Original Article

Effects of high-intensity interval training while using a breathing-restrictive mask compared to intermittent hypobaric hypoxia

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ABSTRACT

Background: Previous studies of the Elevation Training Mask (ETM) describe comparisons between groups using the ETM and controls for effects on aerobic performance. However, comparisons have not been made to intermittent hypoxic training (IHT). Further, how the ETM impacts exercise economy is unknown. Therefore, we sought to determine the effects of training with the ETM compared to IHT on aerobic performance and cycling economy. Methods: Thirty participants were randomized into an ETM, IHT, or control group (n = 10 each). Pre- and post-testing occurred using a ramp VO_2max test on a cycle ergometer allowing submaximal power output (PO) measures of economy. Economy was measured using POs of 100, 125, and 150W. High-intensity cycling interval training (HIIT) occurred 2x/week for 30 min/session for six weeks. Sessions were 20 min of HIIT (30s at 100% peak power output (PPO) of pre VO_2max, 90s active recovery at 25W, 10 bouts) with a 5-minute warm-up and cool-down. Repeated measures ANOVA was used for statistical analyses. RESULTS: All participants improved VO_2max, PPO, and PO at ventilatory threshold 2 pre- to post-training ($p < 0.05$). Interactions between groups showed that the RER for the IHT group increased at 100W and 125W, and decreased at RERmax pre- to post-training while the ETM group showed the opposite response ($p < 0.05$). Conclusion: The ETM and IHT groups performed similarly to the control at maximal and submaximal effort following six weeks of training. The IHT group, but not the ETM group, experienced an increased glycolytic energy shift during submaximal exercise. **Keywords:** Elevation training mask; Altitude; Cycling economy.

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INTRODUCTION

Since the 1968 Mexico City Olympic Games, altitude training has become a frequently used method to improve aerobic performance (i.e. maximal oxygen consumption [VO_2max]) (Balke et al., 1965; Levine, 2002). However, traveling to altitude can be financially demanding and beyond the resources of most individuals (Levine, 2002). In efforts to make altitude training more accessible, various techniques and products were created such as nitrogen houses, hypoxia tents, and hypoxia masks. All of these methods aim to simulate a hypoxic environment through intermittent hypoxic training (IHT) (Levine, 2002).

Intermittent hypoxic training provides discontinuous hypoxia under normobaric (sea level) or hypobaric (atmospheric pressures at altitude) conditions to stimulate acclimatization. This allows individuals living at low altitude to be exposed to short periods of hypoxia simulating a higher altitude (2500 – 3850 m) (Hamlin et al., 2009). The aim of IHT is to improve aerobic performance observed when traveling to altitude. These adaptations target greater levels of erythropoietin, and increases in red blood cell mass, oxygen-carrying capacity, and aerobic performance upon returning to sea-level (Levine, 2002; Levine & Stray-Gundersen, 1997; Stray-Gundersen, Chapman, & Levine, 2001). Although increased red blood cell mass does not always occur with IHT, alternate adaptations of IHT exist. These include improvements to capillary density, glucose transport, glycolysis, and pH regulation (Gore et al., 2007). Currently, the two strategies for IHT are, 1) hypoxic exposure at rest while training occurs in normoxia, or 2) hypoxic exposure during exercise to promote a training stimulus while rest days occur in normoxia (Levine, 2002).

Previous researchers using IHT have exposed trained participants to hypoxia at rest while continuing scheduled training programs in normoxia to assess changes in running economy (Katayama et al., 2003; Katayama et al., 2004; Truijens et al., 2008); however, the results are conflicting. Truijens et al. (2008) found no changes in submaximal VO_2 in trained runners and swimmers when exposed to hypobaric hypoxia for 15 hours per week, for four weeks. However, two studies by Katayama et al. (2003, 2004) showed decreases in submaximal VO_2 in trained runners after IHT. One study by Katayama et al. (2004) exposed the runners to normobaric hypoxia three hours per day for 14 consecutive days and 15 hours per week for four weeks. The other study by Katayama et al. (2003) used hypobaric hypoxia exposures for 90 minutes per day, three times each week for three weeks. Further, in these studies, they used two different tests to determine running economy: continuous increases in speed and grade, and steady-state running (Katayama et al., 2003, 2004).

