, Slovenia) and a semaphore with red and green lights. Both were controlled by micro-automation (Logo DC 12/24V, Siemens, Munich, Germany). The subjects were instructed to exhale and inhale during a two second period of an open solenoid valve (the green semaphore light was switched on) and to hold their breath, using almost all their lung capacity (holding their breath near total lung capacity), for four seconds when the solenoid valve was closed (when the red semaphore light was switched on) (Kapus, Ušaj, & Kapus, 2010; Sharp, Williams, & Bevan, 1991; Yamamoto, Mutoh, Kobayashi, & Miyashita, 1987). Prior to testing and training, the subjects were familiarised with cycling on the cycle ergometer and breathing in time with the metronome. The test began at an intensity of 30 W and increased by 30 W every minute until volitional exhaustion.The subjects breathed through a mouthpiece attached to apneumotachograph during each cycle ergometry test. Expired air was sampled continuously by a metabolic cart (V-MAX29, SensorMedics Corporation, Yorba Linda, USA) for a breath-by-breath determination of pulmonary ventilation($\dot{V}_E$), V_T, end-tidal partial pressure of carbon dioxide ($P_{ET}CO_2$), end-tidal partial pressure of oxygen ($P_{ET}O_2$), and oxygen uptake ($\dot{V}O_2$). The pneumotachograph and O_2 and CO_2 analysers were calibrated with a standard three-litre syringe and precision reference gases, respectively. For further statistical analysis the breath-by-breath data were averaged for each 10 second interval.

Training protocol

The subjects were categorised according to gender and their baseline MIP measures and divided into matched trios. Two subjects of each trio were assigned at random to the experimental group (Group E) by an independent observer and the third to the control group (Group C). Descriptive measures of the subjects and training groups are presented in Table 1.

Group E performed 30 dynamic inspiratory efforts twice daily for six weeks (84 training sessions) against a pressure-threshold load of ~50% MIP. A spring-loaded threshold inspiratory muscle trainer (POWERbreathe, Gaiam Ltd., Southham, UK) was used for this IMT. After the initial setting of the training loads the subjects were instructed by an independent observer to increase the load periodically once a week to a level that would permit them to only just complete 30 manoeuvres. The subjects initiated each inspiratory effort from the residual volume and strove to maximise the tidal volume. This IMT protocol is known to be effective in eliciting an adaptive response (Griffiths & McConnell, 2007; McConnell & Lomax, 2006; McConnell & Sharpe, 2005; Romer, McConnell, & Jones, 2002; Voliantis et al., 2001). The subjects completed a training diary throughout the study to record their adherence to the training. IMT had ceased 48 hours before the post-training testing. Group C received no IMT. The subjects in both groups were recreationally active, although they did not perform any intense exercise training during the research period.

Statistical analyses

The results are presented as means and standard deviations. Intra-group differences between the pre- and post-training values were calculated with a paired, two-tailed t-test. An analysis of covariance (ANCOVA), with pre-training values as covariates and post-training values as dependent variables, was used to test for differences between the groups resulting from different training interventions. Statistical significance was accepted at the $p \leq 0.05$ level. Effect sizes were calculated using Cohen's *d* statistics to assess the magnitude of the treatment with 0.2 being deemed small, 0.5 medium and 0.8 large (Cohen, 1988). All statistical parameters were calculated using the statistics package SPSS (version 15.0, SPSS Inc., Chicago, USA) and the graphical statistics package Sigma Plot (version 9.0, Jandel & Tübingen, Germany).

RESULTS

Descriptive measures of the subjects and training groups are presented in Table 1.

Table 1. Descriptive characteristics of the subjects and training groups

Parameter	All subjects	Group E (N = 14; 6 M, 8 F)	Group C (N = 7; 3 M, 4 F)
Age (yr)	25 ± 2	24 ± 1	27 ± 3
Height (cm)	173 ± 8	172 ± 8	174 ± 9
Body mass (kg)	69± 13	67 ± 9	74± 18
VC (l)	5.08± 1.08	5.03 ± 0.94	5.19± 1.41
$FEV_{1.0}$ ($l \cdot s^{-1}$)	3.99± 0.74	3.98 ± 0.71	4.00 ± 0.86
MIP (cm H_2O)	125± 22	122 ± 21	130± 26
MEP (cm H_2O)	149± 30	142 ± 24	162±38

Values are means ± SD. VC, vital capacity; FVC, forced vital capacity; $FEV_{1.0}$, forced expiratory volume in one second; MIP, maximal inspiratory mouth pressure; MEP, maximal mouth expiratory pressure

All subjects in Group E completed the prescribed training programme. Spirometry parameters and parameters of respiratory muscle strength measured at the pre- and post-training testing are shown in Table 2.

