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The influence of low resistance respiratory muscle training on pulmonary function and high intensity exercise performance

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ABSTRACT

Background/objectives: Respiratory muscle training (RMT) was recognized as an effective means to improve respiratory muscle (RM) strength and enhance exercise performance. The purpose of this study was to examine the effect of low-intensity RMT on RM strength, pulmonary function, and performance.
Methods: Fourteen healthy active adults were assigned randomly to either a training or placebo group. The training group completed six weeks of RMT, which consisted of a first week, 1 set of 15 min/d, 5 d/wk at 10–25% of maximal inspiratory pressure (PImax), and the remaining 5 weeks, 2 sets of 15 min/d, 5 d/wk, at 30% PImax. The placebo group followed the same protocol but with almost no additional ventilatory resistance. Measurement of RM strength and endurance, spirometry, and endurance exercise performance were obtained before and after the RMT program.
Results: In the training group, PImax (+14%) and maximal expiratory pressure (PEmax, +27%), forced vital capacity (FVC, +3.6%), maximal oxygen uptake (VO2max, +11%), and time to exhaustion (Tlim90%, +25%) increased significantly from baseline values ($P < 0.05$). No significant changes were observed in the placebo group. Also, no significant interaction in maximum voluntary ventilation (MVV12), minute ventilation (VE), and respiratory rate (RR) were detected.
Conclusions: These data suggest that low-intensity RMT is an effective tool to improve RM strength, pulmonary elastic properties and endurance exercise performance.

1. Introduction

Generally, it was assumed that "the lung is built for exercise".[1] Therefore, any exercise limitation was attributed to factors other than respiratory system. However, the capability to improve respiratory muscle (RM) efficiency and endurance during exercise was used to contradict this assumption,[2,3] as well as there is sufficient evidence to recognise that RM fatigue during high intensity exercise exists.[4–8] More than two decades ago Johnson et al.[9] reported that endurance exercise with high intensity (VO2max >85%) for 10 min was associated with diaphragmatic fatigue which was manifested by a reduction of trans-diaphragmatic pressure. Respiratory muscle fatigue seems to occur when high levels of respiratory muscle work is required, and it determines a higher competition for blood flow with limb locomotor muscles.[6] Accordingly, respiratory muscle training (RMT) programs were widely used to improve the RM endurance and strength in an attempt to enhance exercise performance.[2,3,7,10–15] The improvement in exercise capacity due to RMT might be attributed to several concurrent mechanisms such as: i. respiratory muscles hypertrophy, ii. changes in respiratory muscle fiber type composition, iii. increased respiratory endurance efficiency, iv. optimization of respiratory muscle neural-motor control (i.e., less motor impulse for the same pressure), v. delayed onset of the respiratory metaboreflex, vi. redistribution of blood flow from respiratory to locomotor muscles with an increased flow to the latter, vii. decreased dyspnoea.[16–19] The diversity in training protocols, modes (isocapnic voluntary ventilation, inspiratory flow resistive loading, and inspiratory pressure threshold loading), and intensities amongst various studies created discrepancy in the outcomes and made the comparison, to some extent, difficult.[20] However, the vast majority of the studies which were conducted in healthy subjects reported an improvement in RM strength as indicated by elevation of maximal inspiratory pressure (PImax),[7,10,12,15,21,22] twitch transdiaphragmatic

