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Effects of a Respiratory Resistance Mask on Forced Expiratory Volume at 1s (FEV1), Forced Vital Capacity (FVC) and the Ratio of FEV1/FVC Lung Function following High Intensity Training (HIT)

Brandie C. Cheshier [1], Bert H. Jacobson [2,*], Carlos A. Estrada [3], Masoud Moghaddam [4], Carter J. Stewart [2]

[1] School of Exercise and Sport Science, Mayborn College of Health Sciences, University of Mary Hardin-Baylor, Belton, Texas, USA
[2] School of Kinesiology, Applied Health & Recreation, Oklahoma State University, Stillwater, OK, USA
[3] Exercise Science, Aurora University, Exercise Science, Aurora, IL, USA
[4] Applied Health Physiology, Salisbury University, Salisbury MD, USA
*Corresponding author Email: bert.jacobson@okstate.edu
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Abstract: Training masks (TMs), marketed as simulated altitude training devices, suggest increased workout capacity, intensity tolerance and recovery. The claim is that the training mask improves respiratory power and breathing mechanics by strengthening the respiratory muscles through breathing resistance provided by the TM. The aim of this study was to compare the effects of a commercially manufactured TM in conjunction with bicycle ergometry, high intensity training (HIT) on selected lung function parameters. Volunteers (N=16) participated in this study and were randomly assigned to an experimental or control group. The experimental group wore the TM with progressive increased respiratory resistance and the control group wore the TM with no respiratory resistance. To determine lung function, pre- and post-test assessments consisted of forced expiratory volume at 1s (FEV1), forced vital capacity (FVC), the ratio of FEV1/FVC. Additionally, to determine the TMs effectiveness of maximal oxygen consumption pre- and post-time to failure during a maximum treadmill test was performed. Training was completed on a cycle ergometer on 3d/wk for 4 wks. Participants exercised at 85% of HRmax with a pedal rate of 100-120 rpm at individually set resistance levels. Training sessions consisted of 10 bouts of 30s exercise followed by 30s of active recovery for a total time of 10 minutes. The respiratory resistance for the experimental group progressively increased over the training period. Repeated measures ANOVAs yielded significant between group difference in FVC ($p = 0.02$) but not for FEV1 or maximum treadmill time. In conclusion, TMs in combination with HIT failed to improve lung function but created sufficient resistance to strengthen the muscles in respiratory ventilation.

Keywords: Exercise, Altitude, Training, Vital Capacity, Lung, Respiratory, Mask

About the Authors

Dr. Brandie C. Cheshier is currently an Assistant Professor of Exercise Science at the University of Mary Hardin-Baylor located in Temple, Texas. Dr. Cheshier holds a Ph.D. in Health and Human Performance from Oklahoma State University. Dr. Cheshier is a Certified Exercise Physiologist by the American College of Sports Medicine.

Dr. Bert H. Jacobson is the school head of Kinesiology, Applied Health, and Recreation at Oklahoma State University in Stillwater, Oklahoma. In addition, he is a Regents Professor in the area of Health and Human Performance, a Fellow in the American College of Sports Medicine, and holder of the M.B. Seretean

Endowed Professorship in the area of Health and Human Performance.

Dr. Carlos A. Estrada is currently an Assistant Professor of Exercise Science as well as the Chair of the Exercise Science Department within the School of Health Science at Aurora University located in Aurora, IL. Dr. Estrada holds a Ph.D. in Health and Human Performance from Oklahoma State University where his primary research consisted of investigating neuromuscular adaptations to anaerobic training.

Dr. Masoud Moghaddam is an assistant professor of Health and Human Performance at Salisbury University. His research is centered on developing scientific methods for investigating the effects of training interventions on body composition and neuromuscular/cardiorespiratory adaptations. Dr. Moghaddam is a Certified Exercise Physiologist by the American College of Sports Medicine and a Certified Strength and Conditioning Specialist by the National Strength and Conditioning Association.

Dr. Carter J. Stewart received his Bachelor of Science in nutrition from Oklahoma State University in Stillwater Oklahoma, Carter was then accepted into the Oklahoma State College of Osteopathic Medicine. As a Doctor of Osteopathic Medicine, his passion is to bring quality care to the underserved areas of Oklahoma.

