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Effects of Simulated Altitude on Maximal Oxygen Uptake and Inspiratory Fitness

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ABSTRACT

International Journal of Exercise Science 10(1): 128-136, 2017 Aerobic exercise at altitude has shown an increase in maximal oxygen uptake. Similar effects have been replicated by way of simulated altitude training, which have influenced various advances in the field of exercise science. Elevation Training Masks© (ETM) claim to stimulate cardiorespiratory fitness improvements similar to training at altitude, however, there is little research to support this claim. The purpose of this study was to research the effect that a hypoxia-inducing mask would have on cardiorespiratory fitness and pulmonary function through the use of a high intensity interval training (HIIT) running program. Seventeen subjects were randomized into either the control group, without the mask, or experimental group, with the mask, and participated in a 6-week HIIT protocol of 4 sessions per week. Each session included a warm up, followed by intervals of running at 80% of their heart rate reserve (HRR) for 90 seconds and followed by 3 minutes of active rest at 50-60% of HRR. A total of 6 intervals were completed per session. Within subjects, there was a significant increase in predicted VO_2max ($F(1,17)=7.376$, $P<.05$). However, there was no significant difference in predicted VO_2max between the control and experimental groups ($F(1, 17)=3.669$, $p= .075$). Forced inspiratory vital capacity demonstrated no significant difference within subjects ($F(1, 17)= .073$, $p > .05$), or between the two groups ($F(1, 17)= 3.724$, $p= .073$). Similar to the VO_2max results, forced vital capacity demonstrated a significant increase within subjects ($F(1, 17)=6.201$, $p<.05$), but there was no significant difference between the control and experimental groups ($F(1,17)=3.562$, $p= .079$). Although the between groups data was not significant, there was a greater increase in the experimental group wearing the ETM compared to the control group not wearing the mask for all 3 variables. Data suggest that HIIT training can be a viable method of improving VO_2max and pulmonary function however, training masks such as the ETM may not lead to greater overall improvements.

KEY WORDS: VO_2max, functional lung capacity, forced inspiratory vital capacity, forced vital capacity, High intensity interval training, elevation training masks, normobaric hypoxia

INTRODUCTION

Cardiorespiratory fitness is defined by the ability of the body to process oxygen, distribute it to the body systems efficiently and maintain exercise intensity (4). Maximal oxygen uptake (VO_2max) is the amount of oxygen used in the body, per kilogram of body weight per minute (4). Searching for new ways to improve the body's ability to utilize the uptake of oxygen is a large facet of exercise science. Exercising aerobically at altitude has been proven to increase VO_2max, as well as generate many other physiological adaptations, including ventilatory adaptations, such as increasing forced vital capacity (FVC) and forced inspiratory vital capacity (FIVC) (2, 5, 19). FVC is the amount of air that can be forcefully blown out after full inspiration. FIVC is a forceful lung inspiration that was preceded by maximal lung expiration.

One advancement in the field of exercise science, simulated altitude training, has worked to generate similar effects to training at altitude. One method of simulating altitude is to induce a normobaric hypoxic condition, or minimize the amount of air allowed to be consumed by an individual (15). In previous years, the equipment used to induce hypoxia has been expensive, however, various companies have begun to mass produce these pieces of equipment known to induce hypoxic conditions. The mass production of these devices have made it easier for the general public to purchase and obtain this specific equipment. However, though the cost is relatively inexpensive in comparison to some products, such as a hypo-barometric chambers, the question has then been raised, "are they really effective?" Regardless of company's claims, or the cost of these devices, the effectiveness of these specific devices to improve aerobic capacity have not been widely peer reviewed.

