**Title and Abstract**

**1a. Title**

**Effect of respiratory muscle strengthening with breathing exercises on Ventilatory functions, aerobic fitness and their association with performance in elite rowers: A randomized trial**

**1b. Abstract**

**Objective:** Rowing is one of the most physically demanding endurance sports requiring high levels of ventilation. The aim of this study was to investigate the effect of RMT on ventilatory parameters, aerobic fitness and rowing ergometer performance among professional rowers in Sri Lanka. **Methods:** Case – controlled randomized study was carried with 20 national male rowers, (experimental (n=11) and a control (n=9) group) aged 20-35 years. 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. **Results:** 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. There were significant improvements in PIF, FVC, and VO2maxin 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. **Conclusion:** This suggests that the RMT program had a significant effect in improving some ventilatory parameters and VO2max of the rowers resulting in better performance.

**Introduction**

**2a. Background:**

Rowing is one of the most physically demanding endurance sports requiring high levels of ventilation (Dunbar, 1994). Rowing involves not only the locomotor muscles of the body but also the respiratory muscles as well (Secher, 1993). Rowers have been shown to have very large total lung capacity (TLC), vital capacity (VC) (Donnelly et al., 1991) and peak expiratory flows (PEF) (Steinacker et al., 1993). Intense exercise has been shown to increase the depth and frequency of respiration with ventilation increasing from a resting value of 5–6 litre /min to more than 100 litre/ min (De Troyer et al., 2005). In addition, 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 (Siegmund et al., 1999; Hodges and Gandevia, 2000).

A rowers’ performance also depends upon the functional capacity of the energy system of which 70% of energy comes from aerobic metabolism (Dunbar, 1994; Secher, 1993). 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 (Joyner and Casey, 2015). Literature suggests that the most limiting factor for oxygen uptake during exercise is the pumping ability of the heart compared to the respiratory system (David and [Edward, 2000)](https://www.researchgate.net/profile/Edward_Howley?_sg%5B0%5D=86DUpfd7TyJVGCu87Wu-qqeRdSSFrHwIS0qICHkKm99RWVoVkxcxP-JdJzOUReXWLeV_5kU.dQotYS9ZOcmmgj_r07wIFMQdbv8wUgNe2RveXspg_LpQk4G3tPkQwKR-tG1jgV2WPYMrGWEdF4p0lACj0XD7_A&_sg%5B1%5D=xkp6h47VFgqK_DHtVmHa2ph9p8Pg1LHCqFYsUrMWGIhcVqKFw0HsI7Zl0U8HCrFHNutHSYQ.179ioxFKksoEKVrV7hWzF39hdM_90zgN9qwH7qLlyqDJeCGWUzYIn2zNghjt1vviWa73PM90r2z_fmDUr6DhUg). But breathing does limit exercise performance because respiratory muscles enforce their own demands upon the oxygen delivery system (Griffiths and McConnell, 2007). Recent investigations have shown that an increase in respiratory muscle demand during intense exercise reduces the limb blood flow (Harms et al., 1997; Sheel et al., 2002) 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 (McConnell and Lomax, 2006; Harms et al., 2000). Therefore, respiratory muscle training (RMT) becomes useful to augment respiratory muscle functions in high intensity sports like rowing.

It is well known that involvement in physical activity and sports helps in respiratory muscle strengthening and improvements in pulmonary function (Prakash et al., 2007). Studies have found that swimmers have better pulmonary functions than other athletes like sprinters due to the intense training involving the respiratory muscles (Mahotra and Shrestha, 2013). Further, it has been shown that improvements in lung functions help to improve exercise performance in trained athletes (Harms et al., 2000; Boutellier and Piwko, 1992). In addition, it is well documented that yoga, which comprises of breathing exercises, improves respiratory parameters (Prakash et al., 2007; Joshi et al., 1992) and respiratory muscle strengthening (Makwana et al., 1998; Madanmohan et al., 2003).

