UNIVERSITY OF WISCONSIN-LA CROSSE

Graduate Studies

EFFECTS OF THE ELEVATION TRAINING MASK ON MAXIMAL AEROBIC CAPACITY AND PERFORMANCE VARIABLES

A Manuscript Style Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Clinical Exercise Physiology

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December, 2015

EFFECTS OF THE ELEVATION TRAINING MASK ON MAXIMAL AEROBIC CAPACITY AND PERFORMANCE VARIABLES

By Lauren Probst

We recommend acceptance of this thesis in partial fulfillment of the candidate's requirements for the degree of Master of Science in Clinical Exercise Physiology

The candidate has completed the oral defense of the thesis.

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ABSTRACT

Probst, L. N. Effects of the Elevation Training Mask on maximal aerobic capacity and performance variables. MS in Clinical Exercise Physiology, December 2015, 44pp. (J. Porcari)

This study was designed to evaluate the effect of the Elevation Training Mask on maximal aerobic capacity (VO_2max) and performance variables. 25 subjects (13 mask, 12 control) completed a 6-week high intensity cycle ergometer training protocol. Pre and post-testing included tests for VO_2max, pulmonary function, maximal inspiration pressure, hemoglobin and hematocrit. Significant differences were seen in pre to post-testing VO_2max in both the mask and control groups. The control group improved by 13.5%, while the mask group improved by 16.5%. There were also significant improvements found in ventilatory threshold (13.9%), power output at ventilatory threshold (31 W), respiratory compensation threshold (10.2%), and power output at respiratory compensation threshold (39.9 W) in the mask group only. Results indicate that the Elevation Training Mask can improve maximal aerobic capacity and performance variables.

ACKNOWLEDGEMENTS

First, I would like to thank the members of my committee for their time and energy spent working with me. Dr. John Porcari and Dr. Carl Foster, thank you for your expertise, guidance and support throughout this entire process.

Thank you to Chris Dodge, whose knowledge in the laboratory guided us to success and completion of all our testing.

My graduate student colleagues, friends, and subjects, thank you for your time, encouragement and assistance completing this thesis. Without all of you, this would not have been possible.

Mom, Dad and Kristin, your never-ending faith in me helped me achieve my goals in both school and life. Thank you for your endless love and optimism guiding me to where I am today.

Finally, a big thank you to my thesis partner, Karlei Forrester. I couldn't imagine going through this entire process with anyone else. Your work ethic and knowledge are an inspiration, and are one of the main reasons this project went as well as it did.

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INTRODUCTION

Jack Daniels and Neil Oldridge (1969) were some of the first researchers to study altitude training as a means of improving maximal aerobic power (VO_2max) and performance. Since then, many others have researched the effects of altitude training on sea-level performance in well-trained or elite athletes (McLean, Gore & Kemp, 2014; Robertson, Saunders, Pyne, Gore & Anson 2010; Julian et al., 2003; Buchheit et al., 2012). One of the major benefits with altitude training is that the exposure to hypoxic conditions stimulates the kidneys to produce erythropoietin (EPO), which increases red blood cell (RBC) production (Paula & Niebauer, 2010). The increase in circulating RBC's increases the oxygen carrying capacity of the blood which has been correlated to improvements in VO_2max and (Levine & Stray-Gundersen, 1997).

Initial studies failed to see improvements in performance after training in hypoxic conditions. It was felt that a major limiting factor was that training intensity was decreased at altitude. Among well-trained and elite athletes this could result in potential deconditioning effects (Levine & Stray-Gundersen, 1997). To compensate for this, Levine and Stray-Gundersen (1997) introduced the "live high-train low" concept. Living at moderate altitude (2,500 m) and training at low altitude (1,250 m) allows for the athlete to train at a higher intensity, thus avoiding any detraining effects.

Another tool used in an attempt to increase exercise performance is inspiratory muscle training (IMT). Romer, McConnell and Jones (2002) conducted a study to determine the effects of IMT on endurance performance in trained cyclists. It was found that 6 weeks of IMT resulted in significant improvements in pulmonary and respiratory muscle function. It was also found that the IMT group had significant improvements in the 20 and 40 km time trial performance compared to the control group. Accordingly, IMT is thought to improve exercise performance, but its results can vary depending upon the IMT protocol methods, which type of IMT device is used, and the length of the training period (HajGhanbari, Yamabayashi, Buna, Coelho, Freedman Morton, Palmer, Toy, Walsh, Sheel & Reid, 2013).

The Elevation Training Mask 2.0 (ETM) (Training Mask LLC, Cadillac, Michigan) is a new product on the market that claims to simulate altitude training. The ETM mask covers the nose and mouth and has different sized openings and flux valves (Figure 1). The openings and flux valves can be adjusted to simulate different degrees of altitude by increasing the resistance of respiration, making it more difficult to breathe while wearing the mask. The multi-level resistance system purportedly allows the user to simulate altitudes ranging from 3,000 ft. to 18,000 ft. On the company website (trainingmask.com), it is suggested that the device can increase endurance and VO_2max, as well as improve lung functions.

Figure 1. Elevation Training Mask

To our knowledge, there is no literature supporting the use of the ETM to improve VO_2max and performance comparable to altitude training and respiratory muscle training (RMT). The purpose of this study was to determine the effect of the ETM on ventilatory threshold (VT), respiratory compensation threshold (RCT), VO_2max, power output (PO) and heart rate (HR).

METHODS

Subjects

Twenty five students from the University of Wisconsin-La Crosse volunteered to participate in the ETM study. Students were moderately trained and varied in fitness levels. The population chosen for this study was based on availability, training ability and fit the representation of the target audience for the ETM product. Each subject completed a written informed consent prior to beginning the ETM study. Approval from the University of Wisconsin-La Crosse Institutional Review Board for the Protection of Human Subjects was also obtained prior to the beginning of the study.