Table 2. Spirometry parameters and parameters of respiratory muscle strength pre- and post-training

Parameter	Group	Pre-training	Post-training	
VC (l)	E	5.03 ±0.94	5.02 ±1.03	
	C	5.19±1.41	5.23±1.41	
$FEV_{1.0}$ (l)	E	3.98 ± 0.71	4.06 ±0.74	
	C	4.00 ± 0.86	3.98± 0.88	
MIP (cm H_2O)	E	122 ±21	164 ±30 ††	**
	C	130±26	133±32	
MEP (cm H_2O)	E	142 ± 24	145 ±29	
	C	162±38	166± 43	

Values are means ± SD. VC, vital capacity; FEV1.0, forced expiratory volume in one second; MIP maximal inspiratory pressure; MEP, maximal expiratory pressure.Significant training effect (paired T test): †† - p<0.01. Significant differences between groups after the training (ANCOVA): ** - p<0.01.

As shown in Table 2, MIP differed among the groups in response to the training period ($p<0.01$). As expected,a higher value ($p=0.01$, $d=1.68$) was observed after training in Group E compared with the pre-training values. By contrast, spirometry parameters and parameters of respiratory muscle strength were unchanged in Group C. Time to exhaustion during incremental cycle ergometry with RBF was extended with the IMT in group E ($p<0.01$, $d=0.95$), whereas this parameter did not change in group C. Between-group differences in time to exhaustion were also significant for the post-training comparisons ($p<0.05$; see Figure 1).

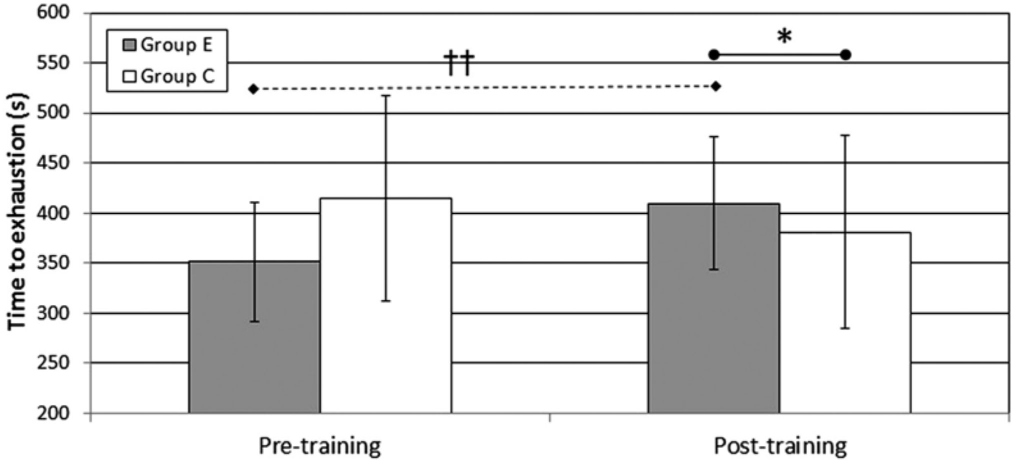

Figure 1. Time to exhaustion obtained during incremental cycle ergometry with reduced breathing frequency pre- and post-training. Values are means ± SD. Significant training effect (paired t-test): †† - p<0.01; significant differences between groups after the training (ANCOVA): * - p<0.05.

Table 3 shows the peak power output obtained at the pre- and post-training incremental tests. Peak power output was defined as the highest work stage completed (i.e. the last work stage thesubject actually sustained for one minute), and hence the power output obtained.