Other researchers found IHT improved anaerobic and aerobic performance when exposed to hypoxia during training rather than during a resting state. Czuba et al. (2017) had trained swimmers perform high-intensity land training specific to swimming while exposed to normobaric hypoxia for 45 – 55 minutes each session, twice a week for four weeks. The swimmers demonstrated improved post-training anaerobic performance on a Wingate test after four weeks of training. Absolute maximal workload increased from pre- to post-training by 7.4%, mean power output by 11.8%, and VO_2max by 6.9% (Czuba et al., 2017). In another study, elite cyclists performed high-intensity training (95% of lactate threshold) while exposed to normobaric hypoxia for 30 – 40 minutes each day, three days per week for three weeks. Similar to previous studies, the researchers reported increased cycling VO_2max (4.0%) and maximal workload (6.6%) (Czuba et al., 2011). Interestingly, even with different modes of exercise, trained swimmers and cyclists demonstrate improvements in performance when exercising in normobaric hypoxia (Czuba et al., 2011; Czuba et al., 2017). Thus, a key factor to potentiate improvements to physical performance during IHT could be the use of high-intensity exercise (McLean et al., 2014). While previous literature described using trained individuals for exercise in hypoxia, high-intensity exercise provides enjoyment to less fit and sedentary individuals (Bartlett et al., 2011). However, most athletes and others looking to improve exercise performance lack the resources to use a hypobaric chamber and hypoxic tents. Instead, a possible alternative to reap the benefits of hypoxic training could be to use the Elevation Training Mask 2.0 (ETM) (Training Mask LLC, Cadillac, MI).

The ETM is a mask covering the nose and mouth restricting respiration with adjustable valves. Through the use of different types of valves, the company states the mask simulates breathing at altitudes ranging from 914 m to 5486 m to enhance athletic performance (Granados et al., 2016; Porcari et al., 2016). Currently, four separate studies observed the effects of wearing the ETM during training protocols lasting 6 – 7 weeks (Biggs et al., 2017; Porcari et al., 2016; Sellers et al., 2016; Warren et al., 2017). Participants in these studies were either moderately trained performing cycling or running HIIT or cadets in the reserve officers' training corps (ROTC) performing mandatory physical training (Biggs et al., 2017; Porcari et al., 2016; Sellers et al., 2016; Warren et al., 2017). The results of these studies showed equivocal findings regarding the ability of the ETM to stimulate an increase in VO_2max with training compared to not wearing the ETM (Biggs et al., 2017; Porcari et al., 2016; Sellers et al., 2016; Warren et al., 2017). However, the two training studies reporting that VO_2max increased post-training from wearing the ETM concluded that there were no significant differences between the control and ETM groups (Biggs et al., 2017; Porcari et al., 2016). A potential reason for differences in VO_2max observations between the four published studies is a possible variability in physical effort between HIIT and mandatory physical training. Further, Porcari et al. (2016) found that cycling HIIT improved peak power output (PPO) in both control and ETM groups. However, only the ETM group improved their aerobic and anaerobic thresholds and respective power outputs (PO) from pre- to post-training; but did not differ from the control. Only the percent change for anaerobic threshold and PO at anaerobic threshold were significantly different from the control. Finally, Porcari et al. (2016) found the ETM group had significantly lower blood oxygen saturation percentages (SpO_2) during training compared to the control (94% and 96%, respectively). This finding was supported by Granados et al. (2016) who changed the ETM restrictive breathing setting to simulate 2743 m and 4572 m while running at 60% VO_2max compared with a control trial. They found that SpO_2 also decreased from 94% to 91% and 89% for the control, 2743 m and 4572 m ETM settings, respectively (Granados et al., 2016). Both studies suggest the decrease in SpO_2 resulted from re-breathing carbon dioxide (CO2) and that SpO_2 did not change as a result of the simulated high altitude (Granados et al., 2016; Porcari et al., 2016). Despite using multiple levels of simulated altitude, none of the studies compared an ETM group with a group performing IHT in hypobaric hypoxia.

Therefore, the purpose of this study was to determine the effects of wearing the ETM compared with IHT in hypobaric hypoxia using a similar cycling HIIT protocol implemented by Porcari et al. (2016). A secondary purpose aimed to determine changes in economy (submaximal VO_2, heart rate [HR], respiratory exchange ratio [RER]) after six weeks of cycling HIIT with the ETM compared with IHT in hypobaric hypoxia, as economy has yet to be assessed with the ETM device. It was hypothesized that the group performing hypobaric IHT would demonstrate a greater increase in VO_2max after six weeks of cycling HIIT compared to the ETM and control groups. A second hypothesis was that the ETM group would perform similarly to the control. Finally, it was hypothesized that those wearing the ETM and performing hypobaric IHT would demonstrate decreased submaximal VO_2, HR, and RER, indicating improved cycling economy, compared to the control.