Procedures

Pilot testing using three individuals was conducted prior to the start of the study in order to determine suitable training workloads for exercise and recovery, and simulated altitude setting for the mask. The pilot study was performed on a Monark 828E Ergomedic cycle ergometer (Monark Exercise AB, Vansbro, Sweden).

Initially, each subject completed a maximal cycle ergometer test to determine VO_2max, VT, RCT, maximal HR and maximal PO. The VO_2max test was performed on an Excalliber Sports Ergometer Lode B.V.

(Medical Terminology, Groninga, Netherlands). The test began at 25 W for three minutes and workload was increased by 25 W every minute until volitional fatigue. Respiratory gas exchange was measured using a mixing chamber based, open-circuit spirometry system (AEI Technologies, Naperville, IL). Heart rate was measured every minute using radiotelemetry (Polar Vantage XL, Polar Instruments, Port Washington, NY) and ratings of perceived exertion (RPE) were assessed each minute using the modified Borg CR-10 scale (Borg, 1982).

Pulmonary function was also assessed for each subject. Forced vital capacity (FVC) and forced expiratory capacity in one second (FEV1) were determined using a Spirometry System (ParvoMedics Inc., Sandy, UT.). Maximal inspiratory pressure was assessed using a digital pressure vacuum meter (Net Tech, Farmingdale, NY). Hematocrit (Hct) measurements were assessed using a capillary tube and Micro Hematocrit Centrifuge (International Equipment Co., Needham Heights, Mass. USA), and hemoglobin levels (Hb) were determined for each subject using a hemoglobin reagent set and hemoglobin standard (Pointe Scientific Inc., Canton, MI), analyzed by the Spectronic 20D+ (Thermospectronic, Rochester, NY).

Based on the preliminary VO_2max results, subjects were placed into two groups. The two groups were the ETM group and a control group. The mask group wore the ETM for all training sessions, while the control group did not wear the mask during the training program. Both groups completed identical training programs.

All subjects completed two workouts, a week prior to training, in order to become familiar with the training protocol and equipment. For the first session, subjects in the mask group sat in the laboratory for 10 minutes while wearing the ETM mask (set at

3,000 ft.) in order to become accustomed to breathing while wearing the mask. They then rode for 10 minutes at a self-selected pace on the cycle ergometers that would be used for training. For the first session, the control group also rode the cycle ergometers for 10 minutes at a self-selected pace. For the second session, both groups completed five, 30-second, moderately-paced interval bouts with 90 seconds rest between intervals. The mask group wore the mask for this session while the control group did not.

Training

Subjects then completed a 6 week high-intensity cycle ergometer training program. Training sessions were held twice a week and each session was 30 minutes in length. For each workout, subjects completed a 5-minute warm-up, 20 minutes of high-intensity intervals, and a 5 minute cool-down. The 20-minute interval segment of the workload included 10 repetitions of 30 seconds at peak PO (from the final stage of the VO_2max test), followed by a 90 second recovery period at 65% of peak PO. During each training session, subjects wore a HR monitor. Heart rates were recorded at the end of the high-intensity portion of each interval. Ratings of perceived exertion, using the CR-10 modified Borg scale, were also recorded after the high-intensity portion of each interval. At the end of the workout, a session RPE was recorded.

Training intensities throughout the 6-week training period were titrated based on the subjects' RPE after interval 10 during their workout. If the control group rated the last interval a 5 (hard) or lower, for two consecutive sessions, then the peak PO was increased by 0.5 kg for the next training session. Similarly, if the mask group rated the last interval a 7 (very hard) or lower, for two consecutive sessions, then the peak PO was increased by 0.5 kg for the next training session. The values of 5 for the control group and 7 for the mask group were determined from the preliminary pilot testing. During pilot testing, at identical workloads, when subjects wore the mask, they perceived the intensity to be 1-2 units higher than when not wearing the mask.

The mask group wore the masks during all training sessions. During week 1, the masks were set to simulate 3,000 ft. During week 2, the masks were set to simulate 6,000 ft. During weeks 3 and 4, the masks were set to simulate 9,000 ft. Finally, during weeks 5 and 6, the masks were set to simulate 12,000 ft.

Oxygen saturation ($SpO_{2)}$ and blood lactate (BLA) were also obtained in order to quantify the intensity of training. Blood lactate was measured during weeks 2, 4 and 6 of training using a finger prick blood sample (Accusport Lactate Analyzer, Accusport, Hawthorne, NY). A finger pulse oximeter was used to measure SpO2 during weeks 4 and 6, using an Allegiance Oxi-Reader 2000 (Allegiance Health Care, McGraw Park, IL).

After completion of the training program, subjects in both the control and mask groups completed the identical test battery as the pretesting.

STATISTICAL METHODS

The data was analyzed using repeated measures ANOVA for a groups by trails design. Post-hoc tested will be done using the Tukey Test. Standard descriptive statistics were used to characterize the subject population and to summarize the responses to training. Pre-testing scores between groups were compared using independent t-tests. Differences between groups over the course of training were determined using repeated measures ANOVA. When there was a significant f-ratio, pairwise comparisons were made using Tukey's post-hoc test. Alpha was set at $p<0.05$ for all analyses.

RESULTS

Twenty five subjects participated in the ETM study, 13 in the mask group and 12 in the control group. Descriptive characteristics of subjects who completed the study are presented in Table 1. The mask and control groups were similar in age, height, weight and BMI at the start of the study. Twenty four subjects completed all 12 training sessions during the 6-week training period. One female from the mask group did not complete the last training session and post-VO_2max testing due to a knee injury. If a session was missed during the week, a make-up session was held on the weekend.

Table 1. Descriptive characteristics of subjects.