Table 3. Peak power output (W) obtained at the pre- and post-training incremental tests

Subject	Group	Pre-training	Post-training
1	E	150	180
2	E	150	180
3	E	150	180
4	E	270	270
5	E	150	150
6	E	150	180
7	E	150	210
8	E	150	150
9	E	180	210
10	E	150	180
11	E	150	180
12	E	150	180
13	E	180	210
14	E	180	180
15	C	300	180
16	C	120	120
17	C	150	180
18	C	210	210
19	C	180	150
20	C	180	180
21	C	210	240

The lowest peak power output obtained at the pre- and post-training incremental tests was 150 W and 120 W, respectively, for Group E and Group C (Table 3). Therefore, the average data of measured respiratory parameters to these work stages and maximal or minimal values during the incremental test with RBF are presented in Figures 2 and 3, respectively, for Group E and Group C.

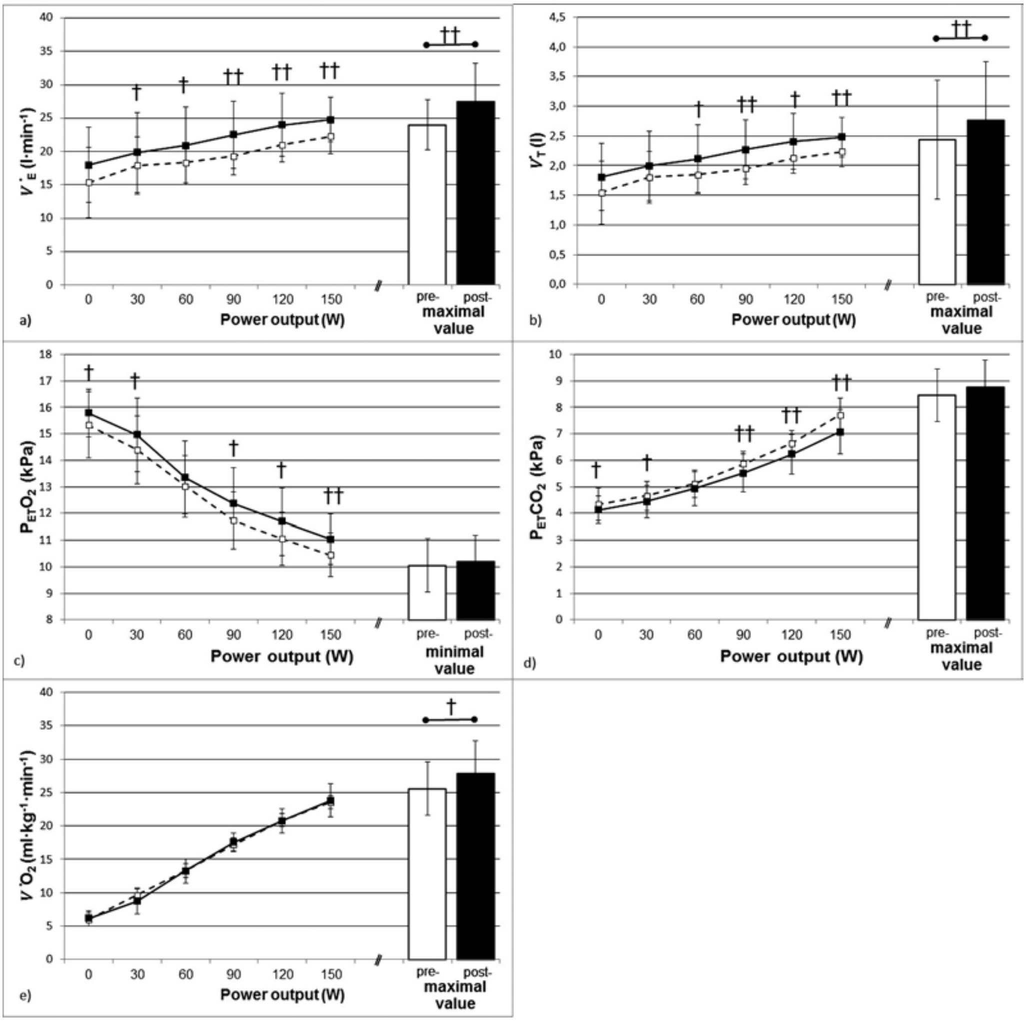

Figure 2. Respiratory parameters ($\dot{V}_E$, minute ventilation (a); V_T, tidal volume (b); $P_{ET}O_2$ end-tidal partial pressure of oxygen (c); $P_{ET}CO_2$, end-tidal partial pressure of carbon dioxide (d)) and $\dot{V}O_2$, oxygen uptake (e)) obtained during the incremental test with RBF pre- (white squares and columns) and post-training (black squares and columns) in **Group E**. Values are means ± SD. Significant training effect (paired t-test): † - $p<0.05$ and †† - $p<0.01$.

As shown in Figure 2, there were significant training changes in $\dot{V}_E$, V_T,$P_{ET}O_2$and $P_{ET}CO_2$ (p varied from 0.01 to 0.05) obtained at submaximal work stages during an incremental test with RBF. In addition, maximal values of $\dot{V}_E$ ($p<0.01$, $d=0.75$), V_T ($p<0.01$, $d=0.81$) and $\dot{V}O_2$($p<0.05$, $d=0.53$) were also enhanced by the IMT in Group E. By contrast, respiratory parameters during the incremental test with RBF did not change (neither in submaximal values nor at maximal or minimal) throughout the training in Group C (Figure 3). Between-group differences in the maximal values of $\dot{V}_E$ and $\dot{V}O_2$were also significant for the post-training comparisons ($p<0.05$).

