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The Effects of Respiratory Muscle Training in Highly-Trained Rowers

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ABSTRACT

Driller MW, Paton CD. The Effects of Respiratory Muscle Training in Highly-Trained Rowers. **JEPonline** 2012;15(6):93-102. Respiratory muscle training has been proposed as a beneficial means of improving respiratory muscle function and performance in athletes. Therefore, the aim of this study was to determine the effects of a 6-wk specific respiratory muscle training program on the performance and respiratory muscle function in highly-trained rowers. Sixteen national representative rowers (8 males and 8 females) were assigned to either an experimental (RMT) or control (CON) group for 6-wks of respiratory muscle training. RMT consisted of 30 breaths (inspiratory and expiratory = 1 breath), twice daily using a commercially available respiratory muscle training device. Athletes performed a series of pulmonary function tests and an incremental VO_2 max test prior to and following the experimental period. There were no statistically significant differences in any of the physiological, performance, perceptual or pulmonary function measures between RMT and CON following the training period ($P>0.05$). However, when comparing RMT to CON using magnitude based inferences, there was a "likely benefit" to perceived dyspnea (mean ±90%CL: -1.4 ±1.4 arbitrary units), mean heart rate (-4.1 ±4.7%) and maximum minute ventilation (-5.6 ±6.3%) during exercise. The results suggest that respiratory muscle training had little effect on exercise performance or pulmonary function in highly-trained rowers despite trends toward improvements in the perception of dyspnea and a decrease in maximum ventilation and mean heart rate during exercise.

Key Words: Fatigue, Dyspnea, Performance, Pulmonary Function

INTRODUCTION

The occurrence of respiratory muscle fatigue during both submaximal (16) and maximal exercise bouts (19) has suggested that respiratory function may in some way limit exercise performance. The respiratory muscles are morphologically and functionally similar to the skeletal muscles involved in locomotion (23) and, therefore, are also subject to fatigue (6). Perret et al. (22) reported that respiratory muscle performance is reduced after exercise, regardless of the preceding exercise intensity, and suggested that respiratory muscle performance may well be compromised in situations with multiple events without sufficient recovery time (18). Furthermore, sports that require a large aerobic power and high ventilation rates, coupled with compromised thorax positioning, such as rowing, place a greater demand on the respiratory system (25). There is however, evidence to suggest that the respiratory muscles can be trained for improvements in both strength and endurance. Such training may help to attenuate respiratory fatigue (29), which provides the premise for specific respiratory muscle training.

The exact mechanism by which respiratory muscle fatigue occurs is still unclear. But, it has been suggested that specific respiratory muscle training may help to attenuate respiratory muscle fatigue by reducing the competition for blood flow and production of metabolites in the respiratory muscles (14). A result of respiratory muscle fatigue may be the feeling of breathlessness or dyspnea. Research has shown that after a period of specific respiratory muscle training, perceptions of dyspnea can be reduced (11). The reduction in perceived dyspnea may be due to the increased respiratory muscle efficiency, strength and/or endurance after a period of specific training, as evidenced by improvements in various pulmonary and spirometry measures such as forced expiratory volume (FEV_1), maximal inspiratory pressure, maximum voluntary ventilation tests (MVV), and maximum ventilation during exercise (5,20,28). In a review of the respiratory muscle training literature, Sheel (2002) revealed improvements in maximal inspiratory pressure ranging from 8-57% along with improvements in vital capacity, total lung volumes, and peak inspiratory flow of 3-5% (24). While gains in respiratory muscle function are important in athletic populations, perhaps an even more critical factor is how these improvements translate to exercise performance.