The purpose of this study was to investigate the effect that one specific, hypoxia inducing mask would have on cardiorespiratory fitness of both men and women. This study investigated Elevation Training Masks© (ETM) (Training Mask, Cadillac, MI) on its ability to alter VO_2max and pulmonary function, through the addition of high intensity interval training (HIIT) while running. HIIT training programs have been shown to improve aerobic capacity regardless of gender or training level (6, 18). The HIIT protocol selected has demonstrated to alter VO_2max, and was used in the study so that both groups would potentially see altered cardiorespiratory fitness, as well as pulmonary changes (23). The hypothesis of the study was the experimental group wearing the ETM would see greater changes in cardiorespiratory fitness and improved pulmonary changes compared to a control group.

METHODS

Participants

The study was conducted using 21 Indiana Wesleyan University students who volunteered to participate in this 6-week study. Seventeen (ages 18-26 years, mean=21.2 years, SD=1.7 years) of the 21 subjects completed the study. Each subject was randomly assigned into either the control (n=8) or experimental group (n=9) using a Microsoft Excel© filter function (Microsoft, Redmond, WA). Subjects varied in gender (males=12, females=5), and were moderately trained individuals who reported regularly meeting ACSM guidelines for cardiorespiratory exercise. Subjects maintained their normal cardiorespiratory exercise, in addition to completion of the 6-week protocol. Upon completion of a Physical Activity Readiness Questionnaire (Par-Q) and informed consent (approved by the Human Subjects Review Board at Indiana Wesleyan University), subjects qualified to participate in the study. All documentation and participant information was kept secure via passcodes on a single laptop and locked in a cabinet.

Protocol

The week prior to the 6-week protocol, subjects were evaluated for initial resting heart rate by way of manual palpation of the radial artery for 15 seconds, resting blood pressure via a sphygmomanometer (Medco, Tonawanda, NY) and stethoscope (Marshall, Tonawanda, NY), submaximal oxygen uptake (VO_2), FVC, and FIVC. Heart rate, blood pressure, FVC, and FIVC were measured while each subject was in an upright, seated position. Resting heart rate and maximal heart rate (HRmax) (206.9 – (age * 0.67)) were used to calculate heart rate reserve (HRR) (1). Blood pressure was monitored for safety precautions during submaximal testing. FVC and FIVC were collected using the FVC function on the spirometer (Medical International Research (MIR) Inc., Waukesha, WI). A treadmill (Matrix, Cottage Grove, WI) single-stage model submaximal test was used to estimate VO_2max (8). Submaximal tests are an effective technique for estimating maximal oxygen uptake in situations with limited time or resources (18). In this study, a single-stage jogging treadmill test validated for use in younger adults was used to estimate VO_2max (8). Following a brief warm-up, subjects were asked to jog at a comfortable, self-selected pace (4.3-7.5 mph for men; 4.3-6.5 mph for women) for 3 minutes. The subject's heart rate was recorded using a heart rate monitor (chest strap and watches) (Polar Electro Inc., Lake Success, NY). The subject had to achieve a minimum heart rate of 130 beats per minute (bpm) but could not exceed 180 bpm. The subject's heart rate was then entered into an equation to estimate VO_2max. (VO_2max – 54.078 – 0.1938*(body weight in kg) + 4.47*(speed in mph) – 0.1453*(HR in bpm) + 7.062*(gender: female=0; male=1) (8). These initial values were recorded and were used to compare the effects of training 6-weeks later.

The 6-week study consisted of each subject performing the same HIIT running protocol 4-days per week on an indoor track. Subjects completed their 4-workouts Monday through Thursday, and were able to make-up a day on Sunday if they had conflicts during the week. A specific HIIT protocol (24) that had shown to have an increase in overall VO_2 was used, however the protocol was modified from 90% of VO_2max to 80% of HRR. This was done to allow subjects to use a heart rate monitor to determine their own intensity during each session. Subjects were required to maintain 80% of their HRR (±5 bpm) for 90-seconds followed by a 3-minute active rest period. During the rest period subjects had to maintain 50-60% of the HRR. A total of 6 intervals of 90-second bursts followed by 3 minute rest periods, concluded one HIIT protocol. Subjects completed 4-HIIT protocols for a duration 6-weeks always including a 5-10 minute jogging warm-up and cool-down. The subjects were split into two groups randomly using the Microsoft Excel© filter function. The first group was the control group (non-ETM), which completed the same HIIT protocol as the experimental group. The second group was the experimental group (with ETM), who wore an ETM for the duration of the 6-week HIIT training protocol. The mask valves were set to simulate 9,000 feet at altitude. The mask can be changed to simulate altitude ranging from 3,000 feet to 24,000 feet. Previous research has found that training at altitudes of 2,000-3,000 meters (7,000 – 10,000 feet) show increased physiological adaptations (7).

