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Effect of a high-intensity short-duration cycling elevation training mask on $\dot{V}O_{2max}$ and anaerobic power. A randomized controlled trial.

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Abstract

This study investigated the effect of high-intensity interval training (HIIT) cycling elevation training mask (ETM) in moderately trained participants on both aerobic ($\dot{V}O_{2max}$) and anaerobic power performance. Sixteen participants, five females (25.8 ± 7.6 years) and eleven males (22.2 ± 3.5 years) took part in this randomized controlled trial. Participants were assigned to the experimental group (ETM, n = 8 participants) wearing an ETM or the control group (CON, n = 8 participants) without the ETM. $\dot{V}O_{2max}$ was determined during a standardized protocol using Cortex Metalyzer-3B on a cycle ergometer. Peak and average power were calculated a 30-second Wingate test. Participants completed 4-weeks (two sessions a week) of high-intensity cycle training. Each training session consisting of 4 separate bouts of 4-minutes of high-intensity cycling exercise. After the training period, ETM reported an increment in $\dot{V}O_{2max}$ (effect size (d) = 1.19), peak power (d = 0.77), and average power (d = 0.76). CON reported an increment only in $\dot{V}O_{2max}$ (d = 1.00). No-between group differences were found in any parameter (ANCOVA), therefore the two protocols should be considered equally effective. In conclusion, this study reported that both HIIT protocols significantly enhance $\dot{V}O_{2max}$ in a very short training period (4 weeks).

Key words: Training, Aerobic fitness, Performance, Environmental physiology, Sports

INTRODUCTION

The use of altitude and intermittent hypoxic training have received substantial attention in the research literature, primarily due to their effectiveness in generating performance gains from very short exercise bouts (1–3). Both simulated and genuine altitude training at moderate (2,000-3,000 m) to high elevations (3,000-4,500 m) are known to result in improvements in both central and peripheral adaptations that increase O_2 delivery and utilization (4–6), and that high-intensity interval training (HIIT) in hypoxia can be more effective than other training modes (*e.g.*, intermittent hypoxic exposure during rest) (7).

There are several different types of altitude training, including live-low train-high (LLTH), whereby an athlete will train in hypoxic hypobaric conditions and take rest in normoxic and normobaric conditions (8). Whilst other methods of altitude training exist, including live-high train-low (LHTL) and live-high train-high, they all aim to make use of reduced partial pressure of oxygen (ppO_2) to enhance the physiological adaptations seen with aerobic endurance training. However, many athletes will struggle to incorporate altitude training into their programme due to the cost of simulated hypobaric chambers, and/or the cost and time constraints of travel to real moderate to high altitude environments. According to earlier research, in order to gain the benefits of hypoxic training an athlete would need to remain at moderate to high altitude for ~2 to 3 weeks (5,9,10). However, this is not always practical so there are techniques designed to mimic the LLTH protocol of hypoxic exposure, including hypoxia tents and the more recent development of the elevation training mask (ETM).

The ETM covers the nose and mouth, restricting the amount of air, and so hypothetically O_2, an athlete can inspire using adjustable vents (11). Manufacturers of these ETM's claim that by using this hypoxic training technique alongside bouts of HIIT, athletes can achieve the same beneficial adaptations over shorter exercise durations without the cost of more elaborate simulated altitude apparatus, or the cost and time constrains of travel to moderate to high altitude environments. There currently exists very limited research that investigate the efficacy of ETM's (11–13). Existing research used training durations ranging from 6 to 7 weeks. However, we know that 4 weeks are usually sufficient to elicit physiological adaptations and maximal aerobic power ($\dot{V}O_{2max}$) and peak power performance improvements using normoxic environment HIIT (2,14). And to date ETM research has used varying types of training prescription to elicit aerobic and anaerobic improvements. As an example, Biggs et al. (2017) used a protocol of 4 sessions per week for 6-weeks, running at 80% of heart rate reserve and found improvements, *e.g.* in $\dot{V}O_{2max}$ (ES = 0.61). However, this study did not found a significant difference between the experimental protocol and control group, which could be related to the running bouts of the exercise that were only 90-second long (13). Recent meta-analyses suggest that HIIT in normoxic environments is most effective when protocols use bouts of over 2-minutes (standardized mean difference = 0.65–1.07, $p < 0.05$) (15). Both Pocari et al. (2017) and Bellovary et al. (2019) defined intensity using a percentage of peak power obtained during pre-testing (11,16). Whilst this was adjusted as the participants adapted to the protocol, using a percentage of peak heart rate is thought to be the most effective way to define intensities to see greater results from HIIT training in normoxic environments (17,18). Finally, Warren et al. (2017) had to rely on incredibly varied exercise stimuli, with training sessions ranging from sprints to bodyweight circuits and physical therapy sessions with male-only U.S. Marine Reserve Officers (19).