Several studies have examined the effects of specific respiratory muscle training on exercise performance, but the literature is inconclusive, with some studies showing improvements (3,4,27) and others not showing any effect on performance (9,30). Some of the inconsistencies in the literature include the experimental design, the performance and pulmonary tests used, and the training status of athletes (20). Voliantis et al. (2001) reported improvements in 6-min rowing distance and 5000 m rowing time of 1.9% and 2.2%, respectively, after 11 wks of respiratory muscle training in the experimental group compared to the placebo group (27). The athletes used in the study were 14 well-trained female rowers in the base/preparation phase of their season. Griffiths and McConnell (8) also reported benefits to 6-min rowing performance (2.7% $P=0.015$) after 4-wks of inspiratory muscle training in club level rowers when compared to the control group. Klusiewicz et al. (15) investigated the use of 11-wks of inspiratory muscle training in elite rowers and reported significant improvements in maximal inspiratory mouth pressure of ~34% in the experimental group. However, the researchers did not measure performance so it is not known whether their changes in inspiratory mouth pressure would translate to rowing improvements. Therefore, very few studies in the literature have examined the use of respiratory muscle training on performance in highly-trained populations during the competition phase of the season. Moreover, it remains to be seen whether or not athletic performance can be further enhanced through specific respiratory training in highly-trained rowers with already well-developed respiratory systems.

In view of the unique respiratory demands of rowing and the discrepancies in the literature with regard to the benefits of respiratory muscle training, it is somewhat unknown to what extent respiratory muscle training may affect performance in highly-trained rowers. The purpose of this study is to determine the effects of respiratory muscle training (inspiratory and expiratory) using a commercially available training device on physiological and performance variables in highly-trained rowers during the competition phase of the season.

METHODS

Subjects

Sixteen national representative rowers (mean ± SD; 8 male: age = 17 ± 1 yrs, body mass = 87.3 ± 6.9 kg, VO_2 max = 5.66 ± 0.42 L·min^{-1} and 8 female: age = 17 ± 1 yrs, body mass = 71.9 ± 5.1 kg, VO_2 max = 3.81 ± 0.18 L·min^{-1}) volunteered to take part in this study. Athletes were required to give written informed consent prior to testing. The athletes were in the competition phase of their season and were preparing for the World Rowing Championships in which they competed soon after completing the study. The research was approved by the institutional Human Research Ethics Committee.

Procedures

The study involved athletes attending two identical testing sessions separated by a 6-wk (42 days) training period. Following baseline testing, athletes were randomly assigned to either the respiratory muscle training (RMT) or the control (CON) group, with an equal distribution of male/female athletes and an equal distribution of members from the three crews in each group. The two testing sessions (pre- and post-) consisted of a series of pulmonary function tests followed 30-min later by an incremental rowing test. All rowers were accustomed to the incremental rowing test procedure. In order to control any dietary variables, athletes completed a 24-hr food diary prior to the first testing session and were instructed to replicate their diet as closely as possible before the second test. Training was also controlled for, with athletes keeping all training the same 72 hrs before testing on both occasions. They were asked to refrain from caffeine (<12 hrs) and to arrive at each session in a fully rested, hydrated state. All testing was performed at the same time of day (±1 hr) to minimize diurnal variation, and tests were always performed on the same rowing ergometer.

Pulmonary function tests were performed to determine the strength and endurance capacities of the respiratory system. All pulmonary function tests were performed using a spirometry mass flow sensor mouthpiece attached to a metabolic cart (Vmax 29 Series, Sensor Medics, USA) with a nose clip applied to prevent breathing through the nostrils. The mass flow sensor was calibrated before each test using a three liter syringe in accordance to the manufacturer's instructions. Upon arrival to the laboratory, the maximum voluntary ventilation (MVV_{12}) test was performed. The test involved athletes breathing normally through the mouthpiece, and then when instructed, they were to breathe rapidly and deeply for 12 sec at a recommended depth of 25-75% of his or her vital capacity. Then, the subjects performed a flow-volume loop test. In this test, the athletes were instructed to breathe normally through the mouthpiece and, when instructed, to inhale completely, filling up their lungs, then immediately exhale maximally until their lungs were completely empty. After the expiration was complete, the athletes were instructed to rapidly and completely inhale. The flow volume loop test measured forced vital capacity (FVC), forced expiratory volume in 1 sec (FEV_1), FEV_1/FVC ratio, and forced expiratory flow between 25-75% (FEF 25-75%). Each subject performed all pulmonary function tests four times separated by 2 min between trials with the best of the four trials used for analysis.