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pressure (Tw Pdi),[23] diaphragm hypertrophy.[4,10] Furthermore, improvements of pulmonary function parameters such as vital capacity and total lung capacity were observed as a result of well-designed training programs.[10] A recent systematic review, which included 10 studies involving recreational as well as professionals intermittent sports athletes, showed that "the ideal" training protocol for those athletes would consist of a combination of an acute (two consecutive sessions of 30 inspirations at 40% of the PImax, with 1 min rest in between) and a chronic part (two sessions per day, four to seven times a week at 50% of the PImax).[22] Would this optimal intensity of training load and the duration of training program still be valid in healthy physically active subjects? It has been reported that training programs that employed higher percentage of PImax and longer training duration produced the highest changes of PImax but with inconsistent concomitancy to exercise capacity.[24] Moreover, some researchers attributed the 'impressive improvement' of RM strength and endurance to the high intensity and long duration of training sessions.[12] On the other hand, other groups achieved similar or even better results with lower intensity and less training duration.[7,23,25] Gething et al.,[26] found that training at higher intensities does not always produce higher PImax values: they noted that training at 80% is more effective in terms of RM strength than training at 100% of PImax. Moreover, PImax measurements recorded higher values as a result of RM training at intensities lower than 80% of PImax.[7] Additionally, training intensities as low as 40%-50% of PImax induced RM structural remodelling, increase in the proportion of myosin heavy chain type I and the size of type II.[27] A systematic review and meta-analysis showed cardiovascular benefit of inspiratory muscle training (IMT) at low intensities (30–50% of PImax) in people with chronic diseases.[28] Since subjects with low inspiratory muscle strength are more susceptible to exercise induced RM fatigue,[29] the main purpose of RM training is to elevate the strength of the main RM muscles, to a certain point, to accomplish the proper ventilatory tasks during intense exercise. An improvement of RM strength would presumably attenuate or may delay the exercise induced RM fatigue which can be translated into enhancement of exercise capacity.[4,5,7] Therefore, in terms of enhancing exercise capacity, implementation of high intensity RMT to achieve the maximum RM improvement is not the cornerstone in RM training program. The relationship between the magnitude of RM strength and changes in exercise capacity cannot be presented as cause and effect.[25] It is more likely that improvement of RM strength to the point that enables the main muscle to resist exercise induced RM fatigue would positively influence the exercise tolerance. The majority of previous studies evaluated the role of moderate to high resistance RM training on respiratory musculature and exercise capacity.[19,30] To our knowledge, to date there is still scarce evidence showing improvements in pulmonary and exercise performance due to low resistance RM training. We are aware of one study where 4 weeks of low resistance (30% of PImax) RM training in young healthy females improved inspiratory muscle strength (i.e., 11% PImax and 16% PEmax)[23]; a second study where 7 weeks of RM training at around 37% of PImax showed improvements to exercise and spirometric parameters in cross-country skiers (i.e., 34% PImax).[14] Conversely, a third study in children (11 ± 1 years of age) undergoing a 6 week low resistance (30% of PImax) RM training did not show changes in inspiratory strength nor in exercise capacity.[31] The aim of this study is to investigate the effect of low resistance RM training program on pulmonary variables and exercise performance including a placebo group. The authors hypothesize that a progressive, specific, and low-resistance RM training would improve both RM strength and exercise capacity. Noticeable changes of some pulmonary function parameters such as forced vital capacity (FVC), forced expiratory volume in 1st second (FEV1) and maximum voluntary ventilation (MVV) are also expected.

2. Methods

2.1. The subjects |

| The experimental protocol was approved (approval code: Alotaibi) by the School of Sport, Health and Exercise Sciences Research Ethics Committee (Bangor University) in accordance with the Declaration of Helsinki. Each subject was informed about the potential risks and benefits of the study and had the right to withdraw at any time. Informed consent was signed individually prior to taking part in the study. A total of 16 healthy, physically active subjects (10 male, 6 female) were recruited in a single-blinded study (see Table 1). The evaluator was a respiratory therapist with master's degree experience. The subject numbers was based on data of Volianitis et al.[7] which gives a power of 90% at ($P < 0.01$). According to our a priori calculation a sample size of around 8 participants per group would yield a statistical power = 0.90, given an alpha = 0.01 and the effect size Cohen's d = 1.8, derived from the performance results published in Table 1 of Volianitis et al.[7] Two female participants, one per group, dropped out during the first week of training. Participants visited the laboratories at School of Sport, Health, and Exercise Sciences, Bangor University, on four occasions. All participants were screened for any contraindication to graded exercise testing and were excluded if they presented or had history of these contradictions. Volunteers with either history of smoking or smokers were excluded. Then, each subject was assigned randomly, using computer generated numbers (www.randomizer.org), to either a training group or a placebo group. Participants in the placebo group were debriefed at the end of the study, none of them reported to have thought to be in a placebo group. Participants were given a set of pre-test instructions to adhere to prior to each testing session. These include avoid strenuous exercise, refrain from eating for 2 h before testing, consume 500 ml of water to ensure euhydration, avoid alcohol or caffeinated beverages at least 3 h preceding the tests. Also, Subjects were encouraged to maintain their daily activities and usual diet. During the first visit participants were familiarised to all test's procedures. Then, participants were tested for pulmonary functions. This was followed by maximal incremental treadmill test to volitional exhaustion. A second visit 48–72 h later was scheduled where participants completed a fixed-work rate treadmill running to volitional exhaustion. After six weeks, a repeated of the above procedures then followed, which included the complete battery of tests as stated above, during two further visits.

2.2. Pretraining assessments |

| For each subject, height and weight were determined using a stadiometer (Seca bodymeter, Hamburg, Germany) and a digital scale (STW-150 KEH, Taipei, Taiwan) respectively. Blood pressure was determined while the subjects had been seated for at least 5 min, using an automatic oscillometric digital blood pressure monitor (Omron HEM-704 C, Omron healthcare Inc., Illinois, USA). Then, 12 leads electrocardiogram (ECG) (Seca CT 3000B, Schiller AG, Switzerland) was recorded while subjects lay in a supine position and was interpreted by a qualified physiologist. All subjects diagnosed as hypertensive or with abnormal ECG rhythms were excluded.

Table 1
Descriptive characteristics of the participants.
Mean values ± (standard deviation).

