“FUNCTIONAL” RESPIRATORY MUSCLE TRAINING DURING ENDURANCE EXERCISE CAUSES MODEST HYPOXEMIA BUT OVERALL IS WELL TOLERATED

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ABSTRACT

Granados, J, Gillum, TL, Castillo, W, Christmas, KM, and Kuennen, MR. “Functional” respiratory muscle training during endurance exercise causes modest hypoxemia but overall is well tolerated. J Strength Cond Res 30(3): 755–762, 2016—A novel commercial training mask purportedly allows for combined respiratory muscle training and altitude exposure during exercise. We examined the mask’s ability to deliver on this claim. Ten men completed three bouts of treadmill exercise at a matched workload (60%VO2peak) in a controlled laboratory environment. During exercise, the mask was worn in 2 manufacturer-defined settings (9,000 ft [9K] and 15,000 ft [15K]) and a Sham configuration (~3,500 ft). Ventilation (VE), tidal volume (VV), respiratory rate (RR), expired oxygen (FeO2) and carbon dioxide (FeCO2), peripheral oxygen saturation (Spo2), heart rate, and RPE were measured each minute during exercise, and subjects completed the Beck Anxiety Inventory (BAI) immediately after. The mask caused a reduction in VE of ~20L/min in both the 9K and 15K configurations (p < 0.001). This was due to a reduction in RR of ~10 b·min⁻¹, but not VV, which was elevated by ~250 ml (p < 0.001). FeO2 was reduced and FeCO2 was elevated above Sham in both 9K and 15K (p < 0.001). V02 was not different across conditions (p = 0.210), but VCO2 trended lower at 9K (p = 0.093) and was reduced at 15K (p = 0.016). V02/VCO2 was 18.3% lower than Sham at 9K and 19.2% lower at 15K. V02/VCO2 was 16.2% lower than Sham at 9K and 18.8% lower at 15K (all p < 0.001). Heart rate increased with exercise (p < 0.001) but was not different among conditions (p = 0.285). Spo2 averaged 94% in Sham, 91% at 9K, and 89% at 15K (p < 0.001). RPE and BAI were also higher in 9K and 15K (p < 0.010), but there was no difference among mask conditions.

The training mask caused inadequate hyperventilation that led to arterial hypoxemia and psychological discomfort, but the magnitude of these responses were small and they did not vary across mask configurations.

KEY WORDS altitude training mask, hypoxia, hypercapnia, ventilatory response

INTRODUCTION

Respiratory muscle training (RMT) elicits a number of beneficial adaptations in endurance athletes. Most notably, reductions in perceived breathing effort (15) and measured breathing work (1,14,31) delay the development of respiratory muscle fatigue (11–13), contributing to an attenuation of the respiratory muscle metaboreflex (1,11–13,29,33) and improvements on both fixed-workload tasks (29) and time trial performance (1,14). Nearly all RMT studies that have been conducted to date have performed RMT at rest (see (15) for review), which is surprising given that the benefits of RMT (in athletes) are all specific to exercise. However, in 2014, an article published in the JSCR questioned whether transitioning RMT from an adjunct training method (at rest) to an athlete’s normal training regimen (during exercise) might impart further benefits (30). In that study, 6 weeks of “Functional” RMT were shown to improve running economy at the speed of the onset of blood lactate accumulation and 1-hour run performance (30). Unfortunately, the interpretation of those findings was limited by the fact that the intervention group performed RMT during the commission of core muscle exercises that were not specific to endurance training.