The incremental exercise test (GXT) was performed to determine VO_2 max, peak power output (PPO), maximum minute ventilation (V_E max) and mean heart rate (HR mean). The GXT was performed according to the Rowing New Zealand Exercise Testing Guidelines, which the athletes were previously accustomed to. According to the guidelines, the starting power output was 75 watts and 150 watts for females and males, respectively. The target power output increased by 25 watts per minute until volitional exhaustion was reached. Athletes were asked to maintain their target power output (± 1 watt) during each step of the test, as visually displayed on the rowing ergometer monitor. Heart rate was recorded continuously during the GXT using a Polar s610i monitor (Polar Electro Oy, Kempele, Finland). The HR mean was the average heart rate for the submaximal stages of the GXT (excluding the final stage for each subject). Cardiorespiratory metabolic variables were measured breath by breath throughout the GXT using an online metabolic analyser (Vmax 29 Series, Sensor Medics, USA). The analyzer was calibrated before each test using alpha gases of known concentration according to the manufacturer's instructions. Mean power output was recorded every minute. Both V_E max ($L \cdot min^{-1}$) and VO_2 max were considered the highest VO_2 value recorded over 1 min during the incremental test. The PPO was determined using the following formula:

$$PPO = W_{com} + (t/60 \times 25)$$

Where W_{com} is the power output for the last full workload completed, t is the time in seconds that the final uncompleted workload was sustained, 60 is the target number of seconds in each workload and 25 is the workload increment in watts. Ratings of perceived dyspnea (or ratings of perceived breathlessness) were taken immediately following the GXT. The scale of perceived dyspnea was a 10-point modified Borg Scale (arbitrary units - AU) as used previously (3). The scale ranged from "No breathlessness at all" to "Maximum breathlessness."

The RMT group performed 30 dynamic inspiratory and expiratory efforts twice daily for 6 wks (82 sessions), using a commercially available respiratory resistance training device (PowerLung™, Houston Texas). The 30 breaths were performed using an exercise protocol of 3 sets of 10 repetitions, set at a load equivalent to 10 RM; a load known to elicit an adaptive response (27). The rest period between sets was 30 sec. To ensure compliance and monitor increased respiratory training load, all athletes in the RMT group were required to keep a training diary of their respiratory muscle training sessions and the morning RMT training sessions were supervised by coaches.

Statistical Analyses

Simple group statistics are shown as means ± between-subject standard deviations unless otherwise stated. Mean effects of training and their 90% confidence limits were estimated with a spreadsheet via the unequal variances t statistic computed for change scores between pre- and post-tests in the two groups. Each subject's change score was expressed as a percent of baseline score via analysis of log-transformed values, to reduce bias arising from non-uniformity of error (2). Perceived dyspnea and FEV_1/FVC were analyzed without log-transformation. Standardized changes in the mean of each measure were used to assess magnitudes of effects and provide the likelihood of the true effects being practically positive, trivial, and negative by dividing the changes by the appropriate between-subject standard deviation (2). Thresholds for assigning qualitative terms to likelihoods were as follows: <1%, *almost certainly not*; <5%, *very unlikely*; <25%, *unlikely or probably not*; <50%, *possibly not*; >50%, *possibly*; >75%, *likely or probable*; >95%, *very likely*; >99% *almost certain*. Magnitudes of the standardized effects were interpreted using thresholds of 0.2, 0.6, 1.2, and <2.0 for *small*, *moderate*, *large,* and *very large*, respectively. An effect size of <0.2 was considered a trivial effect. The effect was deemed unclear if its confidence interval overlapped the thresholds for both small positive and negative effects. Statistical significance was set at P<0.05 for all analyses.

RESULTS

As determined by the training diaries, the compliance to the respiratory muscle training sessions in the RMT group was ~94% (77 ± 3 sessions). There were no statistically significant differences between groups for any of the physiological, perceptual, or performance variables measured during the GXT (PPO, VO_2 max, V_E max, HR mean, dyspnea) pre- to post- experimental period ($P>0.05$; Table 1).

There were also no differences between groups for any of the measured pulmonary function variables (MVV_{12}, FVC, FEV_1 and FEV_1/FVC) following the intervention period ($P>0.05$; Table 2). However, magnitude based inferences revealed a *moderate* effect in the RMT group for both perceived dyspnea and HR mean (Table 1) when compared to CON, indicating a *likely benefit* in the experimental group. The RMT also resulted in a *small* (*ES*: -0.44) effect on V_E max (80%; *likely beneficial*). All other measured variables resulted in either *trivial* or *unclear* effects (Table 1 and Table 2).