	Mask n=13	**Control N=12**
Age (years)		
Male	22.9 ± 3.83	21.0 ± 2.07
Female	20.6 ± 1.14	20.8 ± 1.26
Height (cm)		
Male	178.1 ± 6.83	185.0 ± 9.74
Female	165.6 ± 3.21	168.6 ± 1.54
Weight (kg)		
Male	82.4 ± 14.81	83.8 ± 13.80
Female	60.2 ± 4.09	66.1 ± 8.21
BMI		
Male	25.9 ± 4.15	24.4 ± 3.02
Female	21.9 ± 1.17	23.2 ± 2.61

Changes in study variables from pre to post-testing are presented in Table 2. There were no significant differences in the responses of males and females, thus, only group data are presented. There were no significant pretesting differences between the control and mask groups for any of the variables. Both the mask and control groups had significant increase in VO_2max and PPO as a result of training. There was no difference in the magnitude of improvement between groups. The mask group had significant improvements in VT and PO at VT, RCT and PO at RCT as a result of training. Only the improvements in VO_2 at RCT and PO at RCT were significantly greater for the mask group than the control group.

Table 2. Pre and post-testing performance variables between mask and control groups.

	Pre	**Post**	**Change**
VO_2max (ml/kg/min)			
Mask	44.8 ± 6.43	52.2 ± 7.50#	+ 7.4
Control	43.6 ± 6.21	49.5 ± 7.04#	+ 5.9
PPO (watts)			
Mask	276.0 ± 15.0	311.0 ± 17.0#	+ 35.0
Control	282.0 ± 16.0	310.0 ± 18.0#	+ 28.0
VT (ml/kg/min)			
Mask	29.4 ± 8.09	33.5 ± 6.95#	+ 4.1
Control	29.1 ± 3.58	29.7 ± 6.90	+ 0.6
PO at VT (watts)			
Mask	163.0 ± 64.0	194.0 ± 51.0#	+ 31.0
Control	158.0 ± 39.0	173.0 ± 48.0	+ 15.0
RCT (ml/kg/min)			
Mask	39.1 ± 8.06	43.1 ± 7.16#	+ 4.0*
Control	39.2 ± 5.81	39.6 ± 5.96	+ 0.4
PO at RCT (watts)			
Mask	243.4 ± 17.38	283.3 ± 18.82#	+ 39.9*
Control	262.5 ± 17.38	272.9 ± 18.82	+ 10.4
Maximal Heart Rate			
Mask	186.5 ± 10.40	186.9 ± 8.50	+ 0.04
Control	185.9 ± 10.71	186.1 ± 9.80	+ 0.02

Significantly different than pretest ($p<0.05$)
*Change significantly different than control group ($p<0.05$)

In order to quantify the intensity of training, average HR, session RPE, and workload (watts) for each session were recorded. Additionally, BLA was recorded during weeks 2, 4, and 6 and SpO_2 was assessed during weeks 4 and 6. There were no significant differences in average percent HR max (%HRmax) between the mask group and the control group over the course of the study and exercise HR was consistent across the 12 sessions. Overall the mask group was working at 92± 4.7% of the average % HRmax, while the control group was working at 88± 5.7%. The average % HRmax between groups was not significantly different (Figure 1).

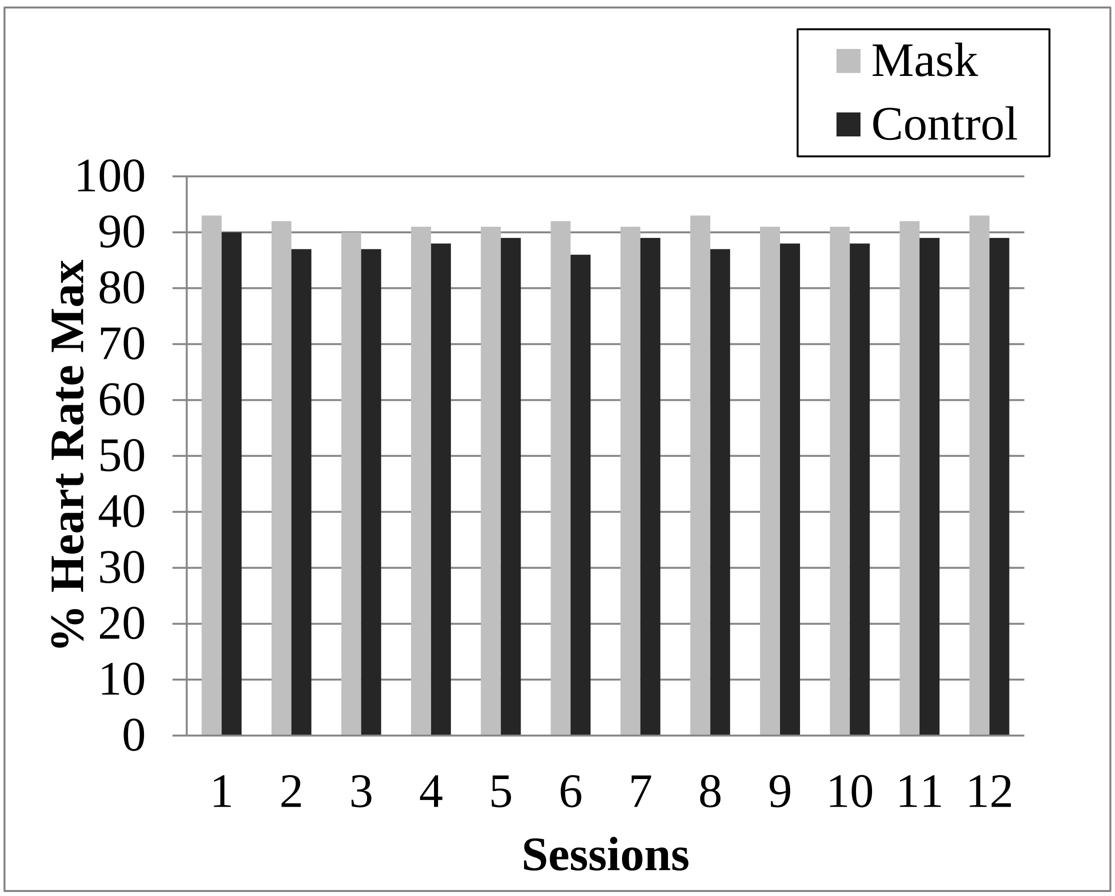

Figure 1. Percent heart rate max of the mask and control groups over the 12 training sessions.