RMT can be carried out using many training devises. However, the high cost in purchasing such devises 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.

**2b. Objectives**

* To investigate the effects of a 12-week RMT program on ventilatory functions (PIFR, PEFR, VC, FVC, FEV1, FEV1 / FVC) in the experimental group compared to the control group in professional male rowers in Sri Lanka Army.
* To assess the effects of a 12-week RMT program on aerobic fitness and rowing ergometer performance in the experimental group compared to the control group in professional male rowers in Sri Lanka Army.

**Methods**

**3a. Trial Design**

This is a case- controlled randomized study.

**3b. Changes to trial design:**

Not applicable

**4a. Participants:**

**Inclusion and Exclusion Criteria**

The subjects were selected based on the inclusion and exclusion criteria.

*Inclusion criteria*

1. Healthy adult national male rowers
2. Non – smokers

*Exclusion criteria*

1. Participants who were suffering from any respiratory illness at the time of data collection
2. Subjects who were on medication for any illness.

**4b. Study settings:**

The study was conducted at the General Sir John KotelawalaDefence University, Ratmalana and Exercise and Sports Science laboratory, Department of Physiology, Faculty of Medicine, University of Peradeniya.

**5. Interventions**

Prior to the commencement of the training program, baseline measurements and tests namely lung volumes, flow rates and capacities, VO2max, 2000m and 5000m rowing ergometer time trial were carried out on all 20 subjects by the principal investigator.

Thereafter, two specific exercise programs, designed by the principal investigator, were proposed for the experimental and the control group independently. Rowers in the experimental group were requested to follow a new protocol of “respiratory muscles training (RMT) program” for 12 weeks, while rowers in the control group were recommended a “general exercise program” which excluded respiratory muscle strength training as a placebo. All the participants were instructed about the testing procedures prior to testing. Each subject was trained under the supervision of the principal investigator. The rowing coaches and physical education staff was requested to continuously reinforce the exercise program during the training period.

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, VC, FVC, FEV1 and Forced expiratory ratio (FEV1/FVC), respiratory muscle strength, VO2 max and ergometer performance were repeated.

**Respiratory Muscles Training Program for the Experimental Group**

This novel respiratory muscle training program followed by the experimental group included a warm-up session, flexibility training, inspiratory and expiratory muscle strength training programs and warm-down sessions.

***Warm-Up session***

Rowers followed a warm-up exercise session prior to performing the respiratory muscle training program. This included 10 minutes of running with normal breathing with inspiration through the nose and expiration through mouth.

***Flexibility Training***

(I) Full body stretch

The subject was asked to straighten the arms and slowly lift them back over the head as far as possible and interlock the fingers of both hands while breathing normally. The closer together the hands were, the greater the stretch. The exercise was repeated more than 30 times. The target of this exercise was to stretch the chest (Thomas et al., 2005).

(II) Lateral stretch

The subject was asked to stand with the feet shoulder-width apart, knees slightly bent and pelvis tucked under and asked to raise one arm over the head while bending sideways from the waist without moving the body below the waist. The trunk was supported by placing the hand or forearm of the other arm on the thigh or hip. This was repeated on the other side, breathing normally. The exercise was repeated more than 30 times. The target of this exercise was to stretch the trunk muscles (Thomas et al., 2005).

***Respiratory Muscle Training***

The specific respiratory muscle training program consisted of inspiratory muscle training and expiratory muscle training. The inspiratory muscle training program used different breathing techniques including diaphragmatic re-education, profound (deep) inspiration and inspiratory hiccups while the expiratory muscle training program was designed with abdominal muscle strength training exercises which included isometric side bridge and curl-up.

***Inspiratory Muscle Training***

1. 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 (Porter, 2013).

1. 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 (Porter, 2013) in the standing position. Thirty (30) repetitions were performed.

1. 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 (Porter, 2013). This was repeated 30 times.

