



(RESEARCH ARTICLE)



Effect of respiratory muscle strengthening with breathing exercises on ventilatory functions, aerobic fitness and their association with performance in elite rowers

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Abstract

This study aimed to investigate the effect of RMT on ventilatory parameters, aerobic fitness and rowing ergometer performance among professional rowers in Sri Lanka. Twenty national male rowers, aged 20-35 years were grouped randomly into an experimental (n=11) and a control (n=9) group. Prior to the study, baseline measurements of ventilatory functions, aerobic fitness (VO₂max) and rowing performance were assessed by a portable spirometer, 2000m and 5000m rowing ergometer and Monark cycle ergometer respectively. Subsequently, rowers in the experimental group were prescribed a RMT program comprising of breathing exercises while control group was prescribed a general exercise program for a 12 weeks after which all the above parameters were assessed again. The association of rowing ergometer performance with the ventilatory functions and aerobic fitness was assessed by pearson correlation. There were significant improvements in PIF, FVC, and VO₂max in the experimental group after 12-weeks (p<0.05) while only VO₂ max improved non-significantly in the control group (p>0.05). Compared to the control, PIF improved significantly in the experimental group (p<0.05). The rowers in the experimental group with higher PIF and VO₂max performed better at 2000m and 5000m ergometer whereas in the control group, only VO₂max was associated with better performance in 5000m ergometer. This suggests that the RMT program had a significant effect in improving some ventilatory parameters and VO₂max of the rowers resulting in better performance.

Keywords: Respiratory muscle strengthening; Aerobic fitness; Ventilatory functions; Rowing performance

1. Introduction

Rowing is one of the most physically demanding endurance sports requiring high levels of ventilation ^[1]. Rowing involves both locomotor and respiratory muscles of the body ^[2]. Rowers have been shown to have very large total lung capacity (TLC), vital capacity (VC) ^[3] and peak expiratory flows (PEF) ^[4, 5]. The respiratory muscles are involved in postural control during the rowing stroke and the flexed posture of the rower places extreme added demands on respiratory system ^[6,7].

A rower needs more energy to perform rowing cycle in which 70% of energy comes from aerobic metabolism ^[1,2]. Studies have shown that oxygen consumption also increases by about 20-fold from the resting state of 250ml/min to 4000ml/m during exercise in the well-trained athlete at sub-maximal intensity level ^[8]. Literature suggests that the most limiting factor for oxygen uptake during exercise is the pumping ability of the heart compared to the respiratory system ^[9]. But breathing does limit exercise performance because respiratory muscles enforce their own demands upon the oxygen delivery system ^[10]. Recent investigations have shown that an increase in respiratory muscle demand during intense exercise reduces the limb blood flow ^[11,12] by diverting blood flow from the limb muscles to the respiratory muscles, the metaboreflex. This accelerates muscle fatigue which has detrimental effects on sports performance ^[13,14]. Therefore, respiratory muscle training (RMT) becomes useful to augment respiratory muscle functions in high intensity

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sports like rowing. It is well known that involvement in physical activity and sports helps in respiratory muscle strengthening and improvements in pulmonary function [15, 16]. Further, it has been shown that improvements in lung functions help to improve exercise performance in trained athletes [14, 17]. In addition, it is well documented that yoga, which comprises of breathing exercises, improves respiratory parameters [15, 18, 19] and respiratory muscle strengthening [20, 21].

RMT can be carried out using many training devices. However, the high cost in purchasing such devices is a drawback for many developing countries like Sri Lanka. This novel RMT program, which included specific exercises for respiratory muscles, was designed to assess its effects on ventilatory parameters, aerobic fitness and performance among professional rowers in Sri Lanka.

2. Material and methods

2.1. Study design and participants

A case controlled randomized study was conducted in 20 male rowers aged between 20-35 years during the competitive period. Age, body weight and height matched rowers were divided into an experimental (n=11) and a control group (n=9). This study was conducted at the General Sir John Kotelawala Defence University and Exercise & sports laboratory Faculty of Medicine, University of Peradeniya. This study was conducted in accordance with the declaration of Helsinki and Ethical Clearance was obtained from Ethics Review Committee, Faculty of Medicine, University of Peradeniya, Sri Lanka (2016/EC/52). This trial was retrospectively registered (UMIN000040345, 09/05/2020).