MATERIAL AND METHODS

Participants

Thirty (15 males, 15 females) participants volunteered to participate in this study (see Table 1) after seeing a posted flyer. Only participants with no known cardiovascular, pulmonary, renal, or metabolic disease could participate. Further, blood pressure was measured prior to starting each session to ensure the individual was not hypertensive (≥ 140/90 mmHg). If the participant was hypertensive, the visit was rescheduled. All subjects had not participated in a cycling training program for the past six months. However, they currently exercised 3.6 ± 1.6 days per week with 2.7 ± 1.5 days being moderate intensity and 1.3 ± 1.3 days being vigorous intensity. Each participant provided written informed consent approved by the University of New Mexico's Office of the Institutional Review Board for human subject research.

Table 1. Physical characteristics for each group (n=10).

Characteristics	CON Group	ETM Group	IHT Group
Age (years)	24.4 ± 5.1	23.1 ± 2.9	23.1 ± 3.6
Height (m)	1.7 ± 0.1	1.7 ± 0.1	1.7 ± 0.1
Pre-Weight (kg)	87.1 ± 18.7*	69.1 ± 18.7	72.2 ± 7.8
Post-Weight (kg)	86.8 ± 18.5*	69.0 ± 17.4	72.9 ± 9.1
VO_2max ($mL \cdot kg^{-1} \cdot min^{-1}$)	33.5 ± 9.6	40.2 ± 8.7	39.9 ± 11.2
PPO (watts)	215.0 ± 46.0	211.7 ± 42.6	238.1 ± 48.8

*Table note: Values are mean ± SD. CON = Control, ETM = Elevation Training Mask, IHT = Intermittent Hypoxic Training, m = meters, kg = kilogram, VO_2max = maximal oxygen consumption, mL = milliliters, min = minute, PPO = peak power output. * denotes significant difference between CON and ETM groups (p = 0.040).*

Experimental Design

All participants completed pre- and post-training VO_2max tests on an electronically braked cycle ergometer (Excalibur Sport, Corval Lode B. V., Lode Medical Technology, Groningen, Netherlands). The VO_2max tests occurred within one week, but no sooner than 48 hours after starting and ending the training protocol. Participants trained twice a week for six weeks on a Monark 828E Ergomedic cycle ergometer (Monark Exercise AB, Varberg, Sweden) based on the protocol described by Porcari et al. (2016). Training sessions consisted of a five-minute warm-up and cool-down at 0.5 kg resistance with a self-selected pace, and 20 minutes of HIIT. Each participant completed 10 intervals of 30 seconds pedalling at 100 rpm at their PPO (determined from their VO_2max test) and 90 seconds of active recovery pedalling at their own pace at 0.5 kg resistance.

Participants were randomized into three groups (10 participants each): an ETM group (5 females and 5 males), an IHT group (4 females and 6 males), and a control group (CON) (6 females and 4 males). The ETM group performed 20 minutes of HIIT while wearing the ETM using the lowest resistive breathing setting (914 m) in a natural altitude environment of 1570 m (totalling 2484 m, according to ETM manufacturer settings). The IHT group performed 20 minutes of HIIT in a hypobaric altitude chamber (Special Devices Center Office of Naval Research, Guardite Corporation, Chicago, IL) simulating 2484 m of elevation. The CON group performed 20 minutes of HIIT without the ETM and without additional elevation (Albuquerque, New Mexico = 1570 m).

All participants had at least 48 hours of rest between training sessions. Participants were instructed to get at least eight hours of sleep, refrain from strenuous physical activity for 24 hours, alcohol for eight hours, and drink plenty of fluids prior to arriving for each testing or training session. All participants were instructed to maintain similar daily living activities throughout the duration of their participation.