Although it was not stated outright, we speculate that study (30) combined RMT with abdominal work because the inspiratory pressure threshold device that was used (POWERbreathe International Ltd., Southam, Warwickshire, UK) required hand contact. This suggests that if a hands-free RMT device were publicly available, it may serve to increase the specificity of RMT-mediated adaptations and provide benefit in endurance athlete populations. However, before any performance-related questions can be answered, it is
“Functional” Respiratory Muscle Training

integral to first establish proof of concept for the aforementioned RMT modality. The Training Mask v2.0 is a commercially manufactured (Training Mask LLC; Cadillac, MI, USA) RMT device that uses a silicone mask and flexible neoprene head strap to seal the face during exercise. The adjustable “resistance caps” on this device also purportedly provide for between 3,000 and 18,000 ft of “Altitude Resistance.” Despite the misgivings associated with this statement and the fact that this mask is more heavily marketed toward high-intensity anaerobic sports like Mixed Martial Arts and Crossfit (27), we speculate that it may benefit endurance athletes within this specific context. Given that the capabilities of this mask have not yet been examined in a controlled, laboratory environment, we have identified 2 major questions that need to be answered. First, it is unclear to what extent changes in the configuration of the training mask’s resistance caps will contribute to changes in RMT, hypoxemia, and hypercapnia. Second, given that hypoxia and hypercapnia both cause psychological discomfort (32) that contributes to reduced training quality (10,17), it is unclear to what extent this mask might reduce an individual’s exercise tolerance.

This study was undertaken to answer these questions. We hypothesized that because the training mask was an RMT, it would cause inadequate hyperventilation during exercise that led to modest arterial hypoxemia. Given the striking similarity between the training mask and resistive breathing devices that are used in laboratories to evaluate the energetics and control of breathing (1,31), we hypothesized that adjusting the resistance caps on this device to alter altitude resistance would not result in meaningful differences being experienced by the end user. As such, the mask would cause some psychological discomfort but overall exercise in the mask would be well tolerated.

METHODS

Experimental Approach to the Problem

The research design was a randomized single-blind crossover. Each subject completed 3 bouts of fixed-workload treadmill exercise at a workload equivalent to 60% individual \( \dot{V}O_2 \) peak. The duration of each bout was 20 minutes. The manipulated variable was the configuration of the training mask (Training Mask 2.0; Training Mask LLC, Cadillac), which was modified to integrate with our open circuit spirometry system (Vmax ENCORE 29C; CareFusion Yorba Linda, CA, USA) and worn by subjects in 2 manufacturer-stated altitude configurations (9,000 ft [9K] and 15,000 ft [15K]) and a sham setting [Sham] in a counterbalanced order. Exercise was always performed in the morning, in a controlled laboratory environment (20–22°C, 10–20% RH). Subjects were instructed to abstain from caffeine, alcohol, and vigorous exercise for 48 hours before each test and to replicate their diet for 24 hours before. They were also screened to ensure that they were not taking any dietary supplements or medications that could influence cardiovascular function or blood constituents. The altitude of the laboratory where this research was conducted (Canyon, TX, USA) was 3,543 ft. All subjects had been in-residence for ≥1 year before study onset.

Subjects

Ten recreationally active men (mean ± SEM: age 25 ± 2 yrs, age range 21–34 yrs, height 177 ± 2 cm, body mass 79.9 ± 3.7 kg, body fat 11.5 ± 4.6%, \( \dot{V}O_2 \) max 53.4 ± 5.1 ml·kg\(^{-1}\)·min\(^{-1}\)) completed this study. Participants were nonsmokers, normotensive, had no overt history of cardiovascular, pulmonary, or metabolic dysfunction as defined by the American College of Sports Medicine (20). The ethics committee of West Texas A&M University (Canyon) approved this study. All subjects gave written informed consent before study participation.

Procedures

Preliminary Data. Body composition and peak aerobic power (\( \dot{V}O_2 \)peak) were measured for descriptive purposes. Body composition was determined by hydrodensitometry, where body density was calculated as the ratio between body mass and volume after correction for water temperature and residual volume (25). \( \dot{V}O_2 \) peak was determined on a treadmill ergometer (TMX425; Full Vision Inc., Newton, KS, USA) in a thermoneutral room.
(19–22 °C, 30% RH) by open circuit indirect spirometry. Treadmill speed and grade were elevated at 1-minute intervals until volitional exhaustion. Test times ranged from 8 to 12 minutes. Ratings of perceived exertion (RPE) were taken at 1-min intervals (5), and a radiotelemetry strap and watch (RS400sd; Polar Instruments, Kempele, Finland) was used to monitor heart rate (HR). Traditional criteria to identify \( \dot{V}O_2 \) peak were used (23). After recovering from the \( \dot{V}O_2 \) peak test, subjects completed 3 additional bouts of steady-state treadmill exercise to determine the workload equivalent to 60% \( \dot{V}O_2 \) peak. This workload was used on all subsequent experimental trials.