1. Introduction

Maximal oxygen uptake (VO_{2max}) is, in part limited by the ability of the cardiorespiratory system to deliver oxygen to the active muscles [1]. Additionally, the balance between energy supply and demand is also governed by diaphragmatic endurance [2] and diaphragm fatigue negatively impairs exercise tolerance [3,4]. In healthy individuals, diaphragm fatigue generally occurs at around 85%VO_2max which limits how long an individual tolerates exercise at high intensity [5,6]. In contrast to passive respiration which solely relies on diaphragm contraction and relaxation, high intensity activity demands greater oxygen delivery involving accessory respiratory skeletal muscles all of which may eventually leads to respiratory fatigue [7]. Respiratory muscles (i.e., diaphragm, sternocleidomastoid, scaleni, pectoralis major, serratus anterior, and intercostals) respond to applied or progressive resistance similarly in how all skeletal muscles respond in that the muscles increase in strength and endurance [6,8]. Therefore, finding new ways to increase cardiorespiratory fitness has been a focus of research for many years. Once such proposed method is to improve cardiorespiratory function by the use of respiratory training masks (TMs) during exercise.

Respiratory training masks, also marketed as elevation training masks are commercially available respiratory resistance training masks with claims of increasing workout capacity, intensity tolerance and recovery. The rationale' behind the claims is that the training mask provides inspiratory resistance, which increases respiratory power and breathing mechanics thereby increasing strength and endurance of the respiratory muscles [9]. The TM covers the mouth and nose and has openings to fit altered sized resistance valves. Selected valves offer greater or lesser degrees of respiratory resistance and according to the manufacturer are adjustable and said to simulate altitudes from 914.4 m. - 5,486.4 m. (3,000 ft. -18,000 ft.) "altitude resistance" by increasing the resistance to inspiratory pulmonary function. However, the claim of simulating altitude is invalid since the partial pressure of oxygen remains the same. As of date, few studies have been conducted with this particular equipment in an attempt to verify these claims and the results have been inconsistent. For example, two studies [10,11] found no significant difference in lung function after training with the original training mask and while Biggs et al [12] did not find significant between group differences in lung function, they did find a significant (p<0.05) difference in force vital capacity (FVC) within subjects after training with the mask.

Because previous studies have resulted in conflicting conclusions regarding the efficiency of the TM, the aim of this study was to compare the effects of a commercially manufactured TM in conjunction with bicycle ergometry, high intensity training (HIT) on selected lung function parameters.

Table 1. Characteristics of the experimental and control group (mean ± SD)

	Control (n= 8)	Experimental (n= 8)
Age (years)	21.25 ± 4.89	20.63 ± 0.74
Weight (kg)	72.06 ± 23.23	68.62 ± 12.73
BMI (kg/m^2)	24.00 ± 2.81	23.08 ± 3.68

2. Methods

2.1 Participants

Sixteen participants (*n*=8 females, *n*=8 males) from a Midwestern University volunteered to take part in the study (Table I). All participants were college-age individuals and met ACSM guidelines for being moderately active. Participants were free from heart and pulmonary disease, asthma, and were not taking blood pressure medication and were informed of the risks of the study before reading and signing a University IRB approved consent form. To determine the safety of participating in a HIT program, the participants completed a PAR-Q, Health and Exercise Status Questionnaire, and a Health Risk Appraisal. Subsequently, participants were randomly assigned into either a control group (*n*=8) or experimental group (*n*=8). The control group wore the TM 2.0 (Cadillac, MI, USA) with no resistance (resistance valves removed), and the experimental group wore the TM with respiratory resistance progressively increasing over the duration of the study.

2.2 Lung Function Assessment

Prior to pre and post-testing, all participants were asked to refrain from caffeine consumption 8 hours prior to testing and were asked to refrain from exercise for 24 hours leading up to exercise testing. Weight, height, and body mass index (BMI) were measured. Following the aforementioned measurements, lung function was assessed using the NDD Easy One Plus Diagnostic Spirometer 2000-1(Ndd Medical Technologies, Andover, MA). Forced expiratory volume at 1s (FEV_1), forced vital capacity (FVC) and the ratio of FEV1/FVC were measured. All participants completed three trials and the best trial was recorded for all three variables.