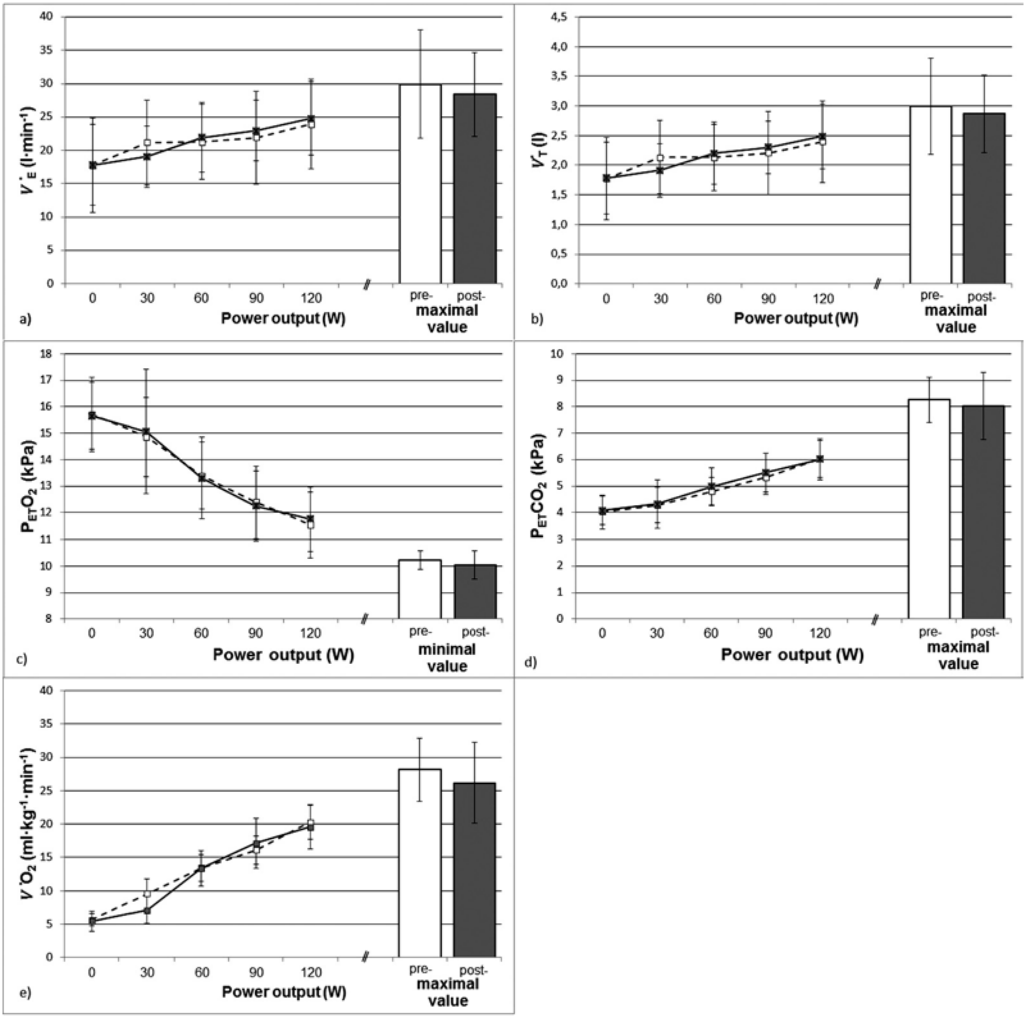

Figure 3. Respiratory parameters ($\dot{V}_E$, minute ventilation (a); V_T, tidal volume (b); $P_{ET}O_2$ end-tidal partial pressure of oxygen (c); $P_{ET}CO_2$, end-tidal partial pressure of carbon dioxide (d)) and $\dot{V}O_2$, oxygen uptake (e)) obtained during the incremental test with RBF pre- (white squares and columns) and post-training (grey squares and columns) in **Group C**. Values are means ± SD.

DISCUSSION

This pilot study is the first to our knowledge to have investigated the influence of IMT on V_T during incremental exercise where breathing frequency is restricted. The data indicate that IMT increased MIP (Table 2) and additionally V_T during the RBF exercise (Figure 2b). The later adaptation could be the reason for the significant improvement in time to exhaustion at incremental cycle ergometry with RBF in Group E (17 ± 15%; Figure 1). On the basis of the large effect sizes, it could be suggested that the training intervention *per se* was primarily responsible for the increased mentioned variables.

The 35 ± 16% increase in MIP after six weeks of IMT (Figure 2) is in accordance with previous IMT studies. However, the increase obtained in some studies was greater (from 45% to 64% reported by Romer & McConnell, 2003; Voliantis et al., 2001) and lower in others (from 15% to 26% reported by Griffiths & McConnell, 2007; Inbar, Weiner, Azgad, Rotstein, & Weinstein, 2000; Johnson, Sharpe, & Brown, 2007;Klusiewicz, Borkowski, Zdanowicz, Boros, & Wesolowski, 2008; McConnell & Sharpe, 2005; Lomax, 2010). Established training principles appear to apply to IMT (Romer and McConnell, 2003), thus these discrepancies may be related, in part, to inter-study differences in the IMT mode, intensity and duration. However, since the scale of physiological adaptation within a system depends on its baseline status (Åstrand & Rodahl, 1986), it seemed that the training improvement is mainly related to the pre-training level of MIP. McConnell (2011) suggested that changes in inspiratory muscle strength due to IMT could be attributed to changes in diaphragm thickness. Indeed, it was shown that diaphragm thickness increased after just four weeks of IMT, which confirmed the presence of rapid fibre growth (hypertrophy) in response to loading (Downey et al., 2007).