***Expiratory Muscle Training***

Abdominal muscles:Internal oblique, External oblique, Rectus abdominis and Transverse abdominis are utilized during forceful expiration, especially in endurance sport. Therefore, abdominal muscles strengthening and endurance exercises were included in the “Exercise program” as follow:

* Isometric Side Bridge
* Curl-ups
1. Isometric Side Bridge

The subject was asked to lie on the ground on his side with the knees straight and the forearm facing to the body. This was followed by lifting the hips and knees off the ground with the forearm perpendicular to the floor. This position was held for 10 seconds, breathing normally. This was repeated on the opposite side. This was done until the subject could hold this position for 60 seconds. Five (5) repetitions were performed on each side. The target of this exercise was to increase strength and endurance in the muscles along the lateral aspect of the abdomen the external and internal oblique and transverse abdominis muscles (Thomas, et al., 2005).

1. Curl-ups

The subject was asked to lie on the back with one or both knees bent and arms crossed on the chest or hands under the lower back. The chin was tucked in while the subject was asked to slowly curl up, one vertebra at a time using the abdominal muscles to lift the head first and then the shoulders. This position was held for 5-10 seconds before returning to the starting position. This was repeated 30 times. The target of this exercise was to increase the strength of rectus abdominis, internal / external obliques and transverse abdominis (Thomas et al., 2005).

***Warm down session***

After the respiratory muscle training program, the rowers followed a warm-down session. This included 10 minutes of running with normal breathing while inspiring through the nose and expiring through mouth.

**General Exercise Program for the Control Group**

The general exercise program followed by the control group consisted of a warm-up session (similar to intervention group), flexibility training and strength training programs for non-respiratory muscles such as biceps, triceps, quadriceps and hamstring muscles. The control group did not receive any intervention for respiratory muscle strength training. This was in addition to the routine exercise schedule followed during the competition season.

 ***Warm-Up session***

Rowers in the control group followed the same warm-up session which was followed by the experimental group. This included 10 minutes of running with normal breathing, inspiration through the nose and expiration through the mouth.

***Flexibility Training***

Flexibility training of the control group included thefollowing:

* Biceps stretching
* Triceps stretching
1. Biceps stretching

The subject was asked to clasp hands behind the back with his palms together, straighten arms and then rotate them so his palms face downward. Then the arms were raised and held until the subject felt a stretch in the biceps muscle. The exercise was repeated 10 times. The target of this exercise was to stretch the bicep muscle (Thomas et al., 2005).

1. Triceps stretching

The subject was asked to lift his bent right arm over the head and with the left arm, the right elbow was gently pulled back until a tension. This was repeated with the left arm. The exercise was repeated 10 times for both arms. The target of this exercise was to stretch the triceps muscle (Thomas et al., 2005).

***Strength training***

In the control group, strength training exercises were included as follows:

1. Biceps curls
2. Triceps curls
3. Hamstring curls
4. Quadriceps strengthening (Straight Leg raises)
5. Biceps curls

The subject was asked to stand up straight with a 2kg dumbbells in each hand at arm's length. The elbows were kept close to the torso and the palms rotated so that they were facing forward. Then keeping the upper arms stationary, the subject was asked to exhale and curl the weights up while contracting the biceps. This was done until the biceps were fully contracted and the dumbbells were at shoulder level. The contracted position was held for a brief pausesqueezing the biceps. Then the dumb-bells’ were lowered slowly to the starting position. The exercise was repeated 30 times (Thomas, et al., 2005).

1. Triceps curls

To begin, the subject was asked to stand up with feet about shoulder-width apart and hold a 2kg dumbbell in both hands. The dumbbells were then lifted over the head until both arms were fully extended with elbows pointing forward. Then with the elbows bent, the arms withdumbbells were lowered towards the back of the head. The exercise was repeated 30 times (Thomas et al., 2005).