Parameter	Training Group	Placebo group
Sex (♂/♀)	5/2	5/2
Age (years)	35 ± 11.6	27.8 ± 6.6
Height (cm)	175.6 ± 12.5	172.8 ± 6.4
Weight (kg)	77.2 ± 14.5	68.9 ± 10.1
Vo2max (ml/min/kg)	45.14 ± 9.28	46.57 ± 9.3

2.3. Pulmonary Function Testing |

| All pulmonary function parameters were obtained using KeyStone3 (vertical dry rolling seal; data sampling rate 200 Hz, measuring range 0–10 L, Ferraris, USA). Prior to testing, volume and flow calibration checks were performed using a 3-L syringe. Forced vital capacity (FVC), forced expiratory volume in the 1st s (FEV1.0), forced expiratory flow between 25 and 75% of vital capacity (FEF25%-75%), and peak expiratory flow (PEF) were measured while the subjects was in sitting position wearing a nasal clip. Three trials were obtained and the highest measure of FVC and FEV1.0 was considered the best trial. Also, three trials of maximum voluntary ventilation for 12 s (MVV12) were obtained and the highest value was recorded. Maximal inspiratory pressure (PImax) was measured at sitting position; participants were asked to expire maximally to residual volume (RV). Then, inspire maximally to the total lung capacity (TLC) and maintain it for 1–3 s. At least three trials were obtained. The highest negative value was considered the best trial. Maximal expiratory pressure (PEmax) was measured at sitting position; participants were asked to inspire maximally to TLC. Then, expire maximally to RV and maintain it for 1–3 s. At least three trials were obtained. The highest positive value was considered the best trial. All spirometry manoeuvres were conducted according to American Thoracic Society (ATS) guidelines.[32] Also, all the tests were obtained by a certified pulmonary function technologist (CPFT) who holds a valid certificate from the National Board of Respiratory Care (NBRC).

2.4. Maximal oxygen uptake |

| All participants performed an incremental exercise test to volitional exhaustion, before and after the RMT program, to determine maximal oxygen uptake (VO2max). Cortex cart (Cortex 3BMetslyser®, Cortex Biophysik Gmbh, Leipzig, Germany) was calibrated at ambient air and known quantities of gas mixture. Also, the pneumotachometer was calibrated with a 3.0 L calibration syringe immediately before each test. Gas and flow measurements were corrected for ambient temperature, barometric pressure, and humidity. The tests were conducted on a treadmill (Woodway GmbH, PPS 55 Med, Steinacherstr, Germany) which was interfaced with Cortex software so all protocols could be modified based on each participants fitness level, and to ensure all operations of the treadmill were automated. Each subject started with 4 min' warm-up, and then a face mask was placed tightly onto their face and connected to a non-rebreathing valve. The test began with 3 min' resting period to establish the ventilatory and pulmonary gas exchange indices baseline. Through the test, the treadmill speed (8–10 km/h) remained constant at a speed selected by the subject (modified Balk protocol), and the inclination increased at a rate of 1% at the end of each minute until volitional exhaustion. The following parameters were measured and/or calculated during all exercise testing and used for subsequent analysis: oxygen uptake (VO2 ml/min.), respiratory exchange rate (RER), minute ventilation (VE L/min), respiratory rate (RR breath/min), and ventilatory equivalent for oxygen (VE/VO2). Also, dyspnoea rating, modified Borg scale, CR-10; Borg,[33] and heart rate (Polar, Oulu, Finland) were determined during the last 5 s of each stage. No encouragement or feedback was provided during the test. The criteria used decide upon the success of the maximal tests were RER >1.15, heart rate >90% of age predicted maximum.

2.5. Time to exhaustion (Tlim90%) |

| Exercise endurance performance was evaluated as the time to exhaustion at 90% of VO2max before and after the RMT program. The Time to Exhaustion (Tlim90%) was defined as the time from onset of running to voluntary exhaustion. Similar to the VO2max test, subjects completed a warm-up of at least 4 min. Then, they ran at a constant speed and inclination that corresponded to 90% of VO2max till exhaustion. All cardiorespiratory parameters were assessed in the same manner as in the VO2max test. Dyspnoea levels and heart rate were obtained at the end of each minute. No verbal encouragement was provided during the test. All tests were conducted under constant temperature (18–22°) and relative humidity (<70%) measured using HiGlo 433 MHz cable free thermometer (Oregon Scientific Inc, Tualatin, Oregon, USA). For retesting the participants were scheduled at the same time of the day (±1 h) where possible, so that any fluctuations due to diurnal effects were diminished.[34]

2.6. Respiratory muscle training |

| The THRESHOLD® Inspiratory Muscle Trainer, Respironics, USA was used in this study. Based on the manufacturer recommendations, appropriate use of the THRESHOLD® device requires the subject to sit in a comfortable upright position. The nose clip needs to be applied to prevent nasal breathing. The subject needs to place the mouthpiece in the mouth and maintain sealed lips. The subject must exhale slowly until near residual volume (RV) is reached. Then, the subject needs to inhale deeply, with enough force to open the valve and maintain deep inhalation until near total lung capacity (TLC) is reached. The last phase is slow exhalation through the device. Subjects were aware that hyperventilation could cause respiratory alkalosis and that subsequently dizziness may occur. To reduce the likelihood of these effects, they were asked to pause for 20 s after the fifth manoeuvre. In this study, training ranged from 10 to 25% of PImax once a day for 15 min in the first week. Then the percentage of PImax increased to 30% twice a day for 15 min for the rest of training period. Training levels for the IMT were calculated based on PImax values obtained from the baseline assessments (see Pulmonary Function Testing) and devices adjusted to the inspiratory pressure resistance accordingly; i.e., adjusting the load (cm H2O) on the scale of the device. Thus, the training protocol was structured to begin from a very low resistance and gradually increase it (see Table 2). Participants in the placebo group received the same device, which had been manipulated so there was almost no inspiratory resistance by fixation of the membrane of the device in the fully open position and followed the same protocol. The first training session was conducted in the physiology laboratory at the Bangor University, to ensure proper procedures, but after that, training was conducted at subjects' homes. A diary log chart was provided to record the training sessions.