**Experimental Data.** On the morning of each exercise trial, subjects reported to the laboratory, where their hydration status was assessed by urine specific gravity (REF312ATC; General Tools & Instruments, New York, NY, USA) to ensure euhydration (USG ≈ 1.020). Next, they were fitted with a radio telemetry strap and watch for HR assessment (RS400sd; Polar Instruments), a photodetector pulse oximeter (O2 Achieve Oximeter; Nonin Medical Inc., Plymouth, MN, USA), and a standard noseclip and mouthpiece for expired gas analysis. After ensuring that they could ventilate comfortably at rest while wearing the modified training mask (described below), subjects commenced treadmill exercise at their predetermined workload. Respiratory rate (\( R_R \)), tidal volume (\( V_T \)), and fractions of expired oxygen (\( F_{E}O_2 \)) and carbon dioxide (\( F_{E}CO_2 \)) were measured continuously during exercise. Minute ventilation (\( V_E \)), oxygen consumption (\( \dot{V}O_2 \)), carbon dioxide production (\( \dot{V}CO_2 \)), and the ventilatory equivalents for oxygen (\( V_E\dot{V}O_2 \)) and carbon dioxide (\( V_E\dot{V}CO_2 \)) were calculated from these values. Heart rate, \( S.PO_2 \), and RPE were collected at 1-minute intervals throughout exercise. Subjects also completed the Beck Anxiety Inventory (BAI) (4) immediately after exercise termination.

**Modified Training Mask.** The commercial training mask examined in this study uses 3 resistance caps to influence inspiratory and expiratory pressures. Each resistance cap contains a flux valve, base and post assembly, and an inlet or outlet valve cover. The flux valve is simply a flexible plastic flap that bends to accommodate airflow. The base and post assembly provides a hard plastic housing in which the flux valve is seated. Inlet and outlet valve covers have a diameter of 3.7 cm. Inlet valve covers can be adjusted to provide between 1 and 4 openings, the diameter of which is 7 mm. The number of inlet valve cover openings determines the inspiratory pressure required to open the flux valves and allow air to enter the device. Outlet valve covers are not adjustable. They have 8 openings, the diameter of which is 7 mm, and provide a nonmodifiable level of expiratory resistance. The neoprene sleeve and facemask that normally connect these 3 resistance caps to the end user were not compatible with our metabolic cart so a standard 4 cm diameter PVC cross fitting connector was substituted. As shown in Figure 1 (Panel A), this PVC connector was affixed to the distal end of our metabolic cart’s mass flow sensor with standard 1.27 cm plumbers tape (Oatey, Cleveland, OH, USA).

This study examined the modified training mask in 2 manufacturer-stated altitude resistance settings and a sham configuration. As shown in Figure 1, each setting required variations in the configuration of the resistance caps. SHAM (Panel B) used 3 outlet covers, 0 flux valves, and was confirmed to impart no inspiratory or expiratory resistance. The 9K (Panel C) used 2 inlet covers that each contained 1 opening, 2 flux valves tuned to the inlet position, and 1 outlet cover with the flux valve set to the outlet position. The 15K...
(Panel D) required the use of 1 inlet cover that contained 2 openings and a flux valve set to the inlet position, 1 inlet cover that contained 1 opening and a flux valve that was set to the outlet position to create a complete seal, and 1 outlet cover with valve flux set to the outlet position.