1. Hamstring curls

The subject was asked to lie prone on the floor and to hold a 2kg dumbbell between the feet. The exercise required pulling the legs towards the buttocks by bending the knees which were followed by lowering the dumbbell slowly to the starting position. This was repeated 30 times (Thomas et al., 2005).

1. Quadriceps strengthening (Straight Leg raises)

The subject was asked to lie down supine on the floor with the left leg lifted straight up without bending at the knee joint (450 angle from the floor). This was held for 10 seconds. This was repeated in the right leg. The exercise was repeated for both legs 30 times.

 ***Warm down session***

Rowers followed a warm down session after the general exercise program. This included 10 minutes of running with normal breathing After the warm-down session, the rowers were instructed to stretch all the major muscle groups (biceps, triceps, quadriceps and hamstring) that were used during the exercise program for 20 to 30 seconds, 2 to 3 times (Thomas et al., 2005).

**6a. Outcomes**

Primary outcomes

* Ventilatory functions: PIFR, PEFR, VC, FVC, FEVI and FEV1/FVC (%)

Method of assessd: using spirometer (Spiro analyzer ST-75)

Time points: (Baseline and 12 weeks)

Secondary outcomes measures

* Aerobic fitness : VO2 max (Volume of maximum oxygen consumption)

Method of assessed: using **Monark cycle ergometer 828E**

Time points: (Baseline and 12 weeks)

* 2000m and 5000m ergometer performance

Method of assessed: using concept II, (Nottingham, UK) ergometer machine

Time points: (Baseline and 12 weeks)

**6b. Changes to outcomes:**

Not applicable.

**7a. Sample size**

The sample size was calculated using G\* power software. A paired sample t-test was used to assess the significant difference before and after the exercise program in the experimental group.

The significant level was 0.05 and power was 0.8. Minimum mean difference expected within the experimental group for the main outcome variable in the study, the 5000m ergometer time trial performance test was 36 +/- 9 seconds according to a similar study by Volianitis et al., (2001).

Calculated sample size = 09

An independent sample t-test was used to assess the significant differenceinall parameters after the two training programs betweenthe control and the experimental group. Minimum mean difference expected between the experimental and the control groups for the main outcome variable in the study, the 5000m ergometer time trial performance test was 36 +/- 9 s and 11 +/- 8 s for experimental and control group respectively based on results of a previous study by Volianitis et al., (2001).

Calculated sample size – 07

The maximum sample size obtained was 20. Therefore, of the 20 rowers, 11 were selected as the experimental group while 9 subjects were selected for the control group.

**7b. Interim analyses and stopping guidelines**

Not applicable.

**8a. Randomization: sequence generation**

Random number generator (calculator) was used to generate the random allocation sequence.

**8b. Randomization: type**

Simple randomisation

**9. Randomisation: allocation concealment mechanism**

In total, 20 male rowers between the ages of 20-35 years were selected from a total population of 40 from the Sri Lanka Army rowing team using the random number generator. The age, height and weight matched study population was divided into two groups: an experimental group (n= 11) and a control group (n= 9).

**10. Randomization: implementation**

Principal investigator generated the allocation sequence, enrolled participants and assigned participants to the interventions.

**11a. Blinding**

Not conducted

**11b. Similarity of interventions:**

Not relevant

**12a. Statistical methods:**

The descriptive statistics were assessed for demographic data and all other measurements in both the experimental and the control group. Changes in lung volumes, capacities, flow rates, aerobic fitness and rowing ergometer performance were considered as major outcome variables. The paired-sample t-test was used for comparison of the parameters taken before (pre-test data at first session) and after exercise programs (post-test data after 12 weeks of exercise program) within the experimental and the control group while the independent sample t-testwas used to comparethe variables between the experimental group and the control group.