Therefore, the aim of this study is to investigate the effect of a HIIT short-duration cycling ETM in both male and female moderately trained subjects, for both aerobic and anaerobic power performance. The study will use a controlled training prescription that is widely recommended and evidenced for HIIT based physiological adaptation and performance improvements (15,17). We hypothesized that HIIT will lead to improvements in both aerobic and anaerobic power in both ETM and non-ETM (CON) groups, however, the authors did not have *a priori* between groups hypothesis.

METHODS

Participants

Five female (25.8 ± 7.6 years; 166 ± 4 cm; 76.2 ± 8.3 kg) and eleven male (22.2 ± 3.5 years; 178.8 ± 7.6 cm; 81.0 ± 17.6 kg) participants volunteered to take part in this study. ETM group and CON group had the following parameters: 22.6 ± 3.9 years, 173 ± 7 cm; 77.3 ± 7.9 kg, and 24.1 ± 5.8 years, 176 ± 10 cm; 81.0 ± 9.1 kg. After receiving University ethics approval (University of Suffolk, Ipswich, UK), and prior to any data collection sessions, all participants received written explanation of all study procedures, were offered an opportunity ask questions of the research team, completed a PARQ and subsequently provided written informed consent. All study procedures conformed to the guidelines set by the 2013 Declaration of Helsinki.

Procedures

The current study was designed to examine the effect of 4 weeks of cycling ETM on $\dot{V}O_{2max}$ and peak power. The primary outcome of this study was the $\dot{V}O_{2max,}$ while anaerobic power parameters were identified as secondary outcomes. This study used a randomized controlled trial design (RCT). Randomization was performed according to a computer-generated sequence. Participants were randomly assigned to one of two groups: one group (ETM, n = 8 participants) performed all training sessions whilst wearing an ETM (FDBRO Workout Fitness Mask, Henzhenshi Longhuaxinqu Guangshidianzichang, China), and the Control (CON, n = 8 participants) performed all training sessions without the ETM. The ETM's were set at the mid-point of air restriction for all sessions, which this FDBRO model claimed to be "3X Height: 2000 meters".

In this investigation, the statistical power of the sample was calculated a priori to verify that a power of 0.80 was respected. A sample size of 16 (using intention to treat analysis to avoid a decrement in participants) reported a power = 0.84 based on $p < 0.05$ and $f = 0.4$. Fourteen participants completed the study, whereas two participants of the control (CON) dropped out because of personal problems not related to the protocol. Sixteen participants (including the drop out) were considered in the final statistical analysis (intention to treat analysis) (20). Figure 1 reported CONSORT diagram showing participants through each stage of this RCT (21).

*****Please, Figure 1 here *****

All participants completed familiarization sessions for all study procedures, at least 48 hours prior to any data collection sessions. All participants had been participating in low volume, moderate intensity, mixed-mode (*e.g.*, cycling, running) exercise for at least 3 months prior to participating in this study. All were non-smokers and not taking any regular medication. Participants were requested to maintain normal dietary behaviors, and normal low volume, moderate intensity exercise training outside of prescribed study sessions. We controlled for potential diurnal variation in test results by completing all post-intervention tests within 1-hour of the pre-intervention test time of day.

Pre-Intervention Baseline Tests: Following anthropometric measurements participants completed a maximal aerobic power, $\dot{V}O_{2max}$ test. Breath-by-breath cardiopulmonary data were collected using a Cortex Metalyzer 3B (Cortex Biophysik GmbH, Leipzig, Germany) and an ergometer (Sport Excalibur lode, Groningen, Netherland) was used to administer the exercise protocol. Cycle power started at 25W, and increased by 25W every 60-seconds until volitional fatigue, or when VO_2 had plateaued despite increases in exercise intensity with a respiratory exchange ratio greater than 1.05 (22). Peak heart rate (HR_{peak}) was determined from this $\dot{V}O_{2max}$ test, to be used for training prescription described below, using a synced Polar T-31 coded transmitter (Polar Electro, Kempele, Finland) (23).
24-hours later, following a 5-minute warm-up on the Wattbike Trainer cycle ergometer (Wattbike, Nottingham, UK), participants completed a 30-second maximal effort Wingate test on the same cycle ergometer, separated by 5-minutes of active recovery. The Wingate test has been established as an effective tool in measuring both muscular power and anaerobic capacity in a 30-second time period (24). Peak power (Ppower) and average power (Apower) were calculated. The test was repeated after 5-minutes of active recovery to calculate the test-retest reliability.