2.3 Oxygen Consumption Assessment

In order to evaluate the effect of TMs on oxygen consumption, participants completed a baseline Bruce maximal exercise test treadmill test (TMX, 43C, Newton, KS USA) to exhaustion. This assessment was repeated subsequent to the completion of training as a means of comparison of the TM training effectiveness on lung function. Heart rate (HR) was continuously measured using a Polar Heart Monitor (Polar USA,

Bethpage, NY USA) and the Borg Rating of Perceived Exertion (RPE) 1-20 was used to subjectively assess the participant's perceived exertion at the last minute of each stage.

2.4 Training Protocol

Participants in both groups completed HIT training 3/wk on nonconsecutive days for 4 weeks. Training was conducted on a Matrix upright stationary bicycle (Matrix, U1X, Cotton Grove, WI USA). For the first training session the participants were introduced to fitting and wearing the TM and breathed with the mask for 10 minutes at rest followed by self-pace bike pedaling for 10 minutes. Training sessions 2 through 12 consisted of identical HIT training for both groups. On the first training session of each week, the respiratory resistance was increased by 914.4m (3,000ft) for the experimental group (week 1: 914.4m; week 2: 1,828.4; week 3 and 4: 2,743.2m). The control group continued to wear the mask with no resistance throughout all training sessions. During the HIT protocol, participants pedaled for 30 seconds at 75%-85% of their age predicted HR_{max} with a pedal rate of 100-120 rpm followed by 30 seconds of active recovery. During the active recovery, the participants pedaled at a slow comfortable rate. Subsequently, training included 10 sets of HIT and rest for a total session time of 10 minutes, excluding the 5-minute warm-up and cool-down. At the end of each training session, participants rated perceived exertion using the RPE scale. Bike resistance level was adjusted at the beginning of each week as determined by the previous week's RPE ratings (two ratings of ≤12) and/or what was needed to maintain a HR within the range of 75%-85% age predicted HR_{max} during exercise.

3. Statistical Analysis

Statistical analyses were performed using SPSS 21.0 for Windows (SPSS Inc., Chicago, IL, USA). Repeated measures ANOVAs were employed to determine within- and between group differences in FEV_1, FVC, FEV_1/FVD, and VO_{2max}.

4. Results

Pre-test analysis yielded no significant group difference ($p > 0.05$) in FEV_1, FVC, or time to failure during the maximal exercise test between the experimental and control group. Results from the two-way repeated ANOVA yielded no significant difference ($p > 0.05$) between the experimental and control group in BMI (p=.543), FEV_1 (p= .722), and time to failure (p=.756) after four weeks of training. However, it should be noted that after training the experimental group experienced a slight, but greater increase in FEV_1 compared to the control group (Figure 1). For instance, in the experimental group, FEV_1 increased by 4.13%, a change from 3.63L to 3.78L. In comparison, the control increased 2.41% in FEV_1, a change from 3.74L to 3.83L After 4 weeks of HIT training, both groups saw a similar increase in time to failure training.