It is well known that during endurance exercise the respiratory muscles perform significant amounts of metabolic work. Indeed, Aaron, Seow, Johnson, & Dempsey (1992) showed that during strenuous exercise respiratory muscles can command ~10%of total oxygen consumption in moderately fit subjects and up to 15% in highly fit subjects. Taking this into account, previous studies have tried to determine the effects of IMT on respiratory muscle functions and in addition on maximal aerobic capacity (Inbar, Weiner, Azgad, Rotstein, & Weinstein, 2000; Riganas, Vrabas, Christoulas, & Mandroukas, 2008; Williams, Wongsathikun, Boon, & Acevedo, 2002),on exercise performance (Forbes, Game, & Syrotuik, 2011; Kilding, Brown, & McConnell, 2010; Voliantis et al. 2001; Williams, Wongsathikun, Boon, & Acevedo, 2002), and on post-exercise inspiratory muscle fatigue (Romer, McConnell, & Jones, 2002). However, interestingly the impact of IMT on breathing parameters such us $\dot{V}_E$, V_T and breathing frequency during exercise has not been examined yet. Hypoventilation is a well-documented phenomenon during exercise with RBF. A reduction of approximately 48% in V_E was demonstrated in previous studies in which 10 breaths per minute was used for the reduced breathing conditions (Kapus, Ušaj, & Kapus, 2010; Sharp, Williams, & Bevan, 1991; Yamamoto, Mutoh, Kobayashi, & Miyashita, 1987). A similar reduction in V_E was reported when swimmers reduced their breathing frequency during swimming from the usual taking of a breath every second stroke cycle to taking a breath every fifth (Dicker, Lofthus, Thornton, & Brooks, 1980) or sixth (Town & Wanness, 1990) stroke cycle. As a reduction in $\dot{V}_E$ is unlikely to benefit exercise performance, it follows that an increase in $\dot{V}_E$ would be advantageous. Due to the prescribed and unchanged breathing frequency in the present study, an increase in V_T was the only mechanism available for increasing $\dot{V}_E$ (Figure 2a). Indeed, our results indicate that IMT does increase V_T during incremental exercise with RBF.