Table 1. Incremental Exercise Test (GXT) Results Pre- and Post- Experimental Period in RMT and CON Groups (Mean ± SD), Including the Effect of RMT Relative to CON with Effect Size (ES) and Practical Likelihoods of the True Effect Being Positive, Trivial, and Negative.

Variable	RMT		CON		?RMT - ?CON (% Difference ±90% CL) Effect Size	Likelihood (%) of RMT being positive, trivial, and negative (Compared to CON)
	Pre	Post	Pre	Post		
PPO (watts)	396.8 ± 47.8	403.5 ± 55.4	410.0 ± 59.2	415.8 ± 59.1	0.2 ±2.1 ES = 0.01	3 / 96 / 1 *Very likely trivial*
VO_2 max ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$)	55.4 ± 5.8	54.6 ± 5.2	57.4 ± 7.2	58.0 ± 8.6	-2.6 ±7.1 ES = -0.22	10 / 37 / 53 *Unclear*
V_E max ($L{\cdot}min^{-1}$)	172.8 ± 27.6	163.2 ± 11.4	170.7 ± 20.9	173.3 ± 23.8	-5.6 ±6.3 ES = -0.40	80 / 19 / 1 *Likely beneficial*
HR mean ($beats{\cdot}min^{-1}$)	168 ± 10	161 ± 12	167 ± 10	167 ± 11	-4.1 ±4.7 ES = -0.66	87 / 10 / 3 *Likely beneficial*
Perceived Dyspnea (AU)	6.9 ± 1.8	6.3 ± 1.8	5.3 ± 2.3	5.9 ± 2.2	-1.4 ±1.4 ES = -0.60	87 / 11 / 2 *Likely beneficial*

PPO = peak power output achieved in the GXT; VO_2 max = peak oxygen uptake value recorded during the GXT; V_E max = maximum minute ventilation recorded in the GXT; HR mean = mean heart rate for the entire GXT; AU – arbitrary units.

Table 2. Pulmonary Function Test Results Pre- and Post-Experimental Period in RMT and CON Groups (Mean ± SD), Including the Effect of RMT Relative to CON and Practical Likelihoods of the True Effect Being Positive, Trivial, and Negative.

Variable	RMT		CON		?RMT - ?CON (% Difference ±90% CL) Effect Size	Likelihood (%) of RMT being positive, trivial, and negative (Compared to CON)
	Pre	Post	Pre	Post		
FEV_1 (L)	4.39 ± 0.73	4.32 ± 0.69	4.18 ± 1.26	4.23 ± 1.18	-2.6 ±6.7 ES = -0.11	4 / 69 / 27 *Possibly negative*
FVC (L)	5.47 ± 1.04	5.40 ± 0.92	5.37 ± 1.28	5.34 ± 1.12	-0.8 ±5.1 ES = -0.03	5 / 84 / 11 *Unclear*
FEV_1/FVC (%)	81 ± 5	81 ± 6	77 ± 7	79 ± 7	-1.5 ±4.1 ES = -0.25	12 / 32 / 56 *Unclear*
MVV_{12} ($L{\cdot}min^{-1}$)	159 ± 35	159 ± 27	136 ± 41	141 ± 38	-0.1 ±6.1 ES = -0.27	5 / 90 / 5 *Likely trivial*

FEV_1 = forced expiratory volume in 1 sec; FVC = forced vital capacity; FEV_1/FVC = ratio of FEV_1/FVC; MVV_{12} = maximum voluntary ventilation in 12 sec

DISCUSSION

In the current study, 6 wks of specific respiratory muscle training in highly-trained rowers did not significantly improve measures of pulmonary function or exercise performance despite *likely benefits* to the perception of dyspnea, HR mean and V_E max during exercise when compared to the control group. The findings support previous research that has reported no additional performance benefit to specific respiratory muscle training in highly-trained athletes (9,29,30). In contrast to the studies that have shown a benefit from respiratory muscle training (4,27), we feel that the same benefits to performance are more difficult to achieve in athletes with already highly-developed respiratory muscles.