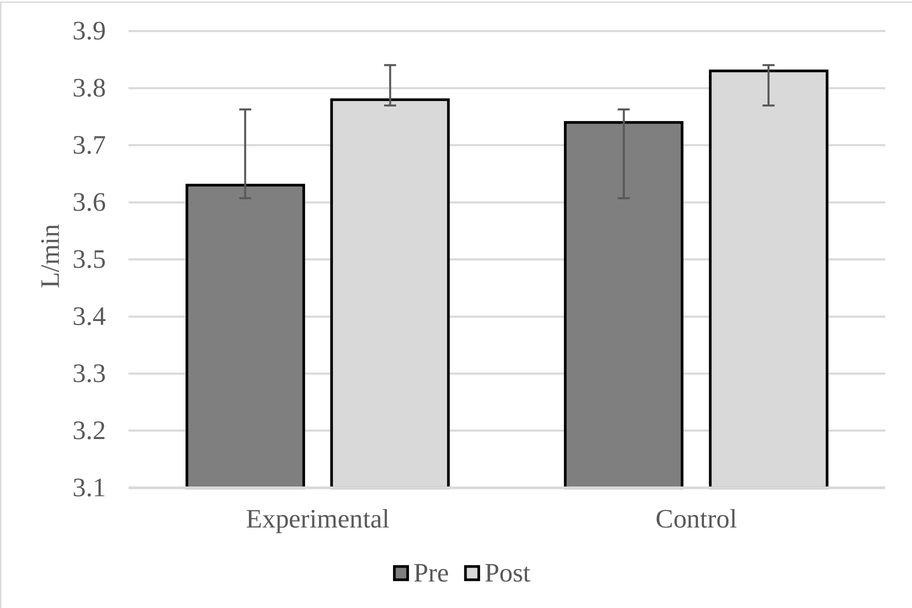

Figure 1. Difference in FEV_1 between the experimental and control group before and after 4 weeks of HIIT. Data is expressed in means and standard deviation.

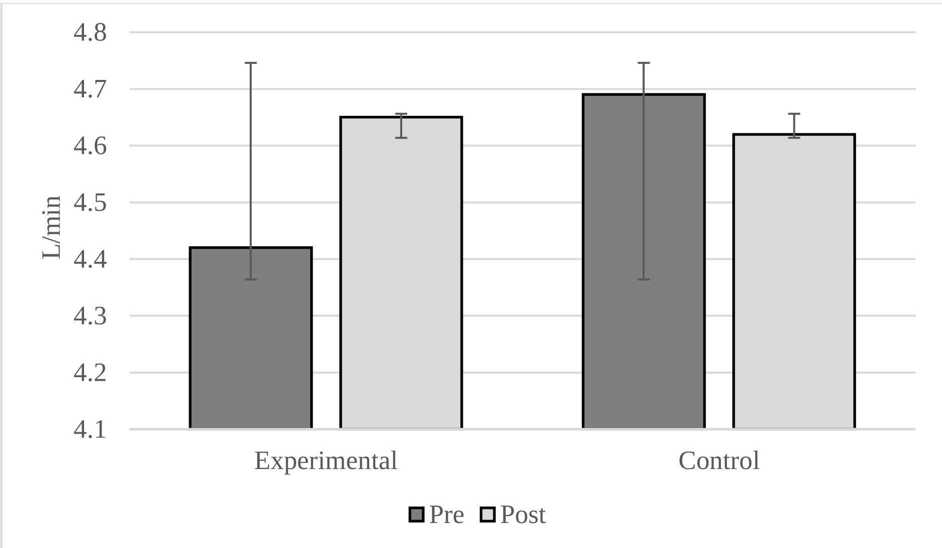

Figure 2. Difference in FVC between the experimental and control group before and after 4 weeks of HIIT. Data is expressed in mean and standard deviation. * Denotes a significant difference between the experimental and control group after training at the 0.05 level.

The experimental group increased their time to failure on the Bruce Test by 33 seconds (pre: 10:56; post 11:30) while the control group increased their time to failure 23 seconds (pre: 12:00; post 12:23).

After training, FVC was significantly higher in the experimental group compared to the control group ($F (1, 4) = 7.484$, $p=0.016$); the experimental group FVC increased 4.97% from 4.42L to 4.65L while the control group saw a 1.49% decrease in FVC after training from 4.69L to 4.62 (Figure 2).

5. Discussion

The aim of this study was to compare the effects of a commercially manufactured TM in conjunction with bicycle ergometry, high intensity training (HIT) on selected lung function parameters. Following 4 weeks of HIT both the control and experimental group exhibited an increased $FEV_1$and time to failure following a maximum treadmill test; however, while not statistically significant, the experimental group had greater increases in both FEV_1 and total exercise time. Wearing the TM in combination with HIT significantly increased FVC compared to HIT alone. Presumably, FVC significantly increased in the experimental group because the TM provided sufficient resistance to force both accessory inspiration and expiration muscles to adapt to the resistance.