Procedures

Maximal Oxygen Consumption Test

Prior to each VO_2max test, the participants' height and body weight were measured using a stadiometer (seca Heavy Plastic Measuring Rod 216, Hamburg, Germany) and weight scale (seca Floor Scale 884, Hamburg, Germany), respectively. Participants performed a ramp VO_2max test on an electronically braked cycle ergometer to volitional fatigue. All participants completed a five-minute warm-up and cool-down at 50 and 40 watts for males and females, respectively. Males performed a 25-watt ramp protocol while females performed a 20-watt ramp protocol. Breath-by-breath expired gas analysis occurred using a Parvo Medics TrueOne Metabolic System (Parvo Medics, Sandy, UT) with a Hans-Rudolph mouthpiece and valve apparatus allowing unidirectional air flow and a nose clamp. The metabolic system was calibrated using the manufacturer guidelines. Participants wore a Polar FT1 heart rate monitor (Polar, USA). Data collected during the VO_2max test included: VO_2 (mL · kg^{-1} · min^{-1}) (VO_2max required two of the four criteria to be met: respiratory exchange ratio (RER) > 1.10, within ± 10 bpm of age-predicted maximal HR, VO_2plateau of ≤ 150 ml · min^{-1}, or ratings of perceived exertion (RPE) > 17), PPO, heart rate (HR), respiratory exchange ratio (RER), and RPE (6-20 Borg scale) (Borg, 1982). Expired ventilation (VE) and ventilatory equivalents for oxygen and carbon dioxide (VE/ VO_2 and VE/VCO_2, respectively) were calculated after the VO_2max test. In addition, submaximal VO_2, HR, and RER were recorded at 100, 125, and 150 watts to determine cycling economy. All breath-by-breath data were smoothed using 11-breath averaging (Robergs, 2001). Finally, VE/ VO_2 and VE/VCO_2 were graphed over time to determine ventilatory threshold 2 (VT2). This was defined as the first obvious increase in VE/VCO_2 with a subsequent increase in VE/ VO_2 (Binder et al., 2008). Further, two researchers independently analysed the determination of VT2 and if there was a disagreement, a discussion occurred to decide the best VT2. Afterward, power output (PO) and VO_2 were recorded at VT2 (PO at VT2 and VO_2 at VT2, respectively).

Training Session Measures

During each training session, HR and RPE (0-10 Borg scale) (Borg, 1982) were recorded immediately after each 30-second high-intensity cycling bout. Ratings of perceived exertion were used to incorporate progressive overload during training. For the CON group, if the RPE for all intervals was ≤ 5 during two consecutive training sessions, then the resistance was increased by 0.5 kg. For the IHT and ETM groups, if the RPE for all intervals was ≤ 7 during two consecutive sessions, then the resistance was increased by 0.5 kg. This was based on the findings of Porcari et al. (2016) who reported that RPE increased by two points on the scale for the same workload when wearing the ETM. Further, the average cycling resistance over the two training sessions was recorded for each week.

In weeks two, four, and six, blood lactate (BLa) (Lactate Plus, Nova Biomedical, Waltham, MA) was measured in duplicate at the ear immediately following the 10th 30-second high-intensity cycling bout. This occurred for both training sessions on the specified weeks. The BLa analyser was calibrated according to manufacturer's guidelines. Finally, SpO_2 was measured during weeks four and six using a finger pulse oximeter (Nonin Go2 Achieve Pulse Oximeter, Nonin Medical Inc., Plymouth, MN). This was recorded in the last five seconds of the 10th, 30-second high-intensity cycling bout for both training sessions during these specific weeks.

Statistical Analyses

All statistical analyses were performed using SPSS (IBM SPSS Statistics Version 19). Standard descriptive statistics were used to characterize and evaluate the participants' training responses. Repeated measures ANOVA using both within and between-subject analyses determined differences between pre- and post-training and between the CON, ETM, and ATL groups. If sphericity was violated, the Greenhouse-Geisser correction was used. For significant F-ratios, Tukey's HSD post-hoc procedure was used for pairwise comparisons. The alpha for statistical significance was set at $p < 0.05$.

RESULTS

Maximal Oxygen Consumption Test

All the participants achieved VO_2max except one individual (only one criterion was met). For this participant's post-test, only the criterion of VO_2plateau was met. The results from the pre- and post- VO_2max tests for each group can be found in Table 2. There were significant increases in VO_2max from pre- to post-training for all groups ($F(1,27) = 6.45$, $p = 0.017$). However, there were no differences between groups nor an interaction. All three groups significantly improved their PPO from pre-to post-training ($F(1,27) = 35.42$, $p < 0.001$). Statistical analysis indicated there was not a significant difference between groups nor was there an interaction for PPO. At volitional exhaustion, the participants' HRmax and RERmax did not differ from pre- to post-training or between groups. However, there was an interaction between the groups and RERmax ($F(2,27) = 3.51$, $p = 0.044$), but not HRmax.

Table 2. Pre and post-training maximal oxygen consumption test results for all three groups.