Specifically, maximal values of V_T increased by 13 ± 14% following the IMT (Figure 2b). Despite breathing with large V_T, a 2 second period of an opened valve was enough for the subjects' expiration and for deep inspiration. The obtained improvement in V_T as result of the IMT was less than the 41% reported after training with RBF (Kapus, 2008). However, it should be emphasised that increased $V_T$was obtained without any additional exercise or RBF training in the present study.The higher $V_T$at the post-training testing allowed the better regulation of blood gases, i.e. it induced a higher submaximal $P_{ET}O_2$ anda lower submaximal $P_{ET}CO_2$ in comparison with the pre-training testing (Figure 2). These measurements could indirectly show the level of O_2 and CO_2 in blood during rest and exercise (Williams and Babb, 1997). Previous studies demonstrated that hypercapnia and/or hypoxia in blood could be the reasons for earlier fatigue during exercise with RBF (Kapus, Ušaj, Kapus, & Štrumbelj, B., 2003; Sharp, Williams, & Bevan, 1991). Therefore, it seemed that a higher V_T (via better regulation of blood gases) enabled higher peak power output during the post-training incremental exercise with RBF (Table 3). This adaptation was the reason for the higher maximal values of $\dot{V}O_2$ during the post-training testing in comparison with the pre-training testing (Figure 2).

Considering this, it could be suggested that IMT may offer some potential benefits (via increasing V_T) for a swimmer's ability to swim with fewer breaths and to hold their breath for longer during the underwater phases (flip turns, gliding, and underwater strokes). This could create an important biomechanical advantage for a swimmer's performance (Chatard, Collomp, Maglischo, & Maglischo, 1990; Kolmogorov & Duplisheva, 1992; Lerda, Cardelli, & Chollet, 2001; Pedersen & Kjendlie, 2006).

Possible study limitations. The presented pilot study has some limitations and the results should be interpreted in the context of its design. Firstly, because the subjects were not blinded for the training intervention one may argue that this might have influenced our results. Although the subjects were naive and were not informed about the potential effect of the IMT on exercise performance with RBF, a placebo-controlled design should be used. Indeed, in most of the previous studies concerning the influences of IMT the experimental group and sham-training control group were compared. Subjects were told that they were participating in a study to compare the influence of strength (like Group E in the present study, which performed IMT) versus endurance protocols (the placebo group, which also used the pressure threshold device, however, performed 60 slow protracted inhalations against minimum pressure threshold once daily for six weeks) (Inbar, Weiner, Azgad, Rotstein, & Weinstein, 2000; Kilding, Brown, & McConnell, 2010; McConnell & Sharpe, 2005; Voliantis et al., 2001). Further, increased V_T during the post-training exercise with RBF could be the learning effect of the IMT. Indeed, at each training session the subjects in Group E performed several rapid inhalations in which they strove to maximise their V_T. To avoid this effect, IMT should be added as an experimental group's supplement to training with RBF which would be otherwise performed by both groups, i.e. experimental and control. Nonetheless, we find these preliminary data to be encouraging as part of the growing literature supporting the use of IMT as a supplement to regular swimming training. Future research is needed to establish the efficacy of this training in a randomised, controlled trial with the experimental design suggested above.