Session RPE was also consistent across the 12 exercise sessions. However, overall session RPE for the mask group was significantly higher than the control group (Figure 2).

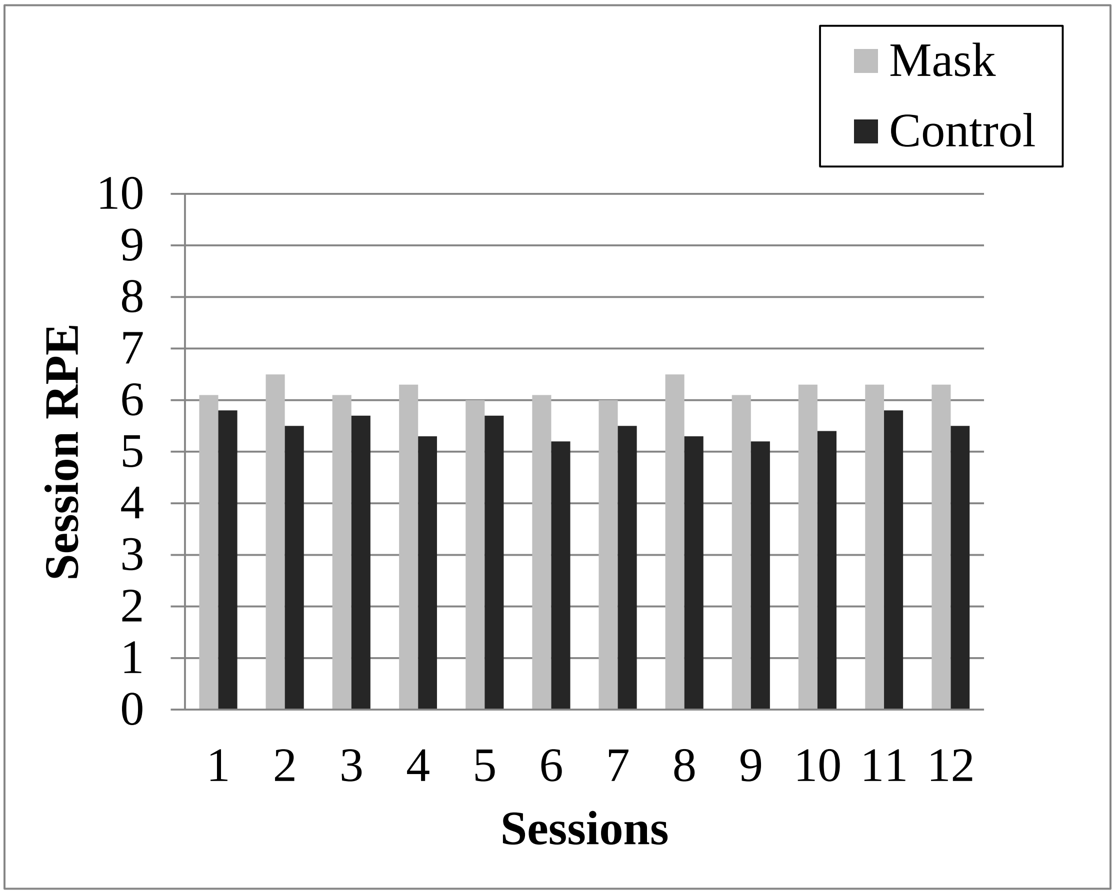

Figure 2. Session RPE of the mask and control groups over the 12 training sessions.

Average workload increased steadily across the 12 training sessions in both groups. During sessions 11 and 12, the exercise workloads for the mask group were significantly greater than the control group. The average recovery % of PPO for the mask group was 23 ± 3.9%, while the control group was 22 ± 3.6% (Figure 3).