	VO_2max	HRmax	RERmax‡	PPO	PPO at VT2	VO_2 at VT
CON						
Pre	33.5 ± 9.6†	184 ± 12	1.24 ± 0.07	215.0 ± 46.0†	191.6 ± 39.3†	30.2 ± 8.1
Post	35.0 ± 11.9	186 ± 13	1.22 ± 0.13	234.5 ± 57.0	200.8 ± 53.6	30.2 ± 9.6
ETM						
Pre	40.2 ± 8.7†	185 ± 8	1.26 ± 0.13	211.7 ± 42.6†	180.9 ± 33.6†	35.6 ± 7.8
Post	41.3 ± 9.0	184 ± 9	1.31 ± 0.13	237.3 ± 39.7	204.9 ± 38.8	37.3 ± 7.0
IHT						
Pre	39.9 ± 11.2†	187 ± 15	1.30 ± 0.11	238.1 ± 48.8†	206.0 ± 41.9†	36.2 ± 8.9
Post	41.8 ± 10.0	186 ± 12	1.14 ± 0.22	255.4 ± 46.6	221.7 ± 45.2	37.5 ± 9.2

Table note: VO_2 = oxygen consumption in $ml \cdot kg^{-1} \cdot min^{-1}$, HR = heart rate in $b \cdot min^{-1}$, PPO = peak power output in watts, VT2 = ventilatory threshold 2, W = watts, ml = milliliters, kg = kilogram, min = minute, b = beats, CON = Control, ETM = Elevation Training Mask, IHT = Intermittent Hypoxic Training. † denotes a significant difference between pre and post ($p < 0.05$). ‡ denotes a significant interaction among the groups ($p = 0.044$).

After data collection, the data for VE/ VO_2 and VE/VCO_2 were analysed to determine PO and VO_2 at VT2. Power output at VT2 significantly increased from pre- to post-training ($F(1,27) = 14.63$, $p = 0.001$) (Table 2). However, there were no differences between groups nor was there an interaction between PO at VT2. For

VO_2 at VT2, there were no differences from pre- to post-training or a difference between groups nor was there an interaction (Table 2).

Finally, there were no changes in participants' body weight from pre- to post-training for the CON, ETM, or IHT groups nor an interaction between groups and body weight (Table 1). However, there was a significant difference between groups ($F(2,27) = 3.64$, $p = 0.040$). The post-hoc test indicated only the CON group weighed more than the ETM group ($p = 0.043$).

Cycling Economy

After the VO_2max test, the data for submaximal VO_2, HR, and RER at 100, 125, and 150 watts were analysed to assess cycling economy (Table 3). At 100 and 150 watts during the VO_2max test, none of the groups displayed a significant change from pre- to post-training VO_2. However, there was a significant difference pre- to post-training for VO_2 at 125 watts ($F(1,27) = 6.55$, $p = 0.016$) (Table 2). Further, VO_2 at 100, 125, and 150 watts did differ between groups ($F(2,27) = 6.59$, $p = 0.005$, $F(2,27) = 5.34$, $p = 0.011$, and $F(2,27) = 5.61$, $p = 0.009$, respectively). The post-hoc test indicated that only CON and ETM differed for VO_2 at 100, 125, and 150 watts ($p = 0.003$, 0.008, and 0.007, respectively). Finally, no interactions for VO_2 at 100, 125, and 150 watts were observed.

Table 3. Pre and post-training submaximal values determined from the maximal oxygen consumption test for all three groups.

	VO_2 at 100 W	VO_2 at 125 W	VO_2 at 150 W	HR at 100 W	HR at 125 W	HR at 150 W	RER at 100 W‡	RER at 125 W‡	RER at 150 W
CON									
Pre	20.0 ± 4.6*	23.2 ± 5.2*†	25.4 ± 5.6*	142.2 ± 24.3†	152.4 ± 23.6†	163.7 ± 24.1†	0.96 ± 0.07	1.02 ± 0.07†	1.08 ± 0.08†
Post	18.9 ± 3.5*	21.0 ± 3.8*	24.1 ± 4.8*	136.5 ± 21.3	146.0 ± 22.1	155.2 ± 21.8	0.98 ± 0.07	1.04 ± 0.10	1.06 ± 0.11
ETM									
Pre	24.7 ± 3.4	27.6 ± 3.1†	31.1 ± 4.0	153.4 ± 19.9†	161.4 ± 18.6†	169.3 ± 18.1†	1.02 ± 0.10	1.07 ± 0.09†	1.13 ± 0.12†
Post	23.6 ± 1.5	26.1 ± 3.1	29.8 ± 3.2	140.8 ± 22.4	150.9 ± 21.9	159.0 ± 20.8	0.96 ± 0.08	1.02 ± 0.09	1.08 ± 0.11
IHT									
Pre	22.5 ± 3.8	25.4 ± 4.3†	28.0 ± 4.2	142.8 ± 23.4†	152.0 ± 24.2†	160.7 ± 24.4†	0.99 ± 0.09	1.02 ± 0.10†	1.09 ± 0.11†
Post	20.7 ± 2.7	23.8 ± 2.1	26.7 ± 2.8	135.4 ± 25.2	145.8 ± 25.4	153.5 ± 26.8	1.04 ± 0.13	1.19 ± 0.16	0.97 ± 0.15