All connections on the proximal end of the cross fitting connector were standard for our particular metabolic cart (Vmax ENCORE 29C; CareFusion Yorba Linda, CA, USA). However, differences in sample line lengths, gas analyzers, pneumotachs, fittings, connectors, and adapters among different metabolic cart manufacturers have previously been shown to interject variability into data sets (23) so a complete description of this setup has been provided. All the components that follow were manufactured by the same company (SensorMedics, Yorba Linda). The spirometer on this metabolic cart contained 2 sampling ports. One connected to a Vmax Drier Tube assembly that contained a Vmax Breath by Breath sample line. The other connected to a Vmax Tube Assembly Direction Sense that contained a Permapure sample line. Both sample lines connected to the Vmax enclosure that housed the combined oxygen and carbon dioxide analyzer. The spirometer attached to the subject via a free flow mouthpiece, plastic adapter, and standard saliva trap assembly. The additional dead space ventilation created by these connections was 240 ml. This is similar to the neoprene sleeve and face-mask that normally connect the resistance caps to the end user, which have a dead space volume of 250 ml.

**Beck Anxiety Inventory.** The BAI is a 21-item multiple-choice self-report inventory that measures the severity of anxiety in adults and adolescents (4). Each of the items on the BAI is a simple description of a symptom of anxiety in one of its 4 expressed aspects: 1, subjective; 2, neurophysiologic; 3, autonomic; and 4, panic related. Each symptom item has 4 possible answer choices: Not at All = 0; Mildly = 1; Moderately = 2, and; Severely = 3. Values for each item are summed yielding an overall or total score for all 21 symptoms that can range between 0 and 63 points. A total score of 0–7 is interpreted as a “Minimal” level of anxiety; 8–15 as “Mild”; 16–25 as “Moderate”; and 26–63 as “Severe.” (3,4) The BAI is psychometrically sound. Internal consistency (Cronbach’s alpha) ranges from 0.92 to 0.94 for adults, and test-retest (one week interval) reliability is 0.75. Concurrent validity with the Hamilton Anxiety Rating Scale, Revised is 0.51; 0.58 for the State and 0.47 for the Trait subscales of the State-Trait Anxiety Inventory, Form Y; and 0.54 for the 7d Anxiety Rating of the Weekly Record of Anxiety and Depression (3).

**Statistical Analyses**

**Data Processing.** All indirect calorimetric data were first inspected for errant breaths then smoothed by a 10 second average. These data were then time averaged to 1 minute values. The first 4 minutes of exercise data were subsequently removed to account for the time it took subjects to achieve steady state. The last minute of exercise data was...
also removed to prevent subject anticipation of exercise cessation from confounding the analysis.

**Statistics.** All statistical analyses were performed with STATISTICA for Windows (version 7.1; StatSoft Inc., Tulsa, OK, USA). Dependent variables were tested for normal distribution using the Kolmogorov-Smirnov test. Nonnormally distributed variables were log transformed to approximate a normal distribution before applying a t-test or repeated-measures analysis. The repeated-factors assumption of sphericity was tested with Mauchly’s sphericity test. When necessary, a Greenhouse-Geisser correction was applied to the F-ratio to correct for sphericity violations. Dependent variables were then examined by 2-factor ANOVAs, where intervention (Sham, 9k, or 15k) and exercise time (1–15 minutes) served as the repeated-measures factors. Significant main and interaction effects were further evaluated using Tukey’s HSD post hoc analysis. All data represent mean ± SE for n = 10. Statistical significance was set at p ≤ 0.05.

**RESULTS**

Ventilation

Ventilatory data are shown in Figure 2. As compared with SHAM, $V_{E}$ was reduced by 20 liters per minute in both 9K and 15K (both $p < 0.001$). $V_{E}$ in 9K and 15K were not different ($p = 0.555$). The reduction in $V_{E}$ in 9K and 15K was due to a reduction in $R_{R}$ of ~10 breaths per minute (both $p < 0.001$). $R_{R}$ in 9K and 15K were not different ($p = 0.797$). The interaction of study condition and time was significant for $V_{T}$ ($p = 0.031$). $V_{T}$ in 9K was increased by ~250 ml over SHAM through 12 min of exercise. $V_{T}$ in 15K was increased by ~250 ml above SHAM through 15 minutes of exercise.