Training Sessions: Participants then completed 4-weeks (two sessions a week) of high intensity cycle training using Wattbike cycle ergometer; training commenced within 1-week of the completion of the pre-intervention baseline tests. Each training session consisting of 4 separate bouts of 4-minutes of high intensity cycling exercise from 90% to 95% HR_{peak} determined from the baseline $\dot{V}O_{2max}$ test. Each 4-minute bout was separated by 3-minutes of active recovery at 70% HR_{peak} (2). The researchers involved in this study monitored the intensity of the cycling exercise and gave verbal feedback to the participants in order to maintain the appropriate intensity. The training sessions were identical for both training groups, apart from one group wore an ETM, and CON did not, for all of the 8 training sessions in total.

Post-Intervention Tests: All procedures described in the pre-intervention baseline test section were repeated, between 48-hours and 1-week, following the final training session.

Statistical Analyses

The Shapiro-Wilk test was used to determine whether data were normally distributed. Data were presented as mean ± standard deviation (SD). Test-retest reliability (two-way mixed model) was assessed using an intraclass correlation coefficient (ICC) and interpreted as follows: ICC > 0.9 = *excellent*; 0.9 > ICC > 0.8 = *good*; 0.8 > ICC > 0.7 = *acceptable*; 0.7 > ICC > 0.6 = *questionable*; 0.6 > ICC > 0.5 = *poor*; ICC < 0.5 = *unacceptable* (25). Smallest worthwhile change (SWC) calculated as 0.2 multiplied by the between-subject SD was reported. Intention to treat analysis was adopted (every participant was considered in the final analysis) (26). Levene's test was used to verify the equality of variance. Two-Ways analysis of variance (ANOVA) was used to detect possible time*group interactions. Between-Group differences was also analyzed using the analysis of covariance (ANCOVA) using baseline values as covariate. Delta difference were reported with 95% confidence intervals (CI) were also reported. Significance was set at $p < 0.05$ and reported to indicate the strength of the evidence. The Cohen's *d* effect size was calculated and interpreted as follows: < 0.20: *trivial*, 0.20–0.59: *small*, 0.60–1.19: *moderate*, 1.20–1.99: *large*, and > 2.00 *very large* (27). Data were analyzed using JASP software (version 0.9.2; JASP, Amsterdam, The Netherlands).

RESULTS

The following test-retest reliability scores were found between the familiarization and baseline session: $\dot{V}O_{2max}$ test was ICC = 0.963, *excellent*, SWC = 1.3 $ml \cdot kg^{-1} \cdot min^{-1}$; Ppower test was ICC = 0.921, *excellent*, SWC = 44.7 W; Apower was ICC = 0.945, *excellent*, SWC = 25.0 W.

Time*Group interactions was not found for any test such as $\dot{V}O_{2max}$ test (F = 0.105, p = 0.750), Ppower test (F = 0.658, p = 0.429), and Apower (F = 0.023, p = 0.882).

*****Please, Figure 2 here, Figure 3 and Figure 4 here*****

ETM comparisons between baseline and follow-up as well as CON comparisons between baseline and follow-up were reported in Table 1.

*****Please, Table 1 here*****

ANOVA between-groups (ETM vs CON) analysis did not reported differences for $\dot{V}O_{2max}$ test (F = 0.048, p = 0.829), Ppower test (F = 0.450, p = 0.834), Apower (F = 0.030, p = 0.864). ANCOVA between-groups (ETM vs CON) analysis did not reported differences for $\dot{V}O_{2max}$ test (F = 0.071, p = 0.794), Ppower test (F = 0.683, p = 0.421), Apower (F = 0.037, p = 0.850).