*Table note: VO_2 = oxygen consumption in $ml \cdot kg^{-1} \cdot min^{-1}$, HR = heart rate in $b \cdot min^{-1}$, PPO = peak power output in watts, VT2 = ventilatory threshold 2, W = watts, ml = milliliters, kg = kilogram, min = minute, b = beats, CON = Control, ETM = Elevation Training Mask, IHT = Intermittent Hypoxic Training. * denotes a significant difference between the Control and ETM groups ($p < 0.05$). † denotes significant differences between pre and post ($p < 0.05$). ‡ denotes a significant interaction among the groups ($p < 0.05$).*

Next, HR at 100, 125, and 150 watts significantly decreased from pre- to post-training ($F(1,27) = 12.20$, $p = 0.002$, $F(1,27) = 11.11$, $p = 0.003$, $F(1,27) = 12.14$, $p = 0.002$, respectively). However, there were no between-group differences for HR at 100, 125, and 150 watts. Further, no interactions were observed for submaximal HR at any workload.

Finally, RER at 100 watts did not significantly differ from pre- to post-training. However, RER at 125 and 150 watts significantly differ from pre- to post-training ($F(1,27) = 4.86$, $p = 0.036$ and $F(1,27) = 12.20$, $p = 0.005$, respectively) (Table 3). Further, interactions between groups and RER at 100 and 125 watts occurred, but not RER at 150 watts ($F(2,27) = 3.82$, $p = 0.035$, $F(2,27) = 7.48$, $p = 0.003$, $F(2,27) = 1.63$, $p = 0.214$, respectively). Finally, RER at 100, 125, and 150 watts did not differ between groups.

Training Sessions

Cycling resistance during training significantly increased each week (206 – 291 watts), except from week 5 to 6 (256 – 291 watts), for all groups. Sphericity was violated so the Greenhouse-Geisser correction was applied ($F(1.6,42.1) = 39.75$, $p < 0.001$). All weeks were significantly different from each other ($p < 0.004$) except between weeks 5 and 6 ($p = 0.116$). However, there were no differences between groups nor an interaction.

The Greenhouse-Geisser correction was used for BLa (Table 4). There were no differences in BLa between weeks or between groups. Further, there was not an interaction between groups and BLa. Finally, there were no differences between weeks during training nor an interaction for SpO_2 (Table 4). However, there was a significant difference between groups ($F(2,27) = 11.18$, $p < 0.001$). The IHT group had significantly lower SpO_2 than both the CON and ETM groups ($p = 0.001$ for both), while CON and ETM did not differ ($p = 0.991$).

Table 4. Blood lactates for weeks two, four, and six, during six weeks of cycling high-intensity interval training.

	Week 2	Week 4	Week 6
Blood Lactate (mmol/L)			
CON	8.0 ± 2.1	8.3 ± 1.6	9.0 ± 2.5
ETM	7.2 ± 2.6	8.9 ± 1.9	10.0 ± 3.1
IHT	9.1 ± 2.1	9.3 ± 2.3	9.0 ± 2.7
Peripheral Oxygen Saturation (%)			
CON	__	94.0 ± 1.5	94.3 ± 1.5
ETM	__	93.8 ± 1.9	94.3 ± 2.2
IHT	__	91.2 ± 1.8*	90.7 ± 2.2*

*Table note: CON = Control, ETM = Elevation Training Mask, IHT = Intermittent Hypoxic Training, mmol = millimoles, L = liters, % = percent. * denotes significant difference comparing the IHT group to the other two groups (p = 0.001).*

DISCUSSION

This study found that the CON, ETM, and IHT groups did not differ on their VO_2max test performances after six weeks of HIIT training compared to baseline. In addition, submaximal HR decreased for all workloads and VO_2 and RER changed only for certain workloads. However, only submaximal VO_2 differed between the CON and ETM groups. Previous literature has noted a positive relationship between lean body mass and VO_2 (Buskirk & Taylor, 1957; Dehn & Bruce, 1972; Fleg & Lakatta, 1988). As some of the participants were sedentary, it is possible the CON group had more sedentary individuals and did not exhibit a similar lean body mass percentage (though not measured) than the other groups. This could have affected the group differences observed between the CON and ETM groups for VO_2 at specific workloads (100, 125, and 150 watts) at baseline and post-training.