Respiration & Breathing Efficiency

Respiratory data are shown in Figure 3 and breathing efficiency data are shown in Figure 4. As compared with SHAM, $F_{E}O_{2}$ was significantly reduced in 9K and 15K (both $p < 0.001$), whereas $F_{E}CO_{2}$ was significantly elevated above SHAM in both conditions (both $p < 0.001$). These differences are most readily explained by the combination of the reduced breathing frequency subjects exhibited throughout exercise when the training mask was worn in the 9k and 15k configurations and the 240 ml additional dead space ventilation this mask provided. Again, we saw no differences in $F_{E}O_{2}$ and $F_{E}CO_{2}$ between the 9K and 15K mask configurations ($p = 0.726$ and 0.489, respectively).
There was no difference in VO2 among the SHAM, 9K, and 15K conditions (p = 0.210). This was an expected finding because all exercise was performed at the same relative workload (60% VO2peak). However, given the additional 240 ml of dead space ventilation this mask provided in both 9K and 15K (which was not provided in SHAM because the breathing resistors had been removed), we anticipated that participants would exhibit retention of CO2 in the early stages of exercise in both 9K and 15K. Indeed, the condition effect for VCO2 was significant (p = 0.017), where VCO2 in 15K was lower than SHAM (p = 0.016) and VCO2 in 9K trended lower (p = 0.093). The difference in VCO2 between the 9K and 15K conditions is most likely due to the variation in the manufacturer-recommended resistance cap configuration at these 2 settings.

VE/VO2 and VE/VCO2 in 9K and 15K were ~20% lower than SHAM throughout exercise (all p < 0.001). As shown (Figure 4), there was no difference in VE/VO2 or VE/VCO2 between 9K and 15K (p = 0.906 and 0.587; respectively). Reduced ventilatory equivalencies for VO2 and VCO2 during matched workload treadmill exercise are indicative of an increased ventilatory efficiency throughout exercise in 9K and 15K.

Cardiovascular, Hemodynamic, and Psychological Responses

For HR, the main effect of exercise time was significant (p < 0.001), but there was no difference among study conditions (p = 0.285), and the interaction effect was also not significant (p = 0.585) [Figure 5]. Despite this lack of effect on HR, the commercial device did cause hypoxemia, as reflected by the significant main effect for study condition (p < 0.001) [Figure 5]. Although participants’ SpO2 responses averaged 94.2 ± 0.2% in the Sham condition, they fell to 91.0 ± 0.2% when the commercial device was worn in the 9K configuration (p < 0.001) and 89.3 ± 0.2% when the device was worn at 15k (p < 0.001). From a statistical perspective, participants’ SpO2 responses across the 9k and 15k conditions were also different (p = 0.025). However, post hoc analysis did not reveal any difference among these conditions at any of the fifteen individual time points we examined (all p > 0.050). Therefore, the practical significance of any difference in hypoxemia between the 9k and 15k device configurations is questionable.

Participants perceived exercise in the mask as making exercise more difficult, as their RPEs were higher throughout exercise when the device was worn in both the 9k and 15k conditions (p < 0.001) [Figure 6]. Their exercise anxiety in these conditions was also higher, as evidenced by their elevated scores on the BAI (p = 0.007) [Figure 6]. However, there was no difference between the two mask configurations on either variable (all p > 0.050). Given that all subjects were able to complete the full 20 minutes of exercise in both experimental conditions and the highest RPE (15.3 ± 1.3) and BAI (7.6 ± 1.9) they attained were well shy of maximal levels, we conclude that overall the addition of this mask to treadmill exercise commenced at the workload equivalent to 60% VO2max was well tolerated.