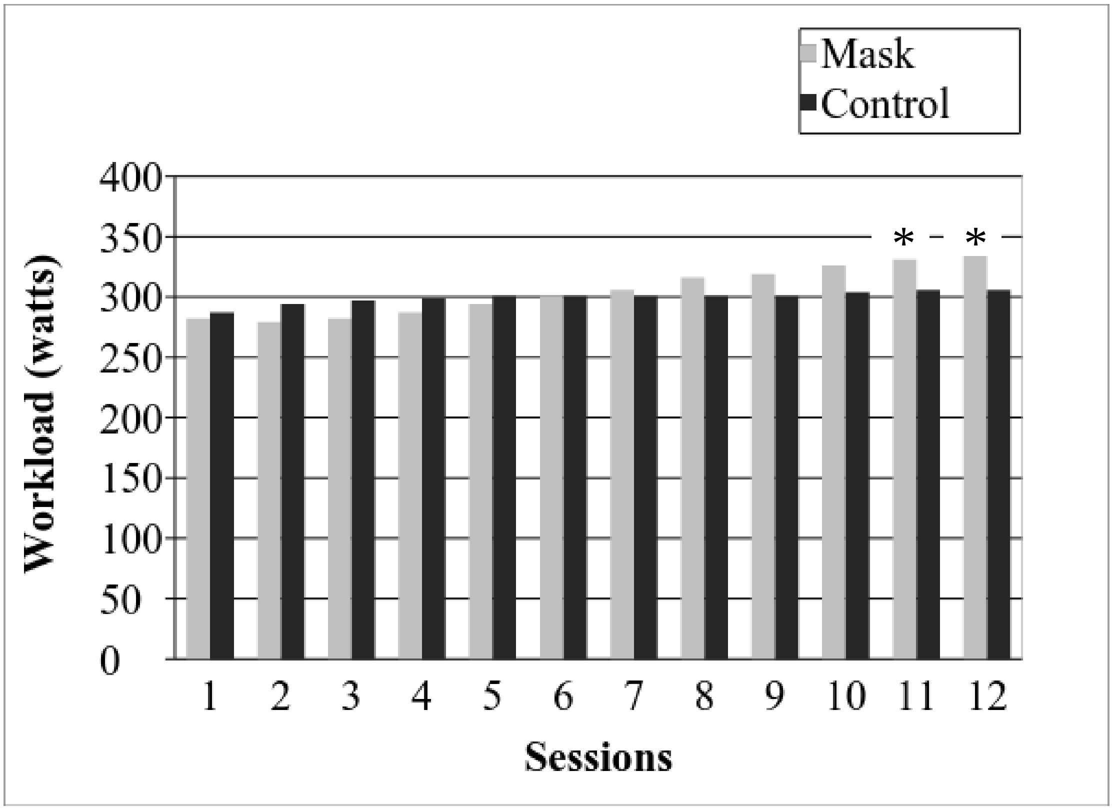

Figure 3. Average workloads of the mask and control groups over the 12 training sessions.

Blood lactate and SpO_2 data are presented in Table 3. There were no significant differences in BLA between groups during weeks 2, 4 or 6. Oxygen saturation was significantly lower in the mask group during weeks 4 and 6.

Table 3. Blood lactate during weeks 2, 4 and 6 and SpO2 during weeks 4 and 6.

	Mask n=13	**Control n=12**
BLA		
2	10.2 ±3.02	11.0 ± 3.49
4	10.1 ± 2.98	10.1 ± 3.39
6	10.9 ± 2.93	9.8 ±3.34
SpO_2 (%)		
4	94.4 ± 3.18*	96.0 ± 1.59
6	93.2 ± 3.04*	95.8 ± 1.71

*Significantly lower than the control group ($p<0.05$)

DISCUSSION

The purpose of this study was to determine the impact of training while wearing the ETM on VO_2max and related performance variables. After 6 weeks of a high-intensity cycle ergometer training program, it was found that both the control group and the mask group significantly improved VO_2max and PPO. However, only the mask group had significant improvements in VT, PO at VT, RCT, and PO at RCT. Additional findings from a separate arm of this study found that there were no hematological (Hb and Hct) improvements in either group which could explain the increase in performance variables.

When looking at VO_2max and PPO, the control group increased VO_2max by 13.5%, and PPO by 28 watts versus increases in VO_2max of 16.5% and PPO by 35 watts in the mask group. Dufour et al. (2006) found similar results after a 6-week intermittent hypoxic training program. A hypoxic group improved VO_2max by 4% and the normoxic group improved by 3% after following identical training protocols. While the results of this study support the findings of the current study, the majority of the literature supports improvements in only altitude (hypoxia) training groups (Levine & Stray-Gundersen, 1997; Stray-Gundersen, Chapman & Levine, 2001; Robertson et al., 2010).

Although the training program elicited significant improvements in VO_2max and PPO in both groups, only the mask group had significant improvements in VT, PO at VT, RCT and PO at RCT. Pre to post-testing improvements for the mask group were 13.9% for VT, 31 watts for PO at VT, 10.2% for RCT, and 39.9 watts for PO at RCT. Both the improvements in RCT values and PO at RCT were found to be significantly different from the control group. The VT and PO at VT were of similar magnitude, but did not reach statistical significance. Dufour et al. (2006) similarly showed significant improvements in VO_2 at RCT (7%) in the hypoxic group, but no significant changes in the normoxic group. It was thought that the high-intensity hypoxic training sessions elicited peripheral muscle adaptations that resulted in the increased performance capacity in the hypoxic group only.

Others have reported that non-hematological benefits from hypoxia exposure can serve as a mechanism for improvements in performance (Gore, Clark & Saunders, 2007). Possible mechanisms for improvements could include a decreased cost of ventilation, increased efficiency, an increase in ATP production, a decreased ATP cost of muscle contraction, and decreased by-product accumulation. Roels et al. (2005) suggested that hypoxic training is most likely anaerobic in nature. An additive mechanism of improvement in performance through hypoxic interval training could be due to an increase in anaerobic capacity.

Since both groups followed identical interval training protocols, and overall training workloads and training HR were not different between groups, it was hypothesized that there must be some sort of added stimulus as a consequence of wearing the mask. Oxygen saturation was lower in the mask group during exercise, but overall SpO_2 was only 2% lower in the mask group (94 versus 96%). At an altitude of 3,000 ft., 6,000 ft., 9,000 ft., and 12,000 ft., saturation levels fall to 97%, 95%, 89%, and 79%, respectively (altitude.org). This would be unlikely to cause these differences in VT and RCT. Because breathing through the mask was somewhat restrictive, it was felt that trapping of CO_2 could be a possible explanation. Thus, a post priori pilot study was done with four subjects. Each subject completed three sets of intervals under masks and no mask conditions, while end tidal CO_2 was measured. It was found that when not wearing the mask, end tidal CO_2 averaged 32.9±6.0 mmHg. When wearing the mask, end tidal CO_2 was 55.6±12.4 mmHg. Thus, it was hypothesized that possibly subjects somehow became desensitized to CO_2, shifting VT and RCT upward.

The current study found significant performance improvements in VO_2max, VT, PO at VT, RCT and PO at RCT while wearing the mask after a 6-week high-intensity cycle ergometer training. The ETM purportedly simulates altitude training and respiratory muscle training, but additional studies are needed in order to determine the exact mechanism resulting in improvements in performance variables.