2.2. Data collection

Initially, anthropometric profile namely body weight, height, fat mass, muscle mass and arm span were assessed in the total study population. The assessment of lung volumes, capacities and flow rates namely; peak inspiratory flows (PIF), peak expiratory flows (PEF), forced vital capacity (FVC) and forced expiratory volume in 1 second (FEV₁) were done using a portable spirometer (Spiro analyzer ST-75) in the standing position according to joint American Thoracic Society and European Respiratory Society guidelines [22]. Astrand- Ryhming submaximal bicycle ergometer test was used for the determination of aerobic fitness (VO₂max) using a Monark cycle ergometer 828E. VO₂ max in litres/minute was predicted using standards tables and a nomogram [23]. The test distance of 2000m and 5000m are commonly used to monitor rowing training and performance. The concept II, (Nottingham, UK) ergometer machine and stopwatch were used for the test and the time spent on the rowing ergometer machine was assessed.

Subsequently, rowers in the experimental group were prescribed a respiratory muscle training program consisting of warm-up, flexibility training, inspiratory and expiratory muscle strengthening and warm down sessions. The flexibility training included stretching of the chest and trunk muscles by introducing full body stretches and lateral stretches which was repeated more than 30 times [24].

The inspiratory muscle training program used three different breathing exercises. *Diaphragmatic re-education*: The subject was asked to perform a slow nasal inspiration and mouth expiration in the standing position which was repeated 30 times. *Profound (deep) inspiration*: The subject was asked to gently breathe in through the nose until total lung capacity was reached and to hold the breath for 10 seconds. This was followed by single mouth expiration in the standing position. *Inspiratory hiccups*: The subject was asked to perform short and sequential inspirations without periods of apnea until total lung capacity, followed by smooth mouth expiration in the standing position [25]. These exercises mainly targeted strengthening of the diaphragm, external intercostals muscles and other accessory inspiratory muscles. Each technique was repeated 30 times with rest intervals between them.

In the present study, abdominal muscles strengthening and endurance exercises namely; Isometric Side Bridge and Curl-ups [24] were introduced in the expiratory muscle training program.

The rowers in the control group were recommended a “general exercise program” which included a warm-up and warm down sessions (similar to intervention group), flexibility training and strength training programs for non-respiratory muscles. The flexibility training included the biceps stretching and triceps stretching [24]. These exercises were repeated 10 times for both arms.

In the control group, strength training exercises were included as follows: Biceps curls, Triceps curls, Hamstring curls and Quadriceps strengthening (Straight Leg raises) [24]. Both programs were introduced in addition to the routine exercise schedule followed during the competition season. The respiratory muscle training program and the general

exercise program were conducted for 7 days per week for 12 weeks after which assessment of the lung parameters (PIF, PEF, FVC and FEV₁), VO₂max and ergometer performance were repeated. During the training program, all participants in both groups were requested to maintain a detailed physical activity-training schedule and an “Exercise program training diary” in order to monitor training adherence.

2.3. Statistical analysis

Data was entered and validated in a SPSS (Statistical Package for Social Sciences (SPSS) version 17.0) database. Changes in lung volumes, lung capacities, flow rates and aerobic fitness were compared before and after the exercise programs in the experimental and control groups using paired sample t test and between the experimental and control group using independent sample t test. The relationship between the two variables was assessed with the Pearson Correlation. Statistical analysis was conducted at a 95% confidence interval, and $p < 0.05$ was considered statistically significant.

3. Results

The Mean age of study sample was 25.3 ± 3.5 years. The Means of anthropometric profile namely: body height, body weight, arm span, fat mass and muscle mass and their association with the 2000m and 5000m rowing ergometer performance of the total study population ($n=20$) are shown in Table 1. The body height, body weight, arm span and muscle mass showed a negative correlation with 2000m and 5000m ergometer tests which were highly significant ($p < 0.01$) while fat mass significantly positively correlated with the 2000m and 5000m ergometer performance test ($p < 0.01$).

Table 1 The relationship of body height, body weight, arm span, fat mass and muscle mass with 2000m and 5000m rowing ergometer performance of the total study population ($n=20$)

| Anthropometric profile | Mean \pm SD | 2000m ergometer performance | | 5000m ergometer performance | |
|------------------------|-----------------|-----------------------------|---------|-----------------------------|---------|
| | | r | p value | r | p value |
| Body Height (cm) | 176.9 \pm 8.9 | -0.85 | 0.00 | -0.77 | 0.00** |
| Body weight (Kg) | 71.3 \pm 5.5 | -0.63 | 0.00 | -0.56 | 0.01* |
| Arm span (cm) | 186.7 \pm 5.7 | -0.86 | 0.00 | -0.52 | 0.01* |
| Fat Mass (Kg) | 5.1 \pm 2.9 | 0.11 | 0.00 | 0.18 | 0.00** |
| Muscle Mass (Kg) | 62.6 \pm 5.7 | -0.22 | 0.00 | -0.28 | 0.00** |