The experimental group had a greater after training increase in FEV_1 and a significantly greater increase in FVC compared to the control group. Similarly, Biggs, England, Turcotte, Cooke, and Williams [9] evaluated the effect of the TM on cardiorespiratory fitness and lung function during a 6-week running high intensity interval protocol. After the 6-week protocol, they reported that the TM group had a greater (non-significant) increase in FVC and forced inspiratory vital capacity (FIVC) compared to the control group. In comparison, Kido et al[8] carried out combined training with breathing resistance and sustained physical exertion to evaluate its physiological effects. After 6 weeks of training on a cycle ergometer, they discovered no significant difference in FVC and force expiratory volume in 1sec (FEV_1) between and within groups. However, they reported that the respiratory resistance group had a significant greater maximal voluntary ventilation (MVV) after exercise training. They believed exercise training with a device that provides respiratory resistance may be beneficial for increasing respiratory muscle function. In addition, Porcari et al [10] evaluated the effects of the TM on aerobic capacity and lung function. After 6 weeks of high intensity interval training on a cycle ergometer, there was no significant difference in pulmonary function between groups.

To our knowledge this is the first study to date to find that the TM, in combination with HIT, significantly increases FVC, but not FEV_1 compared to HIT alone. FVC measures the contractility of the expiratory muscles [13] The resistance provided by the TM may have strengthened the expiratory muscles resulting in an improved FVC. The significant increase in FVC by the experimental group should be regarded with caution because a decrease in FVC was observed in the control group after training. It was expected that after exercise training, FVC would increase as lung function improves. The decrease in FVC is contrary to other studies that have shown training to increases FVC [5,14]. However, in a study examining the effects of moderate-intensity exercise on lung function, researchers also found a decrease in FVC after training [15]. The fall in FVC observed in this current study may be explained by the variability of the measurements obtained by the spirometer because the results are reliant on the participant's effort when performing the maneuvers [16]. Time to failure during the maximal exercise test between the control and the TM group was not significantly different. The nature of the HIT protocol alone can explain the increase in exercise time in both groups. HIT has been shown to increase inspiratory muscle strength more than traditional endurance exercise [16]. An increase in inspiratory muscle strength can lead to a decrease in respiratory muscle fatigue, which in turn increases exercise capacity.

Since altitude presents a lower ambient atmospheric pressure rather than a lack of oxygen, the term Elevation Training Mask may be misleading unless the reference is solely the increase in active respiration muscles. Hence, it has been suggested that the TM is more of a respiratory training device than an actual altitude simulator device [7]. Taking part in exercise such as HIT leads to forced ventilation thereby stimulating gains in respiratory muscle strength and endurance. Such gains lead to improvements in respiratory parameters such as FEV_1 and FVC [10,17]. As such, the benefits of stronger muscles responsible for respiratory ventilation lends itself to greater ventilator efficiency and improved tissue oxygenation which further leads to potential benefits in performance. The TM in combination with HIT may create sufficient resistance to strengthen the muscles responsible for respiratory ventilation and improve respiratory efficiency to allow more oxygen to be delivered to the working muscles.

6. Conclusion

The results of the current study suggest that the TM, in conjunction with HIT, appears to strengthen the muscles involved in respiratory ventilation to enhance respiratory efficiency. However, the TM in conjunction with HIT appears to not improve respiratory parameters such as FEV_1 and FVC greater than HIT alone. The TM can vary resistance from what the manufacturers claim to be 914.4m to 4,876.8m in altitude. In the current study, the experimental group's resistance was limited to 2,743.2m which may not have been sufficient to induce further changes in lung function. Acknowledged limitations of the current study were the small sample size and perhaps the duration of the training protocol (4 wks). Further research should seek a larger sample and sustain training for more than four weeks. Additionally, research should consider a wider range of elevations to determine the optimal TM setting for respiratory muscle training.

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Ethics Approval

Ethics approval was sought from the Institutional Review Board.

Author Contribution Statement

Brandie C. Cheshier – Methodology, Investigation, Data Curation and Original Draft Preparation; **Bert H. Jacobson** – Conceptualization, Supervision and Writing – Review & Editing ; **Carlos A. Estrada** – Data collection and Writing – Review & Editing ; **Masoud Moghaddam** – Validation and Writing – Review & Editing ; **Carter J Stewart** – Writing – Review & Editing

Informed Consent

Written consent was obtained from participants

Availability of data and material

No additional data are available.

Conflict of interest

The Authors have no conflicts of interest to declare that they are relevant to the content of this article.

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