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APPENDIX A

INFORMED CONSENT

INFORMED CONSENT

TRAINING BENEFITS CONSEQUENT TO 6 WEEKS OF ETM TRAINING

I, ________________________________, volunteer to participate in a research study being conducted at the University of Wisconsin-La Crosse.

Purpose and Procedures

- The purpose of this study is to determine potential changes in aerobic capacity, lung function, and red blood cell count following a 6-week training program using the Elevation Training Mask (ETM). The ETM purportedly mimics altitude training providing added resistance while breathing.
- Research assistants will be conducting the research under the direction of Dr. John P. Porcari, a Professor in the Department of Exercise and Sport Science.
- My participation in this study will involve the completion of a series of tests before and after the ETM training period. These tests will include:
    - A maximal aerobic capacity (VO2max) test. For this test I will be asked to perform an incremental cycle ergometer test until I can no longer continue. The test will start out at a slow pace and progressively increase each minute until I can no longer continue. During the test I will wear a chest strap to measure my heart rate and a face mask to analyze by expired air.
    - Lung function will be measured using spirometry.
    - A finger prick blood sample will measure red blood cell count.
- I will be asked to participate in a 6-week cycle ergometer training program, exercising 3 times per week. I will be place in one of the two groups; one group will wear the ETM while training, while the other group will not. The training will be held at the UW-L human performance laboratory and will be supervised. Each session will be 30 minutes in length, including a warm-up and cool-down period.
- Total time commitment for this study will be approximately 8 hours. This will include 90 minutes of training each week for 6-weeks and an hour of the start and end of the study.

Potential Risks

- I may experience muscle fatigue and muscle soreness as a result of completing the exercise tests and workouts used in the current study. Additionally, shortness of breath, irregularities in heart rhythm, heart attack, stroke, and even death are possibilities of vigorous exercise. However, the risk of serious or life threatening complications is very low (<1/10,000 tests) in apparently healthy adults.
- Another possible complication may be claustrophobia using the ETM during training. Subjects will be informed to remove the mask as needed throughout the training.

- Asthmatics will have a higher potential risk to the complications above and will be excluded from this study.
- All testing and training sessions will be stopped immediately if there are any complications.
- In order to minimize potential risks, the researcher conducting the testing are all trained in Advanced Cardiac Life Support (ACLS). The staff conducting the training are all CPR and first aid certified. Additionally, emergency equipment (AED) and protocols are in place in the laboratory where the testing will take place as well as the training facility.

Benefits

- The benefit of the individual subjects in the current study be 1) a knowledge of their individual fitness level, as well as 2) potential increases in aerobic capacity, pulmonary functional capacity, and hematocrit levels.
- As a result of the training sessions I will be participating in, it is reasonable to expect an improvement in at least some of the above measures.

Rights and Confidentiality

- My participant in this study is entirely voluntary.
- I may choose to discontinue my involvement in the study at any time, for any reason, without penalty.
- The results of this study have the potential of being published or presented at scientific meetings, but my personal information will be kept confidential and only group data will be presented.

I have read the information provided on this consent form. I have been informed of the purpose of this study, the procedures, and expectations of myself and the testers, and of the potential risks and benefits that may be associated with volunteering in this study. I have asked any and all questions that concerned me and received clear answers so as to fully understand all aspects of this study.

If i have any other questions that arise I may feel free to contact John P. Porcari, the principal investigator at (608)785-8684. Questions in regards to the protection of human subjects may be addressed to the University of Wisconsin- La Crosse, Institutional Review Board (IRB) for the Protection of Human Subjects at (608) 785-8124.

Subject: ______________________________ Date:_____________________________

Investigator: ___________________________Date:_____________________________

APPENDIX B

REVIEW OF LITERATURE

REVIEW OF LITERATURE

The purpose of this paper is to review the literature regarding the effects of altitude training and RMT on exercise performance. The Elevation Training Mask (ETM) is marketed as a device that stimulates altitude training.

Introduction

In relation to exercise performance, there are still many questions left unanswered about the most beneficial ways to improve training without reaching limits of maximal oxygen consumption uptake (VO_2max) (Inbar, Weiner, Azgad, Rotstein, & Weinstein, 2000). Among many types of training programs to increase exercise performance are altitude training and RMT. Altitude training has been introduced into the exercise world to improve performance, by triggering the production of erythropoietin (EPO), which in turn produces red blood cells (RBCs) (de Paula & Niebauer, 2010). This eliciting of hypoxic conditions and EPO production results in improved oxygen delivery and utilization (Levine & Stray-Gundersen, 1997). Effects of hypoxic conditions, along with training, have resulted in a positive impact on exercise performance in many conditions (Paula & Niebauer, 2010).

Along with altitude training, RMT has been studied as a method to improve exercise performance. Respiratory muscle training is performed by breathing against an inspiratory and/or expiratory load (Illi, Held, Frank, & Spengler, 2012). A study meta-analysis found that many of the studies done on RMT and inspiratory muscle training (IMT) suggest that there is performance enhancement when using these measures

(HajGhanbari et al., 2013). Questions on the exact ability of RMT/IMT to improve performance is based on the variability seen within each separate study in relation to exercise modality, intensity, duration, type of loading/unloading, and athletic level (Johnson, Sharpe, & Brown, 2007).

In an attempt to improve exercise performance, the ETM was produced, purportedly mimicking conditions of altitude training and RMT, by adding resistance to inhalation while breathing. However, there is a lack of research on the ETM to determine its practicality and significance relating to altitude training and IMT. The ETM is a mask that was constructed with a multi-level flux valve system to apply resistance to breathing by restricting airflow. The multi-levels that are created using different valves simulate a specific elevation and claim to produce similar conditions to altitude training.