2.7. Statistical analysis |

| Mixed ANOVA was used to test for between-group effects of the treatments (RMT or placebo) and within-group effects of the interventions (pre- and post-treatment) on each dependent variable: PImax, PEmax, FVC, FEV1.0, PEF, FEF25-75%, MVV12, VO2max, and Tlim90%. Shapiro-Wilk test and Levene's test were used to test for normality and for homogeneity, respectively. All significant interactions were followed up by planned pair wise comparisons, paired sample t-tests and independent t-tests, to allocate significance and the Bonferroni adjustment was used to modify the per family type I error. Minimal detectable change (MDC) was calculated as Standard Error of Measurement $(SEM) * 1.96 * \sqrt{2}$ and the SEM was calculated as standard

Table 2
Respiratory muscle training protocol.

Duration	Intensity as % of PImax	Duration
Day 1–2	10%	1 × 15 min (5 session)[a]
Day 3	20%	1 x 15 min
Day 4–7	25%	1 x 15 min
Week 2	30%	1 x 15 min
Week 3	30%	1 x 15 min
Week 4	30%	2 × 15 min (total 30 min)
Week 5	30%	2 × 15 min (total 30 min)
Week 6	30%	2 × 15 min (total 30 min)

[a] Each session train for 2 min then rest for 1 min.

deviation $(SD) * \sqrt{(1 - ICC)}$, where Intra-class correlation coefficient (ICC) was calculated for mixed models.

3. Results

Of the 14 participants (7 in the training group and 7 in the placebo group), all completed the training program, as indicated by the diary cards. Subjects in the training group reported side stitches and soreness of respiratory muscles after the respiratory training sessions. PImax, PEmax, FVC, FEV1.0, PEF, FEF25-75%, MVV12, VO2max, and Tlim90% resulted in $P > 0.05$ for both Shapiro-Wilk and Levene's tests confirming normality and homogeneity. F statistics is reported in Table 3.

3.1. Respiratory muscle strength and spirometry

A significant interaction between groups and time for PImax, PEmax, and FVC was found following six weeks of RMT. A significant increase in PImax ($P = 0.012$) was observed in the training group, from, mean value (MV) ± standard deviation (SD), 130.5 ± 19.9 cm H2O to 149.2 ± 19.7 cm H2O. This represents an increase of 14.3% in PImax from baseline (see Table 4). No significant increase was observed in the placebo group. The PEmax values showed significant improvement in the training group ($P < 0.001$), from 128.1 ± 25.9 cm H2O 162.9 ± 29 cm H2O, which represents a 27% increase from baseline values. No significant increase was observed in the placebo group over time (Fig. 1). A posteriori Cohen's d calculations revealed large effects for PImax and PEmax (1 and 1.3, respectively). Only in the RM training group, significant improvement was observed in the FVC value as a result of the six weeks of training ($P < 0.01$). FVC increased from 5.51 ± 1.7 (l/min) to 5.71 ± 1.7 (l/min), which represents a 3.6% increase from the pre-training value. No significant changes were observed in the placebo group. FEV1.0 increased from 4.46 ± 1.2 (l/s) to 4.50 ± 1.2 (l/s), but this change does not differ significantly from changes observed in the placebo group. Moreover, the mean value of PEF and FEF25-75% did not change significantly either in the training group or the placebo group. Additionally, there was no significant interaction between group and time for maximum voluntary ventilation (MVV12).

Table 4
Pre-versus Post-IMT. Mean values ± SD.

Parameters	Training group		Placebo group	
PImax (cm H2O)	130.5 ± 19.9	149.2± 19.7[1]	124.4 ± 14.8	125.3 ± 16.9
PEmax (cm H2O)	128.1 ± 25.9	162.9± 29[1]	137.1 ± 44	139.3 ± 8.5
MVV (l/min)	156 ± 36.2	162.8 ± 36.6	150 ± 31.3	150.7 ± 31.5
FVC (L)	5.51 ± 1.7	5.71± 1.7[1]	4.6 ± 0.8	4.5 ± 0.8
FEV1 (l/s)	4.46 ± 1.2	4.50 ± 1.2	4.04 ± 0.7	4.0 ± 0.66
FEF25-75% (l/s)	4.39 ± 0.90	4.19 ± 1.0	4.25 ± 1.0	4.16 ± 1.1
PEF (l/s)	8.61 ± 1.8	9.0 ± 1.6	8.02 ± 1.6	7.78 ± 1.5

PImax, maximal Inspiratory Pressure; PEmax, maximal Expiratory Pressure; MVV.
Maximum Voluntary Ventilation; FVC, Forced Vital Capacity; FEV1.
Forced Expiratory Volume after the 1st second; FEF25-75%.
Forced Expiratory Flow between 25 and 75% of vital capacity.
PEF, Peak Expiratory Flow.
[1] significantly different from baseline ($P < 0.05$).