DISCUSSION

The aims of this study were to evaluate the effect of 4 weeks (two sessions per week) ETM vs. CON cycling training on $\dot{V}O_{2max}$ and power parameters. After 4 weeks of training, ETM reported significant improvements in $\dot{V}O_{2max}$, Ppower, and Apower, while CON reported significant improvements only in $\dot{V}O_{2max}$ (Figure 2, Figure 3, and Figure 4). These findings were in agreement with original authors' hypothesis. Instead, between-group analysis (ETM vs CON training) did not report any significant difference. This study reported that both HIIT methods significantly enhance $\dot{V}O_{2max}$ in a very short training period but ETM can also significantly enhance Ppower and Apower. However, this study does not show a significant between-groups difference and therefore the two training protocols should be considered equally effective.

The use of altitude and intermittent hypoxic training have reported effectiveness in generating performance gains using short-term protocols (1–3). In particular, HIIT in hypoxia can be very effective to stimulate both central and peripheral adaptations such as O_2 delivery and utilization (5,7). The advantages of altitude training to induce physiological adaptations are well reported (8). To take advantage of this type of training, athletes would need to remain at moderate to high altitude for ~2 to 3 weeks (5,9), but this is not always possible. Nowadays, many athletes may struggle to incorporate proper altitude training into their programmes for geographical reasons (lack of adequate altitude locations nearby), cost and time constraints of travel to the appropriate altitude environments, and because of the cost of simulated hypobaric chambers. Therefore, ETM, which is a popular and relatively inexpensive method, may be a valid alternative to real hypoxic altitude training (11). Recently, it has been suggested that healthy adults may be required to perform a high-intensity exercise with an ETM to simulate a hypoxic environment (28), but future research is needed to determine whether repeated exposure to this condition provides similar benefits as altitude training. According to previous research, to obtain some benefits following HIIT, participants should perform at least 2 sessions per week at an intensity of around 90-95% HR_{peak} (17,18). The ETM group reported after only 4 weeks of training a *moderate* increment in $\dot{V}O_{2max}$, Ppower, and Apower, while the CON group reported a *moderate* improvement only in $\dot{V}O_{2max}$. Such aerobic and anaerobic improvements were practically meaningful because they were greater than the respective SWCs (of these tests). The ETM group reported a positive increment in $\dot{V}O_{2max}$ of 2.9 $ml\cdot kg^{-1}\cdot min^{-1}$, Ppower test of 84.2 W, and Apower of 38.0 W, and the respective SWCs were 1.3 $ml\cdot kg^{-1}\cdot min^{-1}$, 44.7 W, and 25.0 W. This was also the case for the CON group, which reported a practically meaningful increment in $\dot{V}O_{2max}$ of 3.3 ml·kg^{-1}·min^{-1} that was bigger than its SWC (1.3 ml·kg^{-1}·min^{-1}). These findings highlight the capacity of a short-duration HIIT protocol to generate meaningful variation in $\dot{V}O_{2max}$, however, the ETM protocol reported additional anaerobic power benefits compared to CON after the training period, which could be explained by the ETM-based physiological adaptations (*e.g.*, glycolytic activity, PCr resynthesis rate, increased reliance on anaerobic metabolism) (29).

As previously reported, the rationale for the use of ETM is related to the capacity of this instrument to cover the nose and mouth causing a restriction in the amount of air, and so hypothetically O_2, that an athlete can inspire (11). Previous research reported that ETM can cause a pronounced increase in oxyhemoglobin and total hemoglobin vs. control condition (30). Other research reported that ETM causes modest hypoxemia and limited discomfort (31). Up to now, manufacturers have claimed that by the combination of hypoxic training technique such as ETM and HIIT, athletes may achieve similar adaptations that can be obtained at high altitude environments or greater benefits than training without O_2 restriction (*i.e.*, hypoxia). This could be particularly useful and practical for athletes because they could obtain equivalent physiological adaptations without the burden of more elaborate simulated altitude apparatus, or the cost and time constraints of travel to moderate to high altitude environments. However, the current evidence about the validity of ETM is very limited. In particular, this is true for short-duration HIIT (4 weeks), where previous research focused its attention to longer training protocols of ranging from 6 to 7 weeks (12,13). Previous research reported that 4 weeks of HIIT should be enough to obtain some physiological adaptations in moderately trained participants (14), therefore this training duration was implemented in the current protocol with a training frequency of 2 sessions a week. As reported above, significant *moderate* time effects were found in all tests in the ETM group after 4 weeks of training, therefore the data of the present study further support the existing evidence for the use of short-term HIIT in eliciting positive effects relevant to moderately trained participants. The findings of this study are especially interesting because they show for the first time that the combination of HIIT and ETM can be beneficial as a short-duration protocol and this is particularly important for athletes that have limited available training time due to travel and schedule restrictions These results could be also applied to athletes of other sports (*e.g.* team sports) who may need to improve both aerobic and anaerobic power quickly and do not have enough time for extensive moderate-intensity protocols because of congested match schedules or the need for tactical and technical skills training (32,33). Additionally, the combination of HIIT and ETM may be a useful new training strategy to obtain both aerobic and anaerobic adaptations as well as marginal gains in performance for professional athletes.