Altitude Training

Levine and Stray-Gundersen (1997) took it a step further and sparked the interest of altitude training with their “live high-train low” protocol in hopes of improving athletes’ exercise performance. This live high-train low training that they created was based off of the idea that acclimating to hypoxic conditions increases EPO conditions, which in turn increasing RBC production. This increase in RBC volume creates a higher oxygen carrying capacity for the athlete, sufficiently increasing the potential to improve exercise performance. Training at low altitude allows for the athlete to permit training that is at a sufficient intensity to improve their performance and avoid any detraining effects (Paula & Niebauer, 2010).

In the 1997 study by Levine and Stray-Gundersen, it was hypothesized that acclimating to a moderate (2500m) altitude, plus training at low altitude would improve sea-level performance in well-trained runners. They separated their participants randomly into three training groups, live high-train low, live high-train high and live low-train low. All three of the groups were first trained at sea-level as a lead-in phase to account for any inequivalent training prior to the study. Participants were then split up into groups, participating in living and training conditions that they were assigned. Training included a 4-week mesocycle program, increasing intensity during the first three weeks of testing, and slightly tapering the 4th week of training to prepare for the next weeks of competition. After the training sessions were done, two weeks of competition were completed to assess any improvements that may have been made. It was found that the two groups living at altitude increased both their EPO and RBC volume. The live high-train low, as well as the live high-train high group improved VO_2max by 5% and RBC volume by 9%. One major factor that was concluded in this study was that the increase in VO_2max can be translated to improved performance at sea-level. It was also found that running performance was improved in the live high-train low group.

Expanding on the idea of the live high-train low protocol, Stray-Gundersen, Chapman and Levine (2001) conducted another study that tested their previous hypoxic training model in elite runners, rather than the well-trained competitors that were used in the previous study. It has been previously suggested that elite runners will not have the same amount of increase, or any at all in exercise performance, when acclimated to high altitude due to already being close to maximal structural and functional adaptations of the respiratory system. The elite runners were trained for 4 weeks at a low altitude of 1250 m, while living at 2500m at altitude. The 4-week training period involved a high intensity training program, following a 3000m-time trial at sea-level. The study found showed significant improvements in performance. The EPO levels, on average, were double the original values at sea-level. This stimulated the production of increased red cell mass and hemoglobin (Hb) concentration. As a result, VO_2max improved by 3% on average, and 3000m time trial performance improved by 1.1%. Some of the elite runners beat their previous times by as much as 28 seconds, showing a significant improvement resulting from altitude training. This study implies that the training protocol used in these studies results in a significant improvement in elite runners, contradicting prior beliefs.

In an attempt to improve results, while trying to avoid possible detraining effects, Robertson, Saunders, Pyne, Gore, and Anson (2010) designed a training protocol labeled live high-train low-train high (LH/TL+TH). Due to the most optimal training program not being established, a slight change in design from those conducted by Levine and Stray-Gundersen (1997) was tested in hopes of improving exercise performance in athletes. The live high-train low- train high group spent 14 hours per day in a normobaric hypoxic facility, performed their normal training at sea level and also completed a hypoxic training program throughout the week. The hypoxic training performed by the athletes included one long duration, one moderate duration and two high intensity sessions per week at altitude. The findings of this study suggest that the LH/TL+TH protocol showed substantial increases in VO_2max and Hb concentrations, as well as small improvements in time trial performances. Although there was a change in time trial performance, it was trivial and was not seen as practically significant. The addition of the train high program along with the LHTL regimen was not seen as substantial enough to imply that it is a better training program for athletes seeking to improve sea-level performance.

Continuing on the idea of ideal timing for training and return to sea level, Chapman, Laymon Stickford, Lundby and Levine (2014) researched the timing of return from altitude training for optimal sea level performance. The de-acclimation response to hematological, ventilatory and biomechanical factors was studied to determine the best timing to return for competitive performance. The research showed that the relationship between these factors may not be apparent at an individual level, but can influence performance through their interaction. The hematological effects show that the increases in RBC and Hb mass, along with oxygen delivery, are the most important factors behind improving sea level performance.

In another attempt to improve exercise performance similar to the original Levine and Stray-Gundersen study of 1997, Julian et al., (2003) tested the effects of strictly intermittent normobaric hypoxia exposure in highly trained distance runners. The design of this study was conducted to test if the exposure to normobaric hypoxia at rest is a sufficient stimulus to spark the changes associated with improved exercise performance, such as EPO, and Hb concentrations. Fourteen national-class distance runners completed a 4-week regimen. Subjects were exposed to hypoxic and normoxic conditions at an even ratio for 70 minutes, 5 times per week, while at rest. After baseline measurements were taken, and the training regimen was completed, testing was done to determine the effect of improvements in exercise performance. It was found that there were no changes in any of the physiological adaptations or exercise performance. This training regimen did not improve VO_2max or 3000m time trial performance in highly trained distance runners.

Based on all of the previous findings, it is clear that the best method to improving exercise performance while utilizing altitude training is still unknown. A meta-analysis conducted by de Paula and Niebauer (2010) summarized the current literature on high altitude training to determine whether or not it actually improves performance or if improvement in exercise performance due to altitude training is strictly a myth. The studies that were researched included those done on the LHTL protocol, specifically looking for physiological changes in EPO, Hb concentration, RBC volume, and performance measures such as VO_2max. It was found that there was a lack of control groups and randomization, eliminating any comparisons that could be made between groups. It was also found that due to the different exercise modalities and intensities of workouts, the results are not sufficiently consistent in their findings. The EPO effects found were associated in improvements in most studies, while some found no changes at all. Hemoglobin concentration, VO_2max, and time trial performance fell under a same pattern of having very mixed results as to whether or not altitude training improved performance. Overall, the bulk of the literature studied by de Paula and Niebauer (2010) did not support that exposure to hypoxic conditions improved exercise performance.