3.2. Exercise performance

There were significant interactions between groups and time for VO2max and Tlim90%. In the training group, the results of post-training-exercise tests showed significant improvements in the maximal oxygen uptake (VO2max) and the time to exhaustion (Tlim90%) test (Fig. 2). The VO2max increased from 45.1 ± 9.3 (ml/kg/min) to 50.1 ± 11.3 (ml/kg/min) ($P = 0.003$), and the Tlim90%

Table 3
Two-way mixed ANOVA and post hoc results.

Parameters	Effect	F (dftime, dferror)	p-value	Effect size (ges)	Post hoc (adj Bonferroni)	MDC
Tlim90% (minute)	group	0.292 (1, 12)	0.599	0.023	0.014[1] (RT group)	2.18 (minute)
	time	12.898 (1, 12)	0.004[1]	0.050		
	group*time	7.201 (1, 12)	0.020[1]	0.029		
VO2max (ml/kg/min)	group	0.007 (1, 12)	0.934	0.001	0.003[1] (RT group)	4.30 (ml/kg/min)
	time	18.556 (1, 12)	0.001[1]	0.031		
	group*time	6.479 (1, 12)	0.026[1]	0.011		
MVV12 (l/min)	group	0.269 (1, 12)	0.613	0.022		9.10 (l/min)
	time	4.926 (1, 12)	0.046[1]	0.003		
	group*time	2.973 (1, 12)	0.110	0.002		
FEF25-75% (l/s)	group	2.179 (1, 12)	0.166	0.149		0.40 (l/s)
	time	0.523 (1, 12)	0.483	0.002		
	group*time	0.884 (1, 12)	0.366	0.003		
PEF (l/s)	group	2.187 (1, 12)	0.165	0.000		0.75 (l/s)
	time	0.007 (1, 12)	0.933	0.000		
	group*time	0.343 (1, 12)	0.569	0.000		
FEV1.0 (l/s)	group	0.742 (1, 12)	0.406	0.006		0.28 (l/s)
	time	0.009 (1, 12)	0.927	0.000		
	group*time	1.713 (1, 12)	0.215	0.000		
FVC (l)	group	1.967 (1, 12)	0.186	0.141	0.002[1] (RT group)	0.38 (l)
	time	5.834 (1, 12)	0.033[1]	0.001		
	group*time	29.080 (1, 12)	<0.001[1]	0.003		
PEmax (cm H2O)	group	0.165 (1, 12)	0.692	0.013	<0.001[1] (RT group)	37.6 (cm H2O)
	time	13.034 (1, 12)	0.004[1]	0.075		
	group*time	10.185 (1, 12)	0.008[1]	0.059		
PImax (cm H2O)	group	2.831 (1, 12)	0.118	0.168	0.012[1] (RT group)	21.3 (cm H2O)
	time	7.244 (1, 12)	0.020[1]	0.079		
	group*time	5.972 (1, 12)	0.031[1]	0.066		

Ges, Generalized eta squared; MDC, Minimal Detectable Change.
Tlim90%, Time to exhaustion; VO2max, maximal oxygen consumption.
MVV12, Maximum Voluntary Ventilation; FEF25-75%, Forced Expiratory Flow between 25 and 75% of vital capacity.
PEF, Peak Expiratory Flow; FEV1.0, Forced Expiratory Volume in the 1st second: FVC, Forced Vital Capacity.
PEmax, maximum expiratory pressure; PImax, maximal inspiratory pressure.
[1] $P < 0.05$.s.