Maximal Oxygen Consumption and Training Session Comparisons

The results of the current study were similar to those found by Porcari et al. (2016), with all groups increasing in VO_2max, PPO, and PO at VT2 after training, no difference in pre- to post-HRmax, and a lack of observed differences between groups for these measurements. No differences between the CON and ETM groups were expected as the current study used a protocol by Porcari et al. (2016); however, similar performances for the ETM and IHT groups were unexpected. Therefore, the hypothesis stating the ETM group would perform similarly to the CON group on the VO_2max test was accepted, but the hypothesis suggesting there would be a different between ETM and IHT groups was rejected. Another training study using the ETM observed no difference in VO_2max between a CON and ETM group after participating in a HIIT running protocol, although they did find a significant increase in predicted VO_2max in both groups (Biggs et al., 2017). However, training studies by Sellers et al. (2016) and Warren et al. (2017) failed to show a training effect such as improved VO_2max when participants used the ETM. The reason for the contrasting results may be explained by differing exercise intensities and exercise modes used for these studies. The present study, along with that of Porcari et al. (2016) and Biggs et al. (2017), used more traditional exercise modes (i.e. cycling and running) compared with Sellers et al. (2016) and Warren et al. (2017) who used military personnel training protocols. In a systematic review by McLean et al. (2014), it was reported that improvements in VO_2max from IHT requires the training intensity to be > 70% VO_2max. This would improve high-intensity exercise capacity such as that observed in the present study as the exercise portions of the HIIT during training sessions were performed at the participants' PPO from the pre- VO_2max with BLa ranging from 7.2 – 10.0 mmol/L. Additionally, weekly resistance progressively increased until the last week of training, suggesting that high-intensity exercise was maintained throughout the training program. In contrast, the possibility exists that the intensity of the military personnel training protocols used by Sellers et al. (2016) and Warren et al. (2017) provided an inconsistent training intensity, diminishing a significant training effect. Another consideration is the present study incorporated an IHT group as well as CON and ETM groups; whereas, the other studies used only CON and ETM groups (Biggs et al., 2017; Porcari et al., 2016; Sellers et al., 2016; Warren et al., 2017).

In the current study, the lack of differences between groups may be because the IHT group was not exposed to hypoxia for a sufficient duration to produce haematological changes. Roels et al. (2005) found that twice a week for seven weeks of IHT did not improve haematocrit and haemoglobin concentrations. Roels et al. (2005) suggested the hypoxic exposure time of 114 $min \cdot wk^{-1}$ was not sufficient enough to stimulate the desired increase in oxygen-carrying capacity related to living at moderate altitude (2500 m). Even though the IHT group demonstrated lower SpO_2 (91%) than the CON and ETM groups (94% for both), the IHT group only spent 60 $min \cdot wk^{-1}$ at lower oxygen saturation levels. This could explain why the IHT group performed similarly on the post-training VO_2max test as the other groups, as they did not have a sufficient stimulus to increase their oxygen-carrying capacity. However, the current study supports the findings by Czuba et al. (2011, 2017) that IHT when exercising in hypoxia can improve VO_2max and PPO. Finally, the hypothesis stating the IHT group would increase their VO_2max more than the ETM and CON groups was rejected. Since the CON group had similar results to the ETM and IHT groups from this six-week training study, the use of an ETM or IHT was no more effective than the control condition.

Cycling Economy

To further the research on ETMs, this study also analysed potential economy changes of VO_2, HR, and RER during submaximal cycling. This study found that VO_2 at submaximal workloads only changed pre- to post-training at 125 watts, and there were no differences between groups.

This was in disagreement with the original hypothesis as only one submaximal workload showed a decrease in VO_2. If a decreased VO_2 at all submaximal workloads had been observed, this would have been advantageous for the participants' endurance performance because they would have been exercising at a lower percentage of their VO_2max for any given work rate, ultimately becoming more economical (Katayama et al., 2004). The contradictions in results from this study could be from the differences in IHT strategies used. In the Katayama et al. (2003, 2004) individuals maintained their regular training programs at sea level and were exposed to hypoxia during rest. Therefore, exercise intensity would not have been impaired as exercise was performed in normoxic conditions (Fulco et al., 1998). There were differences between these studies and the present study: only the present study had participants exercise under hypoxic conditions and economy measurements should occur during steady state exercise. Therefore, a limitation of the present study was the economy measurements were analysed during a ramp protocol where intensity continuously increased rather than at steady state.