As altitude training is further investigated, cheaper, less time consuming and more effective techniques are being created in the attempt to improve exercise performance. Most athletes are not going to be able to spend the time needed in order to participate in the LHTL or live high-train high (LHTH) studies. Thus, the concept of live low-train high (LLTH) was developed (McLean, Gore, & Kemp, 2014). This protocol was created to allow athletes to remain in their typical living conditions, only needing to go to high altitude during the shorter training periods. In this study, exposure times, training intensities, training modalities, degrees of hypoxia and performance outcomes assessed differed between four conditions to study different effects in multiple types of LLTH conditions. Group 1 was on a continuous low-intensity training in hypoxia, group 2 performed an interval hypoxic training (IHT) program, group 3 performed repeated sprints in hypoxia and group 4 performed a resistance training program in hypoxia. Each group was exposed to hypoxia during training for up to 3 hours, 2-5 times per week. A majority of the LLTH reports suggest no benefits of training under hypoxic conditions in high altitude. Most of the benefits found in this study related to high-intensity, anaerobic performance. Most of the high altitude training studies conducted are aimed at improving endurance performance, but this study shows that more time exposure to altitude may be needed to elicit training improvements.

Respiratory Muscle Training

Respiratory muscle training to improve exercise performance has equivocal results. Exercise capacity has been questioned relating to the pulmonary system and limitations of the respiratory system during maximal exercise (Coast, Clifford, Henrich, Stray-Gundersen & Johnson, 1990). Modification of respiratory muscles through RMT is suggested to increase breathing endurance, while its counterpart, IMT, is shown to increase diaphragm thickness, maximal inspiratory muscle strength, endurance, shortening velocity, and power output (Johnson, Sharpe, & Brown, 2007).

In a study conducted by Harms, Wetter, St. Croix, Pegelow, & Dempsey (1999), it was hypothesized that the workload of breathing normally during high intensity exercise would impair overall exercise performance. Strenuous constant-load exercise was used with respiratory muscle loading and unloading conditions. The study was run over a 6-8 week period, using separate testing days for each trial, with subjects completing 3 control study trials and 3 respiratory muscle unloading trials. One to six months later these groups were assigned to two control trials and three loaded trials. Significant findings of this study showed that decreasing the work of breathing through respiratory muscle unloading ultimately led to longer exercise tolerance; unloading trials showed a decrease in VO_2max. Respiratory muscle unloading during exercise reduced VO_2max by causing hyperventilation and reducing the perception of respiratory and limb discomfort during exercise. Loading conditions created a perception of added work, simulating respiratory muscle fatigue and reducing some performers to slowing their pace.

A study done by Williams, Wongsathikun, Boon, and Acevedo (2002) supported the idea that IMT fails to improve endurance capacity. Seven collegiate distance runners participated in the study. After preliminary testing, all subjects participated in a 4-week IMT program, performed at 50-65% of maximal inspiratory mouth pressure (MIP), for 25 minutes per day, 4-5 times per week. Results found no improvements in HR, minute ventilation, VO_2 and ratings of perceived dyspnea post IMT. The increase in respiratory muscle strength was unable to transfer to improvements in VO_2max or endurance exercise capacity. This indicates that IMT is not an effective way to train in high-intensity exercise settings.

Although most studies found that IMT did not transfer to improvements in exercise performance, some studies found minimal, but significant improvements, suggesting that it has the potential to be beneficial. In 2001, Sonetti, Wetter, Pegelow, and Dempsey conducted a study on RMT versus a placebo condition and the effects each has on endurance exercise performance. A 5-week study, completed in 25 total sessions for 30-35 minutes per day for 5 days a week included RMT with nine cyclists. Each week there was an in-lab training session, where RMT intensity was increased afterward. The RMT group found significant improvements in MIP, inspiratory pressure and breathing frequency during training. It caused increases in peak work rate achieved, as well as, time to exhaustion. The placebo group found similar significant changes. The only difference was that the RMT group increased on the 8km time trial performance test slightly more than the placebo group. In this specific study with highly fit and competitive subjects, it seems as though the increase in performance may be explained through a placebo effect. If you believe you are working with a training program that is supposed to increase your performance, there are many factors that can influence your exercise performance results.

Romer, McConnell, and Jones (2002) conducted a study to determine the effects of IMT on endurance performance in cyclists. Sixteen trained cyclists had a preliminary assessment on inspiratory muscle and pulmonary functioning, followed by time trials of 20 and 40 km. After baseline measures were taken, a 6-week IMT program was completed, followed by the 20 and 40 km time trial to determine improvements in any exercise performance. Throughout the training, subjects were advised to complete a physical activity diary with details on training volume and intensity. Results showed that the control group did not have any pulmonary or respiratory muscle function improvements, but the training group saw significant increases. Although there were changes in respiratory muscle strength and pulmonary function in the training group, neither group had a change in VO_2max. It was also found that after the training group had faster times in both 20 and 40 km trials. This study shows evidence of improved performance after IMT.

A meta-analysis done by HajGhanbari et al. (2013) was conducted in order to determine if RMT has the potential to improve exercise performance and respiratory muscle strength and endurance. Twenty-one studies were analyzed to better understand the effect that RMT can have on athletes. Within this meta-analysis, there were multiple differences in participants and training regimens. There were multiple athletic levels, different training intensities and durations, as well as different types of RMT. It was found in most studies that inspiratory and respiratory muscle training can improve athletic performance and respiratory muscle strength and endurance.

Conclusion

The exact effects that altitude training and RMT have on exercise performance are still not completely understood. The ETM tries to simulate both of them in order to induce improvements in performance. There is little information known about the ETM due to a lack of research, but its claims lead to the purpose of this study.

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