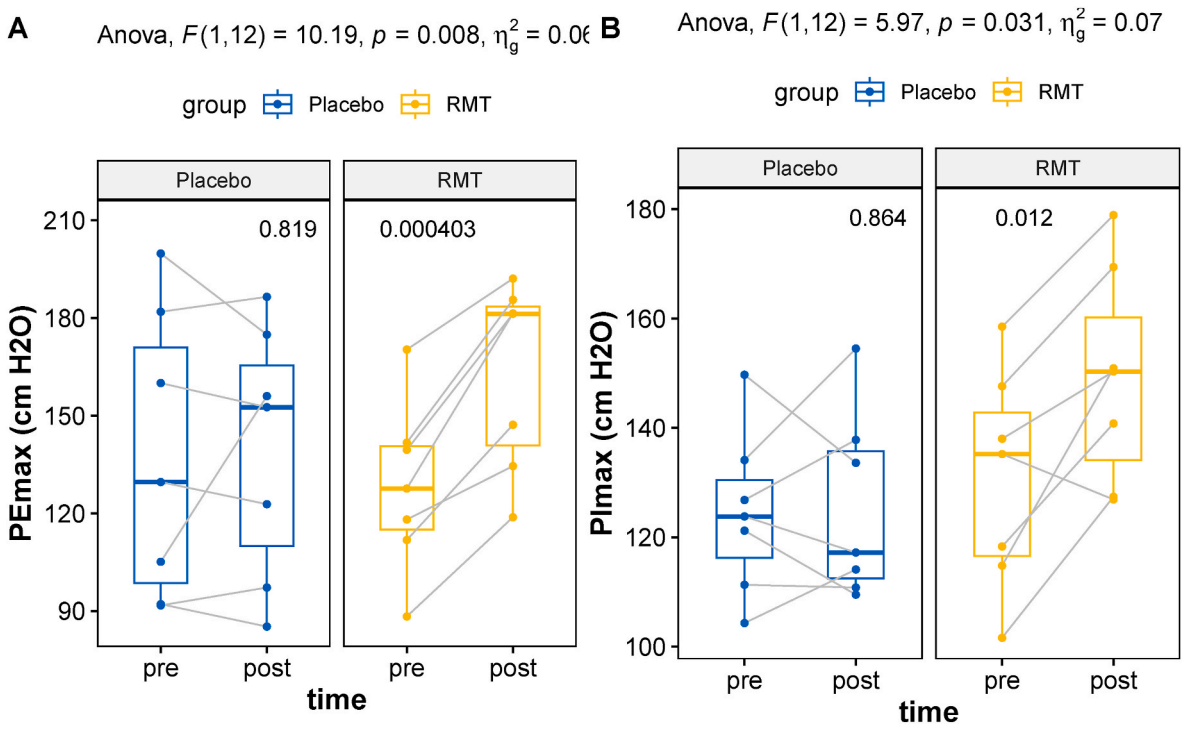

Fig. 1. Effects of respiratory muscle training (RMT) on Respiratory muscle strength, PEmax = Maximal expiratory pressure, PImax = Maximal inspiratory pressure.

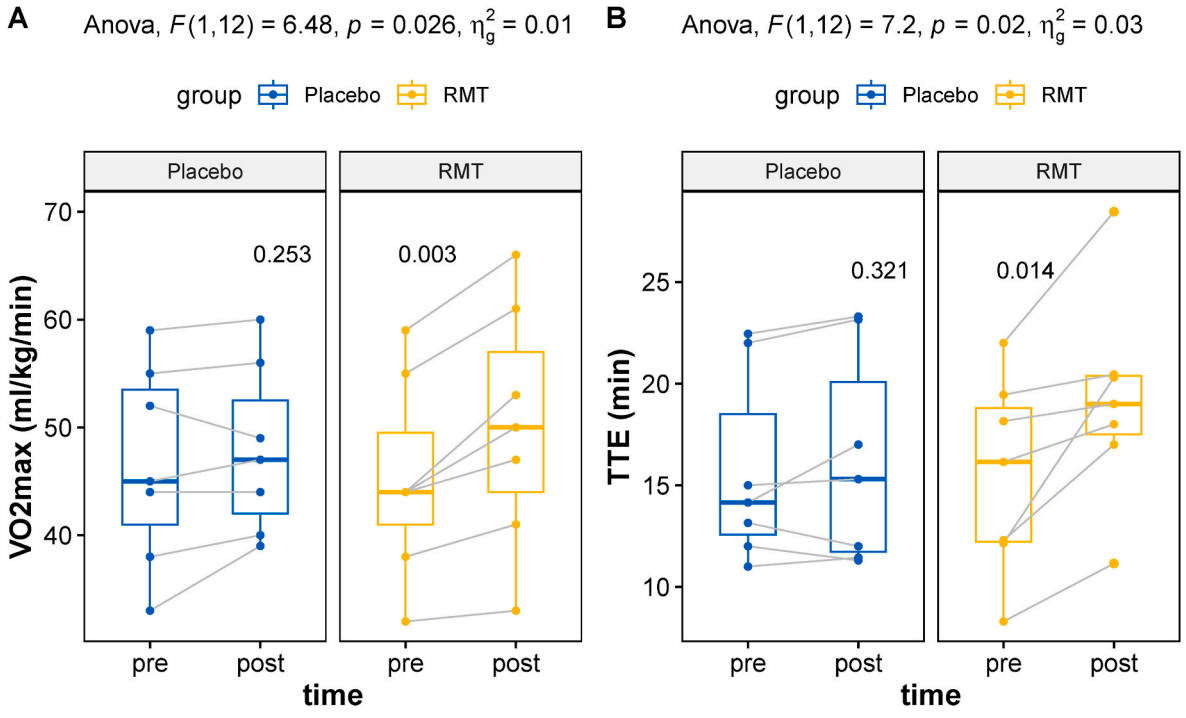

Fig. 2. Effects of respiratory muscle training (RMT) on Exercise performance, VO2max = maximal oxygen consumption, TTE = time to exhaustion.