Despite the positive effects reported by both groups following this short-term HIIT, this study does not report any significant difference between ETM and CON in $\dot{V}O_{2max}$ test ($p = 0.794$), Ppower test ($p = 0.421$), and Apower ($p = 0.850$), therefore this RCT cannot demonstrate that ETM represents a superior method to obtain aerobic and anaerobic performance enhancements in moderately active participants. These results may be explained by the short duration of the protocol, which consisted of only 4 weeks (8 sessions) of training. In our opinion, a longer training protocol ranging from 8 to 12 weeks may be more suitable to find between-groups differences, therefore future studies could investigate the effects and the differences of HIIT when performed with and without ETM. Authors explain the current non-significant results because the two cycling protocols were identical in design and therefore can have induced similar physiological adaptations. However, the ETM group reported both Ppower and Apower *moderate* improvements following the training protocol but CON did not, for this reason, we believe that further research is needed to verify the results reported in this study using a longer training protocol duration, which could be a more suitable to observe physiological differences between ETM and CON training.

This study is not without limitations, first, a relatively low sample size was enrolled in this study. Despite this sample was calculated *a priory* obtaining an adequate power (0.84), a larger sample size could have offered a better chance to find between-groups differences and could have helped to better understand the time-related physiological adaptations. In order to mitigate this limitation, authors adopted a robust design such as a RCT (following CONSORT guidelines) and an intention to treat analysis to account for dropouts. Second, a short-duration HIIT protocol was used, which could have limited the time to obtain physiological adaptations and could have masked the differences between ETM and CON. However, previous research reported that 4 weeks of HIIT are sufficient to find some aerobic and anaerobic adaptations, which have been confirmed by the current study. Therefore, future research should verify and further explore the findings of this study using a longer training protocol. Third, in this study the ETM's were set at the mid-point of air restriction for all sessions, but different settings may be more effective, therefore future studies could investigate how different ETM settings can affect training adaptations. Lastly, this study enrolled a sample of moderately trained participants and therefore the current results should be applied to this type of population. Future studies could replicate this protocol with amateur and professional cyclists or different sports populations in order to verify the benefits of the combination of HIIT and ETM.

Conclusions

This study supports the previous knowledge that short-duration (4 weeks) HIIT performed twice a week can elicit physiological adaptations in moderately trained participants. The combination of HIIT and ETM guarantee *moderate* positive improvements in $\dot{V}O_{2max}$, Ppower, and Apower, while CON reported significant improvements only in $\dot{V}O_{2max}$. However, this RCT did not find significant differences between ETM and CON, therefore the two protocols should be considered equally effective. Future research is needed to verify the superiority of ETM vs. CON using longer HIIT duration. Practitioners could utilize the findings of this study for designing short-term HIIT-ETM protocols, which can be particularly important for athletes that have limited training time availability due to travel and schedule restrictions, or for obtaining aerobic and anaerobic adaptations and marginal performance gains in professional athletes.

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Figure 1

CONSORT diagram showing the flow of participants through each stage of a randomized controlled trial. ETM = Elevation training mask; CON = Control.

Figure 2

Time effect following ETM and CON training compared to baseline. $\dot{V}O_{2max}$ = maximal aerobic power; ETM = Elevation training mask; CON = Control; *: $p < 0.05$ = pre-post analysis.

Figure 3

Time effect on peak power following ETM and CON training compared to baseline. ETM = Elevation training mask; CON = Control; *: $p < 0.05$ = pre-post analysis.

Figure 4

Time effect on average power following ETM and CON training compared to baseline. ETM = Elevation training mask; CON = Control; #: $p = 0.051$ = pre-post analysis