[SD- Standard deviation; r - Correlation coefficient; * $p < 0.05$ - Significant; ** $p < 0.01$ - Highly Significant]

Table 2 shows lung volumes, lung capacities and flow rates namely: Peak Inspiratory Flow (PIF), Peak Expiratory Flow (PEF), Forced Vital Capacity (FVC) and Forced Expiratory Volume in one second (FEV₁) in the control ($n=9$) and the experimental groups ($n=11$) before and after introducing the 12-week non- respiratory muscle and respiratory muscle training (RMT) programs respectively. After introducing the RMT program, a significant difference was observed in PIF and FVC ($p < 0.05$) in the experimental group with no significant difference in other parameters. In contrast, no significant difference was observed in all the respiratory parameters in the control group after introducing the non-respiratory muscle training program.

Table 2 Lung Volumes, Lung Capacities and Flow Rates of the Rowers in the Control ($n=9$) and Experimental Group ($n=11$) before and after 12-week Exercise Programs

| Lung Parameters | Control group Mean \pm SD | | | Experimental group Mean \pm SD | | |
|----------------------|-----------------------------|----------------|---------|----------------------------------|----------------|---------|
| | Pre training | Post training | p value | Pre training | Post training | p value |
| PIF (L/s) | 10.2 \pm 0.6 | 10.5 \pm 0.6 | 0.64 | 10.0 \pm 0.8 | 11.8 \pm 0.9 | 0.001** |
| PEF (L/s) | 10.8 \pm 1.4 | 11.2 \pm 0.9 | 0.52 | 11.0 \pm 3.0 | 11.4 \pm 1.2 | 0.56 |
| FVC (L) | 5.4 \pm 1.3 | 5.3 \pm 1.3 | 0.31 | 5.2 \pm 1.6 | 6.3 \pm 1.3 | 0.04* |
| FEV ₁ (L) | 5.8 \pm 1.1 | 5.7 \pm 1.4 | 0.31 | 5.6 \pm 1.2 | 6.0 \pm 0.9 | 0.15 |

[PIF: Peak Inspiratory Flow; PEF: Peak Expiratory Flow; FVC: Forced Vital Capacity; FEV₁: Forced Expiratory Volume in one second SD - Standard deviation; * $p < 0.05$ - Significant; ** $p < 0.01$ - Highly Significant]

At the end of 12 -week training program: PIF, PEF, FVC and FEV₁ were compared between the control and the experimental groups are shown in the Table 3. A significant increase was observed in PIF and FVC in the experimental group compared to the control group ($p < 0.05$) while there was no significant difference in PEF and FEV₁.

Table 3 Comparison of Lung Volumes, Lung Capacities and Flow Rates between the Control (n=9) and Experimental Group (n= 11) after the Respective Training Programs

| Lung volumes, capacities and flow rates | Mean \pm SD | | p value |
|---|----------------|--------------------|---------|
| | Control group | Experimental group | |
| PIF (L/s) | 10.5 \pm 0.6 | 11.8 \pm 0.9 | 0.04* |
| PEF (L/s) | 11.2 \pm 0.9 | 11.4 \pm 1.2 | 0.22 |
| FVC (L) | 5.3 \pm 1.3 | 6.3 \pm 1.3 | 0.04* |
| FEV ₁ (L) | 5.7 \pm 1.4 | 6.0 \pm 0.9 | 0.27 |

[PIF: Peak Inspiratory Flow; PEF: Peak Expiratory Flow; FVC: Forced Vital Capacity; FEV₁: Forced Expiratory Volume in one second ; SD - Standard deviation; * $p < 0.05$ - Significant; ** $p < 0.01$ - Highly Significant]

Figure 1 reflects the aerobic fitness in the control and the experimental groups before and after the 12 week non-respiratory and respiratory muscle training programs. The experimental group showed 2% significant improvement ($p < 0.05$) in aerobic fitness while the improvement in the control group was 1% which was not significant ($p > 0.05$). However, there was no statistically significant difference in the improvement in aerobic fitness between the control and the experimental groups after the respective training programs ($p > 0.05$).