increased from 15.35 ± 4.9 (minute) to 19.19 ± 5.1 (minute) (P = 0.014). These changes represent 11% and 25% improvements in VO2max and Tlim90% respectively. A posteriori Cohen's d calculations revealed large to moderate effects (0.9 and 0.5, respectively). No significant changes were observed in the placebo group. Since the difference in age between the training and the placebo group could have confounded the VO2max results, we have performed an ANCOVA adjusting for the age and weight differences at baseline. We found that the post-test differences in VO2max between the two groups were still statistically significant, $F(1,11) = 5.917$, $P < 0.0001$. Moreover, we did not find any interaction for HRmax, yet a simple effect of time was found for the placebo group which showed a lower HR max at post-test. Importantly, Rating of Perceived Exertion (RPE) at end of the maximal test did not show any significant difference. There were no significant changes in body weight in both groups pre and post training. Also, no significant changes observed in VE or RR, either in the training group or

Table 5
Pre-versus Post-IMT. Mean values ± SD.

Parameters	Training group		Placebo group	
	Pre-IMT	Post-IMT	Pre-IMT	Post-IMT
VO2max (ml/kg/min)	45.14 ± 9.28	50.14± 11.3[1]	46.57 ± 9.3	47.8 ± 7.8
RPE (max test)	3.12 ± 0.77	3.06 ± 1.30	3.40 ± 1.02	3.18 ± 0.76
HRmax	175 ± 11.1	172 ± 14.5	184 ± 9.14	178 ± 8.98
Vtmax	2.42 ± 0.86	2.51 ± 0.93	2.58 ± 0.73	2.73 ± 0.67
RERmax	1.24 ± 0.05	1.20 ± 0.06	1.23 ± 0.04	1.24 ± 0.06
TTE (minute)	15.35 ± 4.9	19.19± 5.1[1]	15.74 ± 4.76	16.21 ± 5.2
VE (L/min)	108.3 ± 33.2	104.74 ± 26.2	106.3 ± 27.9	111.6 ± 37.7
RR (breath/min)	44.48 ± 8.4	39.04 ± 6.96	55.08 ± 12.06	51.56 ± 13.9
RPE (@TTE)	4.50 ± 2.13	4.07 ± 1.79	5.81 ± 1.72	5.74 ± 1.75
HR (@80%TTE)	172 ± 12.1	170 ± 15.8	180 ± 10.2	177 ± 8.26
RER (@TTE)	1.09 ± 0.05	1.10 ± 0.03	1.13 ± 0.04	1.09 ± 0.05

VO2max, Maximal Oxygen uptake; RPE, Rating of Perceived Exertion.
HRmax, Heart Rate maximum; Vtmax, Tidal Volume maximum.
RERmax, Respiratory Exchange Ratio maximum, TTE, Time To Exhaustion test.
VE, Minute VEntilation at corresponded time; RR, Respiratory Rate at corresponded time.
[1] Significantly different from baseline ($P < 0.05$).

the placebo group (see Table 5).

4. Discussion

The main finding of this study is that progressive and specific low resistance inspiratory muscle training enhanced both RM strength and endurance exercise capacity in healthy subjects.

4.1. Respiratory muscle strength |

| The present study produced 14% improvement in PImax, as a result of training intensity at 30% of PImax, while same intensity and similar protocol yielded 30% improvement in an early study conducted on young healthy women.[23] Other groups reported increase by 10%, 8%, and 41% of PImax respectively after training at 50% of PImax.[7,35,36] It is obvious that factors other than intensity can affect the magnitude of improvement of RM strength. They are more likely to be general physical activities, which may provide training stimulus to RM[37] or quantities and/or quality of the training.[21] Also, it seems that the magnitude of PImax improvement is inversely related to the baseline values of RM strength. In other words, subjects with low PImax baseline would exhibit more pronounced improvement than those who began their training at a high PImax. This seems to be consistent with results found in people with chronic diseases,[28] where net changes analysed over 7 studies (for a total of 202 subjects), employing low resistance (30% of PImax), yielded a weighted mean difference equal to 28.42 (95% CI 12.37–44.46) cmH2O (for more details see Fig. 2 in Ref. 28). In the present study, the PImax mean value increased from 130 cm H2O to 149 cm H2O. Also, similar training intensity produced an increase of PImax from 98.3 cm H2O to 131 cm H2O.[23] It is interesting to notice that another meta-analysis in endurance athletes of various disciplines (i.e., cycling, endurance track sports, intermittent sprint-type sports, rowing, swimming, diving, and special forces athletes, for a total of 352 subjects including controls, see details in Fig. 5 in Ref. 30) undergoing a high-resistance RMT (50% of PImax or greater), recorded net changes equal to 23.69 (95% CI 15.31–32.06) cmH2O, not larger than the ones observed for low resistance RMT.[30] Moreover, the same study showed how athletes such as swimmers and divers did not improve.[30] Previous studies showed that the magnitude of improvement in PImax post RMT was mediated by respiratory muscle strength baseline levels, training modes, intensity and duration, and fitness levels.[38] In view of this, low intensity RMT could be more beneficial for sedentary or diseased subjects than for highly trained athletes. In the present study, although the training program was aimed to enhance inspiratory muscle strength, the PEmax showed impressive improvement which differ somewhat from other studies[11,26] but in agreement with the results of Suzuki et al.,.[23] Several possible reasons can be offered to explain such improvement: first, during the training sessions, the expiratory muscles are recruited to perform forceful expiration, it has been shown that exercise-induced activation of the transversus abdominis/internal oblique muscle may modulate an increase in expiratory pressure[39]; second, external and parasternal muscles have mechanical advantages during inspiration as well as expiration.[40] Third, abdominal muscles are recruited during inspiratory mechanical loading.[41] These factors collectively or independently might contribute to the significant improvement in PEmax observed in the present study.