Interestingly, the present protocol resulted in significant changes in pre- to post-training submaximal HR and RER without changes in VO_2 for all workloads. Submaximal HR decreased for all groups at 100, 125, and 150 watts. The results for HR were similar to those reported by Katayama et al. (2004), who found submaximal HR decreases with a decrease in submaximal VO_2 after training. However, the data show that RER only changed pre- to post-training at 125 and 150 watts. Further, there were interactions between RER and the three groups at 100 and 125 watts and RERmax, but not at 150 watts. The interaction suggests RER increased for the IHT group and slightly increased for the CON group from pre- to post-training at 100 and 125 watts while the ETM group decreased. In addition, RERmax decreased for the IHT groups and slightly decreased for the CON group but increased for the ETM group. At submaximal workloads, an increase in RER after IHT is consistent with previous literature (Katayama et al., 2004). Katayama et al. (2004) reported a non-significant ($p = 0.07$) increase in RER during normoxic submaximal running after resting in hypoxia during IHT. Therefore, to observe a significant increase in RER, participants may need to perform high-intensity exercise in a hypoxic environment during IHT. Under hypoxic conditions, there is a transition from fatty acid oxidation towards the metabolism of glucose, a more efficient fuel source for energy production (Gore et al., 2001). The shift toward glucose use possibly occurred because exposure to high altitude during exercise resulted in increased glycolytic flux (Brooks et al., 1998). Therefore, this increase in RER suggests that the IHT group utilized glucose rather than fatty acids for more efficient energy production at submaximal workloads of 100 and 125 watts (Gore et al., 2001), whereas the ETM groups did not and continued to have a lower RER until RERmax.

A possible reason that submaximal HR and RER changed independently of submaximal VO_2 could be explained by the duration of hypoxic exposure and ETM use. A limitation of the present study is that participants were only exposed to hypoxia or used the ETM one hour per week for six weeks (six hours). However, other studies exposed participants to hypoxia for 4.5 hours per week for three weeks (13.5 hours), three hours per day for 14 consecutive days (42 hours), and 15 hours for four weeks (60 hours) (Katayama et al., 2003, 2004; Truijens et al., 2008). If the present study required participants to use the ETM or increased the duration of hypoxic exposure, perhaps submaximal VO_2 could have decreased, providing stronger claims for economic changes. Another limitation of the present study is the assumption that the ETM adds 914 m of elevation to the current elevation. The estimated change in elevation for each flux valve claimed by the mask manufacturer has not been validated. For the present study, since Albuquerque's elevation is 1570 m, the ETM would hypothetically add 914 m to this elevation if this claim is correct. The IHT group cycled at 2484 m of simulated hypobaric hypoxia to equal the baseline altitude plus the 914m of elevation change theoretically added by the mask. Another potentially confounding variable is that the current literature on the ETM and IHT made their measurements at sea level; whereas, the present study performed measurements at 1570m (Biggs et al., 2017; Granados et al., 2016; Katayama et al., 2003, 2004; Porcari et al., 2016; Sellers et al., 2016; Truijens et al., 2008; Warren et al., 2017). This difference makes direct comparisons to previous literature more difficult. However, all participants in the present study were acclimatized to Albuquerque's elevation for at least six months prior to starting this study to ensure all participants were at their physiological baseline for this altitude. A final limitation of the study is the differences in body weight between the CON and ETM groups. This possibly resulted in the differences between groups for submaximal VO_2; however, participants were randomized to groups prior to any testing occurring.

CONCLUSION

In conclusion, both the ETM and IHT groups performed similarly on a VO_2max test compared to a CON group following six weeks of HIIT cycling. Furthermore, using the ETM or IHT did not inhibit increases in VO_2max as all three groups showed improvements. Some changes in cycling economy were observed during the VO_2max test, though these should be interpreted with caution as they were not measured during steady-state exercise. Submaximal HR decreased for all three groups, but submaximal VO_2 changed only from pre- to post-training for just one submaximal workload. Finally, although no differences were observed between groups, significant interactions between submaximal RER and the group condition suggested the IHT group experienced a shift toward increased glucose metabolism for more efficient fuel production; however, the ETM group did not experience a similar shift in substrate utilization. This work contributes to the current literature suggesting the ETM is not a simulator of hypobaric hypoxia (Porcari et al., 2016). In addition, this research observed changes in aerobic performance and cycling economy in individuals using the ETM at altitude rather than sea level. Finally, future researchers should continue analysing training adaptations when using the ETM by determining changes in running economy and during resistance exercise.

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CONFLICT OF INTEREST

The authors state there were no conflicts of interest related to this study.

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