Table 4 shows the relationship of respiratory parameters (lung volumes, capacities and flow rates), aerobic fitness and 2000m and 5000m rowing ergometer performance in the control and the experimental groups. In the experimental group, all the respiratory parameters showed negative correlation with both the 2000m and 5000m ergometer performance, while only PIF showed a significant relationship with 2000m ergometer performance test ($r = -0.69$; $p = 0.02$). In the control group, PEF and FEV₁ showed negative correlations while PIF and FVC showed a positive correlation with 2000m and 5000m ergometer tests however they were insignificant.

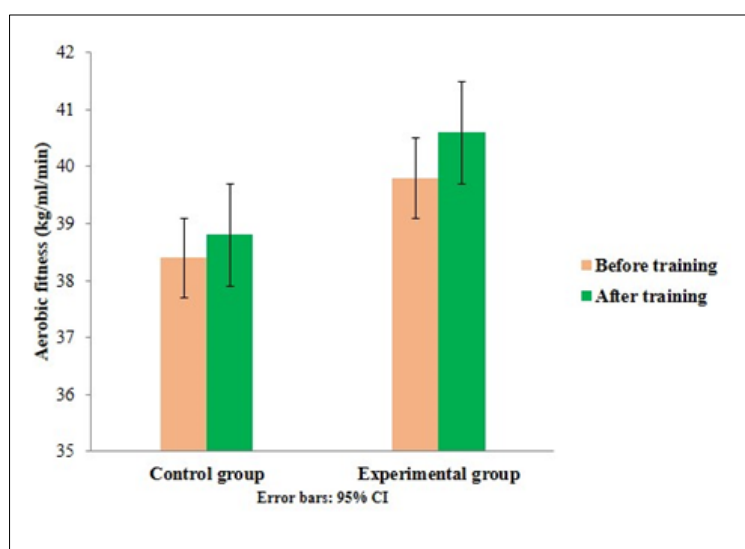


Figure 1 Aerobic fitness of the control and the experimental group before and after 12 week exercise programs. Aerobic fitness significantly improved in the experimental group ($P = 0.04$) while the control group ($P = 0.27$) did not show significant improvement at the end of 12 week respective training program. Confident interval (CI)

Aerobic fitness showed a significant negative correlations between and both the 2000m ($r = -0.77$; $p < 0.01$) and 5000m ergometer performance test ($r = -0.67$; $p < 0.05$) in the experimental group while in the control a significant negative correlation was observed only with the 5000m ergometer performance test ($r = -0.68$; $p < 0.05$).

Table 4 The relationship between respiratory parameters and aerobic fitness with the ergometre performance in the control group (n=9) and the experimental group (n=11)

| Flow volumes, lung capacities and flow rates | Control group Mean \pm SD | | | | Experimental group Mean \pm SD | | | |
|--|-----------------------------|------|-----------------------------|-------|----------------------------------|--------|-----------------------------|-------|
| | 2000m ergometre performance | | 5000m ergometre performance | | 2000m ergometre performance | | 5000m ergometre performance | |
| | r | p | r | p | r | p | r | p |
| PIF (L/s) | -0.05 | 0.88 | 0.14 | 0.72 | -0.69 | 0.02* | -0.09 | 0.79 |
| PEF (L/s) | -0.37 | 0.33 | -0.57 | 0.11 | -0.01 | 0.99 | -0.22 | 0.52 |
| FVC (L) | 0.12 | 0.76 | -0.51 | 0.17 | -0.43 | 0.18 | -0.08 | 0.82 |
| FEV ₁ (L) | -0.12 | 0.76 | -0.61 | 0.08 | -0.28 | 0.39 | -0.02 | 0.96 |
| Aerobic fitness | -0.06 | 0.88 | -0.68 | 0.04* | -0.77 | 0.00** | -0.67 | 0.04* |

[PIF: Peak Inspiratory Flow; PEF: Peak Expiratory Flow; FVC: Forced Vital Capacity; FEV₁: Forced Expiratory Volume in one second ; r = correlation coefficient ; SD – Standard deviation; *p< 0.05- Significant; **p< 0.01- Highly Significant]

4. Discussion

In the present study, when comparing the pre and post-training values of ventilatory parameters, it was observed that PIF and FVC improved significantly in the experimental group ($p < 0.05$) while no improvements were observed in all lung parameters in the control group ($p > 0.05$) after the respective training programs (Table 1). Furthermore, PIF was significantly higher ($p = 0.04$) in the experimental group compared to the control group after the 12 weeks RMT program (Table 2). Several past studies have also shown similar findings with improvement in PIF following RMT using the RMT device [29-31]. Peak inspiratory flow (PIF) is known to be the fastest flow rate achieved during a maximum inspiration and provides a measure of the maximal contraction of the inspiratory muscles [32].