4.2. Spirometry |

| The association between RM strength and flow-volume loop parameters, which represent the elastic properties and resistance of the respiratory system, was not established in previous studies.[11,12,26,42] This was not the case in the present study; an increase of FVC significantly was reported post RM training program. However, other parameters remained unchanged (FEV1, PEF, and FEF25-75%). These data are in agreement with early studies.[10,36] Inconsistency among the previous studies could be attributed different RMT protocols and/or variation in instructions provided to perform spirometry maneuver. The majority of pulmonary function technician's emphasis forceful exhalation, with little or no encouragement during deep inspiration phase prior to expiration manoeuvre which can be a source of error.[43] Our spirometric data was obtained by certified pulmonary function technologist and Enright's comment was taken in consideration.[43] Also, while most of the studies that failed to detect changes in lung volumes reported an improvement only in inspiratory muscle strength, but expiratory muscle strength remained unchanged or unknown[11,12,26] our results showed improvement of both inspiratory and expiratory muscle strength. Therefore, FVC improvement can be explained by the ability of RM to generate more negative pressure during inspiration and fully exhale the air to residual volume. Additionally, the nature of the present RMT program requires inflation of the lung near to TLC for prolonged duration. This mechanism is considered a physiological trigger for surfactant release, which may subsequently improve lung compliance and elasticity.[44]

4.3. Exercise performance |

| Improvement of endurance exercise tolerance (Tlim90%) which was accompanied by an increase of VO2max, but not with changes in minute ventilation or respiratory rate, was a major finding in the present study. Subsequent to RMT, an increase of VO2max can be attributed to an increase of oxygen saturation[4] or a reduction of RM oxygen

consumption[45] during heavy exercise. Also, attenuation of muscle sympathetic activity (MSNA) which occurs in parallel with RM fatigue[46] during exercise can lead to improvement of VO2max.[47] Minimal detectable change for VO2max (4.3 ml/kg/min) against the observed change in the RMT group (5.0 ml/kg.ml) as well as not interactions for HR max nor for RPE at max seem to confirm that this improvement may be caused by a better oxygen extraction. However, we did not measure oxygen delivery in this study therefore future studies should be focusing on this aspect. The magnitude of exercise performance enhancement seems not to be related to the intensity of RMT. Our results showed a 25% improvement in Tlim90% as results of training at 30% of PImax, whereas others who utilised 50% training intensity[25,36] reported an improvement by 21% and 26%, respectively. An increase of RMT intensity to 80% produced similar result.[10] Surprisingly, Guenette et al.,[25] found that subjects with the highest increase in PImax showed the smallest change in exercise performance. Therefore, it can be concluded that exercise performance enhancement is more related to the ability of RM to resist fatigue other than other factors. In fact, in the present study the magnitude of RM fatigue was not measured immediately after the first Tlim90% test, but based on the previous reports,[4,5,48,49] the presence of such fatigue can be assumed. The onset of RM fatigue is related to the strength of these muscles. Subjects with low PImax are more susceptible to fatigue than those who have higher PImax measurements.[29] Therefore, in the absence of other systemic responses, exercise performance improvement in the present study can be attributed to increase of RM strength and subsequently increase resistance and/or delay the onset of RM fatigue. It is very likely that changes in RM contractile properties[27] is the ergogenic factor that stands behind increased capability of RM to resist fatigue during heavy exercise for longer duration.

4.4. Limitations |

| Next to the lack of direct measurement of respiratory muscle fatigue, main limitations of this study were its small size, with only 4 females, which will require larger studies to be conducted in the future, the use of healthy and physically active individuals who may not have reached above population average aerobic capacity, which implies that the improvements seen in this study may be difficult to replicate in a highly trained population. Moreover, in this study VO2max and time to exhaustion were used to evaluate cardio-respiratory endurance performance. Yet sports performance is determined also by technical and psychological components.[50]

5. Conclusions

This study demonstrates that a low resistance RMT program may be sufficient to elicit a pronounced improvement in respiratory muscle strength and exercise tolerance in adults engaged in recreational activities. Further studies are required to investigate the role of low resistance RMT on highly trained subjects and in clinical settings.

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Declaration of competing interest

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