**12b. Additional analysis:**

Not applicable

**Results**

**13a Participant flow**

In total, 20 male rowers between the ages of 20-35 years were selected from a total population of 40 from the Sri Lanka Army rowing team using the random number generator. The age, height and weight matched study population was divided into two groups: an experimental group (n= 11) and a control group (n= 9).

The rowers were informed about the details of the research project at the General Sir John KotelawalaDefence University gymnasium. Written informed consent was taken from each subject prior to the administration of the questionnaire which included the following information;

* Demographicdata: Name, Age or Date of birth
* General information of rowing sport: Rowing experience, Type of boats, Durationof training
* Smoking history: Duration and number of ciggerettes per day/week/month
* Alchoholabuse : Amount , Frequency
* Medical and surgical history: Type of disease, Use of medication
* Presence of injuries
* Data collection :Anthropometric profile, Lung volumes, capacities and flow rates, ,Rowing ergometer performance (2000m and 5000m), Aerobic fitness (VO2 max)
* Data collection was carried out at the General Sir John Kotelawala Defence University and the Exercise and Sports Science laboratory, Department of Physiology, Faculty of Medicine, University of Peradeniya. Prior to the commencement of the training program, baseline measurements and tests namely lung volumes, flow rates and capacities, VO2max, respiratory muscle strength including maximal inspiratory (PImax) and maximal expiratory pressures (PEmax), 2000m and 5000m rowing ergometer time trial were carried out on all 20 subjects by the principal investigator.
* Thereafter, two specific exercise programs, designed by the principal investigator, were proposed for the experimental and the control group independently. Rowers in the experimental group were requested to follow a new protocol of “respiratory muscles training (RMT) program” for 12 weeks,while rowers in the control group were recommended a “general exercise program” which excluded respiratory muscle strength training as a placebo. All the participants were instructed about the testing procedures prior to testing. Each subject was trained under the supervision of the principal investigator. The rowing coaches and physical education staff was requested to continuously reinforce the exercise program during the training period.
* 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, VC, FVC, FEV1 and Forced expiratory ratio (FEV1/FVC), respiratory muscle strength, VO2 max and ergometer performance were repeated.

**13b. Losses and exclusions**

After randomization, no one of the experimental and control group member did not loss and exclude from the study.

**14a. Recruitment**

 Ethical approval: 20/10/2016

 Recruitment date: 10/12/2016

 Overall trial date: from 20/02/2017 to 20/ 05/ 2017

**14b. Reason for stopped trial**

After the completion interventions, trial was stopped.

**15. Baseline Data**

|  |  |  |  |
| --- | --- | --- | --- |
| **General information** | **Respiratory functions** | **Aerobic fitness** | **Rowing performance** |
| Age (years) | Peak Inspiratory flow (PIF) (L/s) | Volume of Maximum oxygen consumption- (VO2 max)- ml/ml/Kg | 2000m rowing ergometer time trial (minutes) |
| Height (cm) | Peak Expiratory flow (PEF) (L/s) |  | 5000m rowing ergometer time trial (Minutes) |
| Weight(kg) | Vital capacity (VC) (L) |  |  |
| Body Mass Index (BMI) (kg/m2) | Forced vital capacity (FVC) (L) |  |  |
| Fat mass (kg) | Forced Expiratory Volume in one second FEV1 (L) |  |  |
| Muscle mass (kg) | Forced Expiratory Ratio FEV1/FVC (%) |  |  |
| Chest expansion (cm) | Peak Inspiratory Mouth Pressure **(PImax) - mmHg**  |  |  |
| Arm span (cm) | Peak Expiratory Mouth Pressure **(PEmax)- mmHg**  |  |  |
| Rowing experience (years) | Inspiratory Mouth pressure (mmHg) |  |  |
|  | Expiratory mouth pressure (mmHg) |  |  |

**16. Numbers analyzed**

For each group, number of participants were included in each analysis and the analysis was by original assigned groups.

**17a. Outcomes and estimation**

For each primary and secondary outcome, results for each group, and the estimated effect size were assessed with 95% confidence interval.