The novel RMT training program conducted in this study included profound (deep) inspirations and inspiratory hiccups, exercises that strengthen the inspiratory muscles, while isometric side bridge, curls ups improved expiratory muscles strength. In addition, it also included full body stretch and towel stretch techniques to stretch the chest wall. These techniques would have helped to strengthen the respiratory muscles, improve the lung capacity (FVC) and PIF and increase chest expansion in the experimental group compared to the control group. These exercises have similarities with deep breathing techniques used in pranayama yoga practice during which the respiratory muscles are stretched fully towards the chest wall represented by increased chest wall expansion together with increased lung volumes, capacities and flow rates namely FVC, FEV₁ and PEF in healthy subjects [15, 33,34]. Long term benefits of yoga has been shown to increase chest expansion, breath-holding time and PEF [34-36]. Studies on clinical population have shown contradictory results with improvement seen in ventilatory function, hypoxia and relief of dyspnoea in chronic obstructive pulmonary disease (COPD) patients [38, 39] while, some studies suggested that there was no influence of RMT in patients with respiratory diseases [40, 41].

In the present study, significant improvement was seen in VO₂max overtime in the experimental and the control group with only the experimental group showing significant improvements. No significant difference was observed in VO₂max between two groups after the respiratory muscle training program ($p > 0.05$). Many studies have examined the effect of respiratory muscle training on VO₂max in different sports and revealed that VO₂max was not altered by RMT while a small group of studies have shown a statistically significant decrease in sub-maximal O₂ following RMT across different sports [30].

When considering the relationship between ventilatory functions and performance, it was observed that there was a negative relationship between lung functions and 2000m and 5000m ergometer performance in both the groups in the present study. However, only PIF significantly correlated with 2000m performance in the experimental group. This indicates that higher inspiratory flow rates are associated with lower ergometer time performance. However, contradictory outcomes have been observed concerning the relationship of ventilatory functions with sports performance following RMT. One study in athletes' documented that there was a significant negative relationship with FVC and running times [40] while in another study done on cyclists observed improvements in cycle endurance time subsequent with improved ventilatory functions following RMT [41]. This is in contrast to another study which showed that there was no improvement in performance in well-trained athletes after RMT [17].

When considering aerobic fitness, the present study revealed that there was a significant negative correlation between $VO_2\text{max}$, and the 2000m and 5000m ergometer performance test in the experimental group ($r = -0.68$; $p < 0.05$) (Table 3) while in the control group only the 2000m performance was significant. Similarly, several past studies have reported a significant correlation between the 2000 m ergometer rowing performance and $VO_2\text{max}$ values [42]. However, another study stated that no significant correlation exists between aerobic fitness and 2000 meter ergometer performance in both male and female rowers [43]. Though past research has consistently demonstrated that success in rowing is associated with higher $VO_2\text{max}$, some studies stated that $VO_2\text{max}$ alone is not a good predictor of rowing performance in rowers with similar endurance capacity [4].

The effect of RMT on lung functions and exercise performance has been inconclusive because of the differences in research design such as inappropriate performance outcome variables, ineffective RMT protocols, small sample sizes and the lack of carefully matched experimental and placebo groups [43]. However, Hopkins in 2004 has stated that the use of a well-designed case-controlled study with an appropriate RMT protocol would elicit significant improvements in respiratory functions and exercise performance [43]. Some studies have suggested that self-motivation of athletes also contributes to a positive impact on exercise performance following RMT [10, 29, 31].

5. Conclusion

Overall, our findings suggested that applying this novel RMT program in the training schedules of rowers resulted in improving some respiratory functions (PIF) and aerobic fitness ($VO_2\text{max}$) and these were associated with greater performance in both 2000m and 5000m rowing ergometer tests. This highlights the importance of introducing RMT in training protocols of sportsmen and women in Sri Lanka, in addition to peripheral muscle training program, as a routine practice to improve the sports performance. This novel RMT could also be used in rehabilitation of clinical populations, especially in developing countries, as RMT devices are costly and inaccessible for many.

Compliance with ethical standards

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Disclosure of conflict of interest

There are no conflicts of interest among the authors.

Statement of ethical approval

This study was conducted in accordance with the declaration of Helsinki and Ethical Clearance was obtained from Ethics Review Committee, Faculty of Medicine, University of Peradeniya, Sri Lanka (2016/EC/52). This trial was retrospectively registered (UMIN000040345, 09/05/2020).

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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