It could be concluded that IMT increased $V_T$during incremental exercise where breathing frequency was restricted. However, further research is needed to establish the efficacy of this training as a supplement to regular exercise training with or without RBF.

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REFERENCES

Aaron, E. A., Seow, K. C., Johnson, B. D., & Dempsey, J. A. (1992). Oxygen cost of exercise hyperpnea: Implications for performance. *Journal of Applied Physiology, 72*(5), 1818–1825.

Åstrand, P. O., & Rodahl, K. (1986). *Textbook of Work Physiology: Physiological Bases of Exercise.* Singapore: McGraw-Hill Co.

Cardelli, C., Lerda, R., & Chollet, D. (2000). Analysis of breathing in the crawl as a function of skill and stroke characteristics. *Perceptual and Motor Skills, 90*(3), 979–987.

Chatard, J. C., Collomp, C., Maglischo, E., & Maglischo, C. (1990). Swimming skill and stroking characteristics of front crawl swimmers. *International Journal of Sports Medicine,11*(2), 156–161.

Cohen, J. (1988). *Statistical Power Analysis for the Behavioural Sciences.* Hillsdale: Lawrence Erlbaum Associates.

Dicker, S. G., Lofthus, G. K., Thornton, N. W., & Brooks, G. A. (1980) Respiratory and heart rate responses to tethered controlled frequency breathing swimming. *Medicine and Science in Sport and Exercise,12*(1), 20–23.

Downey, A. E., Chenoweth, L. M., Townsend, D. K., Ranum, J. D., Ferguson, C. S., & Harms, C. A. (2007). Effects of inspiratory muscle training on exercise responses in normoxia and hypoxia. *Respiratory Physiology and Neurobiology, 156*(2), 137–146.

Forbes, S., Game, A., & Syrotuik, D. (2011). The effect of inspiratory and expiratory respiratory muscle training in rowers. *Research in Sports Medicine,19*(4), 217–230.

Griffits, L. A., & McConnell, A. K. (2007). The influence of inspiratory and expiratory muscle training upon rowing performance. *European Journal of Applied Physiology, 99*(5), 457–466.

Inbar, O., Weiner, P., Azgad, Y., Rotstein, A., & Weinstein, Y. (2000). Specific inspiratory muscle training in well-trained endurance athletes. *Medicine and Science in Sports and Exercise, 32*(7), 1233–1237.

Jakovljevic, D. G., & McConnell, A. K. (2009). Influence of different breathing frequencies on the severity of inspiratory muscle fatigue induced by high-intensity front crawl swimming. *Journal of Strength and Conditioning Research, 23*(4), 1169–1174.

Johnson, M. A., Sharpe, G. R., & Brown, P. I. (2007). Inspiratory muscle training improves cycling time-trial performance and anaerobic work capacity but not critical power. *European Journal of Applied Physiology, 101*(6), 761–770.

Kapus, J. (2008). *Učinki vzdržljivostne vadbe z nižjo frekvenco dihanja: doktorska disertacija* [The influence of training with reduced breathing frequency]. Unpublished doctoral dissertation, Ljubljana: Fakulteta za šport.

Kapus, J., Ušaj, A., Kapus, V., & Štrumbelj, B. (2003). The influence of reduced breathing during intense front crawl swimming on some respiratory and metabolic values in blood. *Kinesiologia Slovenica, 9*(1), 12–17.

Kapus, J., Ušaj, B., & Kapus, V. (2010). Some metabolic responses to reduced breathing frequency during constant load exercise. *Medicina Sportiva, 14*(1), 13–18.

Kilding, A. E., Brown, S., & McConnell A. K. (2010). Inspiratory muscle training improves 100 and 200 m swimming performance. *European Journal of Applied Physiology, 108*(3), 505–511.

Klusiewicz, A., Borkowski, L., Zdanowicz, R., Boros, P., & Wesolowski, S. (2008). The inspiratory muscle training in elite rowers. *Journal of Sports Medicine and Physical Fitness, 48*(3), 279–284.