Johnson et al. (13) suggested that although highly-trained athletes are not completely protected from diaphragm fatigue, they may be able to perform a greater amount of diaphragmatic work at a given level of fatigue. This further suggests that chronic endurance training, as is typical in rowing, leads to a respiratory muscle training effect in humans similar to those reported in rodent models (23). It has also been previously shown that elite endurance athletes have greater inspiratory muscle strength and endurance than untrained athletes (17). Accordingly, we believe that the respiratory musculature of our highly-trained rowers at the start of the study may explain the lack of a significant effect on basic spirometric measures and performance following a period of specific respiratory muscle training. However, while we did not find any performance benefit in our rowers following respiratory muscle training, there were trends towards a *moderate* decrease in HR mean and a *small* decrease in V_E max for the same given power output during exercise when compared to the control group (mean ±90%CL: -4.0 ±4.7% and -5.6 ±6.3%, respectively), potentially contributing to the *moderate* decrease in the perception of dyspnea (-1.4 ±1.4).

The lower HR mean and V_E max during exercise in the respiratory muscle training group may suggest improvements in ventilatory efficiency. Gething et al. (2004) observed a decrease in exercising HR of ~6 beats·min^{-1} at the end of a 5-min bout of fixed workload cycling after 6 wks of respiratory muscle training (7). Similarly, Swanson (26) also reported a significant decrease in HR after 6 wks of respiratory training. The mechanism by which HR might decrease following respiratory muscle training can only be speculated upon. One explanation for changes in cardiovascular response to exercise is an improvement in respiratory muscle efficiency, thereby preserving the metabolic requirements of the respiratory muscles and redistributing blood flow to the working muscles, and/or a delay/attenuation of the metaboreflex-induced increase in sympathetic vasomotor outflow (24). Perhaps, the magnitude of improvement in ventilatory efficiency in the current study was not enough to translate to any performance benefits. Our study would not be the first to show this, with Morgan et al. (21) reporting improvements in ventilatory measures despite no difference in VO_2 max test or time to exhaustion test performance in moderately trained cyclists. Similarly, both Williams et al. (30), and Inbar et al. (12) reported significant improvements in respiratory muscle function that did not translate to VO_2 max test performance in well-trained endurance runners after a period of respiratory muscle training. However, like the current study, a common factor in all of these studies (12,30) is the performance tests used and the possibility that they were not precise enough to detect any differences in exercise performance.

A limitation of working with the highly-trained athletes in the current study was that the athletes were brought together for training period in preparation for an international competition, and the performance tests used had to comprise a regular part of the prescribed testing for their sport, which could not be altered. Ideally, we would also have implemented a time-trial type test to evaluate whether or not the HR mean and V_E max differences would translate to performance in a test with more precision and reliability.

It is likely that the trend for a lower HR mean and V_E max during exercise contributed to a lower perception of dyspnea in the respiratory muscle training group (24). Dyspnea causes an individual to alter the depth of a breath or the level of ventilation (1), possibly with the physiological aim of protecting and limiting strain on the respiratory muscles and to prevent the development of respiratory muscle fatigue. In healthy individuals, a significant conscious perception of the “effort” to breathe usually does not occur until heavy-intensity exercise is achieved and hyperventilation begins to develop. There is evidence to suggest that dyspnea during heavy endurance exercise may contribute to exercise limitation (10). To date, very few studies have shown significant improvements in the perception of respiratory effort during exercise following a period of respiratory muscle training (24). However, it is clear that, given the importance of dyspnea during exercise, the observations in the current study warrant further investigation.

CONCLUSIONS

The current study was the first to examine the effects of respiratory muscle training (inspiratory and expiratory) using a commercially available training device on pulmonary, perceptual and performance variables in highly-trained rowers during the competition phase of the season. While the findings would suggest a *likely benefit* to ratings of perceived breathlessness, the trend towards a decrease in HR and V_E max following specific respiratory muscle training did not translate to improvements in exercise performance in an incremental rowing test. It is possible that the athletes in the current study already had highly-developed respiratory musculature, which may explain the lack of any additional benefits from respiratory muscle training. Given the trends towards the improvements in the RMT group, we would suggest further research is warranted.

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