Discussion

We hypothesized that the elevation training mask examined in this study would cause inadequate hyperventilation that led to arterial hypoxemia, but the overall magnitude of the hypoxic stimulus would be minimal and would not vary across different manufacturer-defined altitude settings. As such, we further hypothesized that the mask would cause subjects to experience some psychological discomfort, but overall exercise in the mask would be well tolerated. The principal findings of this study supported these hypotheses.

Stated simply, hypoxemia occurred secondary to the combination of the reduced breathing frequency imparted
by the masks resistors, and the rebreathing of expired CO2 that had been allowed to accumulate in the mask's large dead space area (~240 ml). In traditional CO2 rebreathing experiments, the accumulation of metabolic CO2 during exercise is known to increase ventilatory drive by way of the central and peripheral chemoreceptors (7,19). Acute altitude exposure also increases VE (17). However, in this study, the mask’s 3 resistance caps impeded inspiratory and expiratory flow, causing participants to reduce VE as a consequence. This led to reductions in the ventilatory equivalents for oxygen uptake and carbon dioxide removal as well as reductions in peripheral oxygen saturation, the combination of which caused subjects to report increased ratings of perceived exertion and higher scores on the BAI.

Although the mechanism by which these acute exercise alterations were afforded differs from conventional altitude training, similar responses have previously been described in environmental hygiene scenarios where external respirators are worn (26). In those situations, the addition of inspiratory and expiratory resistance, as well as dead space, contributes to reductions in R and a small increase in VT (2,16). The net effect of these changes is a small reduction in VE that reduces endurance exercise capacity (6,32) and limits maximal exercise performance (22). Although increased fluctuations in thoracic pressure have also been reported, the additional work of breathing attributed to ventilators is small and has not been shown to influence HRs during submaximal exercise (21). In contrast, respirators are known to reduce the visual field and contribute to generalized stress and discomfort during work performance (32), similar to what was shown during exercise in this study.

**Practical Applications**

The training mask examined in this study did provide for RMT and cause hypoxemia when it was worn during endurance exercise that was undertaken at a workload equivalent to 60% VO2peak. Importantly, the magnitude of hypoxemia was much less than what occurs at terrestrial altitude (10), and there was virtually no difference between the two altitude resistance mask configurations that were tested. Elevations in RPE and anxiety were also modest, suggesting that the use of this mask may be well tolerated by endurance athletes during submaximal exercise.

However, just because something can be used does not mean that it should be. In that regard, although this study establishes proof of concept for the use of training mask during endurance exercise, it is important to discern the select scenarios in which such action might prove useful. Clearly the training mask should not be adopted full-time. Reductions in sustained exercise tolerance (6) and maximal exercise capacity (22) would reduce training quality and negatively impact endurance exercise performance. However, given that the weekly training volume of a collegiate endurance runner ranges between 100 and 160 km and requires 10–15 hour to complete (9), it would be seen that the mask could be incorporated part-time. Although it remains to be seen, this might contribute to an increased sport specificity of RMT-mediated adaptations like those shown in the Tong et al. study and/or remove the need for stand-alone RMT to be performed.

Most endurance athletes naturally adhere to a polarized training model (24), consisting of ~80% of training being conducted at low intensity (<65% of peak power output) and ~20% at high intensity. Such training is already known to elicit superior adaptations in maximal oxygen consumption, running economy, and run performance (8,18,28). Perhaps incorporating the training mask into some of this low-intensity conditioning may further these benefits.

**Acknowledgments**

This research was supported by the University Kilgore Research Center (Grant# RE-00997). All authors declare that they have no conflict of interest. The results of this study do not constitute endorsement of the product by the National Strength and Conditioning Association or the JSCRT.

**Author Contributions:** M. Kuennen and J. Granados conceptualized the study. M. Kuennen and J. Granados wrote the article. T. Gillum, W. Castillo, and K. Christmas provided edits. All authors contributed to data collection and analysis.

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“Functional” Respiratory Muscle Training


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