Kolmogorov, S. V., & Duplisheva, A. (1992). Active drag, useful mechanical power output and hydrodynamic force coefficient in different genders and performance levels. *Journal of Biomechanics, 25*(3), 311–318.

Leith, D. E., & Bradley, M. (1976). Ventilatory muscle strength and endurance training. *Journal of Applied Physiology, 41*(4), 508–516.

Lerda, R., Cardelli, C., & Chollet, D. (2001). Analysis of the interactions between breathing and arm actions in the front crawl. *Journal of Human Movement Studies, 40,* 129–144.

Lomax, M. (2010). Inspiratory muscle training, altitude and arterial oxygen desaturation: A preliminary investigation. *Aviation, Space, and Environmental Medicine, 81*(51), 1-4.

Maglischo, E. W. (2003). *Swimming Fastest.* Leeds: Human Kinetics.

McConnell, A. K. (2011). *Breathe Strong, Perform Better.* Leeds: Human Kinetics.

McConnell, A. K., & Lomax, M. (2006). The influence of inspiratory muscle work history and specific inspiratory muscle training upon human limb muscle fatigue. *Journal of Physiology, 577*(1), 445–457.

McConnell, A. K., & Sharpe, G. R. (2005). The effects of inspiratory muscle training upon maximum lactate steady-state and blood lactate concentration. *European Journal of Applied Physiology, 94*(3), 277–284.

Miller, M. R, Hankinson, J., Brusasco, V., Burgos, F., Casaburi, R., Coates, A., Crapo, R., Enright, P., van der Grinten, C. P. M., Gustafsson, P., Jensen, R., Johnson, D. C., MacIntyre, N., McKay, R., Navajas, D., Pedersen, O. F., Pellegrino, R., Viegi, G., Wanger, J., & Force, A. E. T. (2005). Standardisation of spirometry. *European Respiratory Journal, 26*(2), 319–338.

Sharp, R. L., Williams, D. J., & Bevan, L. (1991). Effects of controlled frequency breathing during exercise on blood gases and acid-base balance. *International Journal of Sports Medicine, 12*(1), 62–65.

Pedersen, T., & Kjendlie, P. L. (2006). The effect of breathing action on velocity in front crawl swimming. In J. P. Vilas-Boas, F. Alves, F., A. Marques (Eds.), *Biomechanics and medicine in swimming 10* (pp. 75–77). Porto: Portuguese Journal of Sport Sciences.

Riganas, C., Vrabas, S. I., Christoulas, K., & Mandroukas, K. (2008). Specific inspiratory muscle training does not improve performance or Vo2max levels in well trained rowers. *Journal of Sports Medicine and Physical Fitness, 48*(3), 285–292.

Romer, L. M., & McConnell, A. K. (2003). Specificity and reversibility of inspiratory muscle training. *Medicine and Science in Sports and Exercise, 35*(2), 237–244.

Romer, L. M., McConnell, A. K., & Jones, D. A. (2002). Inspiratory muscle fatigue in trained cyclists: effects of inspiratory muscle training. *Medicine and Science in Sports and Exercise, 34*(5), 785–792.

Town, G. P., & Vanness, J. M. (1990). Metabolic responses to controlled frequency breathing in competitive swimmers. *Medicine and Science in Sport and Exercise, 22*(1), 112–116.

Volianitis, S., McConnell, A. K., Koutedakis Y., McNaughton, L., Backx, K., & Jones, D.A. (2001). Inspiratory muscle training improves rowing performance. *Medicine and Science in Sports and Exercise, 33*(5), 803–809.

Williams, J. S., & Babb, T. G. (1997). Differences between estimates and measured Paco$_2$ during rest and exercise in older subjects. *Journal of Applied Physiology, 83*(1), 312–316.

Williams, J. S., Wongsathikun, J., Boon, S. M., & Acevedo, E. O. (2002). Inspiratory muscle training fails to improve endurance capacity in athletes. *Medicine and Science in Sports and Exercise, 34*(7), 1194–1198.

Yamamoto, Y., Mutoh, Y., Kobayashi, H., & Miyashita, M. (1987). Effects of reduced frequency breathing on arterial hypoxemia during exercise. *European Journal of Applied Physiology, 56*(5), 522–527.