**17b. Binary outcomes**

For binary outcomes, presentation of both absolute and relative effect sizes is recommended

**18. Ancillary analyses**

Results of any other analyses performed, including subgroup analyses and adjusted analyses, distinguishing pre-specified from exploratory

**19. Harms**

No harms or unintended effects were not identified in each group

**Discussion**

**20. Limitations**

* The major limiting factor of the current RMT exercise program was that this training schedule did not include major resistant training programs for the respiratory muscles during inhalation and exhalation for adaptation of the respiratory muscles to occur. In contrast, many RMT devices require the participant to inspire or expire against a fixed flow resistance load which could be controlled. Therefore to improve the effects of this program, it is recommended that special resistant balloons, example a thera band, which has different strengths (given in different colors) be introduced to generate a resistant load. In all forms of resistance training, not only should the intensity of the exercise be increased, but the overall volume and duration should also be changed. Training at a higher volume, by increasing the number of repetitions, might produce more favorable metabolic changes in the respiratory muscles. Further investigations are also warranted for posture-specific RMT to enhance ventilatory functions in the different rowing postures as the group that received RMT was shown to have better ventilatory parameters than the control.
* Major ventilatory demands are placed on the respiratory muscles during the rowing cycle. However, the Sri Lankan rowers have not been entrained in the correct breathing techniques to overcome the ventilatory demands. This could have resulted in some discrepancies observed in the present study. Therefore, it is recommended that the trainers and coaches of rowers in Sri Lanka should be educated about the proper breathing technique to reap the benefits of RMT.
* Studies have shown that female rowers have weaker respiratory muscles than male rowers and that RMT may benefit female rowers more than male rowers. However, female rowers were not included in the present study. Therefore, further studies must be carried out in female rowers to assess whether RMT has an added advantage for female rowers.
* As it is the first time that the Sri Lankan rowers have been introduced to RMT they had lack of awareness about RMT which would have resulted in insufficient self-motivation to follow the training schedule daily. Therefore, it is recommended that an education program on RMT be conducted for coachers, trainers and sportsmen to familiarize about the benefits of RMT.

**21. Generalizability**

Up to date there have been no studies evaluating the effects of respiratory muscles strengthening programs on performance in any sport including rowing in Sri Lanka. Also, there is a paucity of literature on the effects of RMT specifically on sport-specific factors namely aerobic fitness, lung functions and performance in rowers. This exercise program could be included in the daily training routines of not only rowers but also other aerobic sports.

Findings of this study can be generalized to sports like aerobic sports. It would also aid in planning and modification of training programs and competitive tactics and help to develop the aerobic sports to an internationally recognized level in the future in Sri Lanka. This training program could also be useful in a clinical setup, where it could be included in the rehabilitation programs of patients with respiratory diseases such as COPD, asthma, emphysema, etc. in Sri Lanka.

**Interpretation**

**Potential benefits**

By participating to this research, rowers are able to train respiratory muscle training (RMT) program for the effects of lung functions, aerobic fitness and respiratory muscle strength. This study also helps to clarify the message regarding the RMT and rowing specific sports performance in future. We plan to disseminate the findings of our research by means of publications in peer-reviewed journals, research presentations.

**Risks, Hazards & Discomfort**

Any information that is obtained in connection with this study and that can be identified with rowers remain confidential and is disclosed only with participants permission, except as required by law. If a rower feels any hazards and discomfort during the research study, he can withdraw his consent to participate in the study at any time.

**Other information**

**23. Registration**

This trial was retrospectively registered in UMIN clinical trial registry (UMIN000040345, 08/05/2020).

**24. Protocol**

Full trial protocol is accessed in following link.

<https://upload.umin.ac.jp/cgi-open-bin/ctr_e/ctr_view.cgi?recptno=R000046022>

**25. Funding**

This research study was conducted with self-funding.