Post-testing protocols were conducted the same as pre-testing. All subjects went through identical testing where resting heart rate, resting blood pressure, submaximal VO_2, FVC, and FIVC were measured and collected. Prediction equations were once again used to predict VO_2max. Once data was collected, data was analyzed for differences between pre- to post-testing values.

Statistical Analysis

The researchers wanted to evaluate the effectiveness of the HIIT program as well as the effect of the ETM mask. Therefore, a 2x2 mixed-design ANOVA series using the software program Statistical Package for the Social Sciences© (SPSS) was used. This statistical method allows for comparison both within subjects (pre-test vs. post-test) and between subjects (control vs. experimental) as compared to a repeated measures which evaluates only the pre-test vs. post-test measurements. This test compared predicted VO_2max, FIVC, and FVC values within subjects from pre-testing to post-testing as well as between the control and experimental group. A p-value, in this study, of <0.05 is considered significant. Additionally, a large effect size is considered to be above 0.14.

RESULTS

A 2x2 between groups ANOVA was used to analyze the change in predicted VO_2max between the control group and experimental group from pre- to post-testing. There was no significant difference between the control group and experimental group ($F(1,17)= 3.669$, $p= 0.075$, partial ETA squared= 0.197) (see Figure 1 and Table 1).

Table 1. Means (±SD) for between subjects comparison.

	Group	Pre-test	Post-test	p value
VO_2max (ml/kg/min)	Non-ETM	45.23± 4.05	46.26± 2.87	0.075
	With ETM	48.05± 4.94	51.19± 5.33	
FIVC (L/sec)	Non-ETM	3.38± 1.26	3.60± 1.01	0.073
	With ETM	4.36± 1.26	4.68± 1.13	
FVC (L)	Non-ETM	3.70± 1.27	3.98± 0.87	0.079
	With ETM	4.53± 0.97	5.00± 1.08	

A 2x2 between groups ANOVA was also used to look at the pre- to post-testing values of FIVC between the control and experimental groups. There was no significant difference between the 2 groups ($F(1, 17)= 3.724$, $p= .073$, partial ETA squared= .199) (see Figure 2 and Table 1).

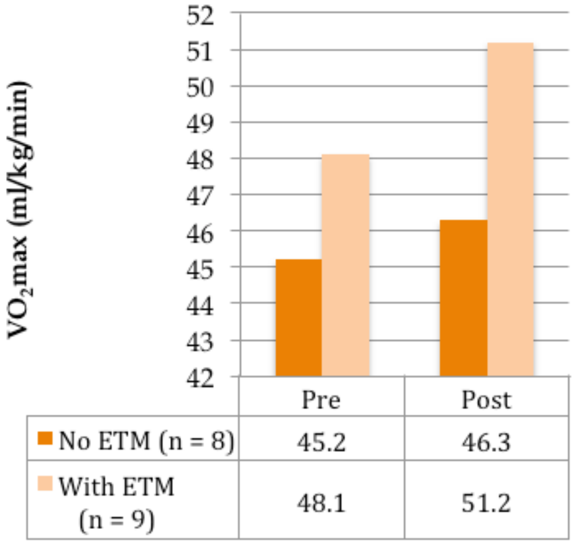

Figure 1. The VO_2max mean values of the control versus the experimental group are shown from the pre-testing and the post-testing results.

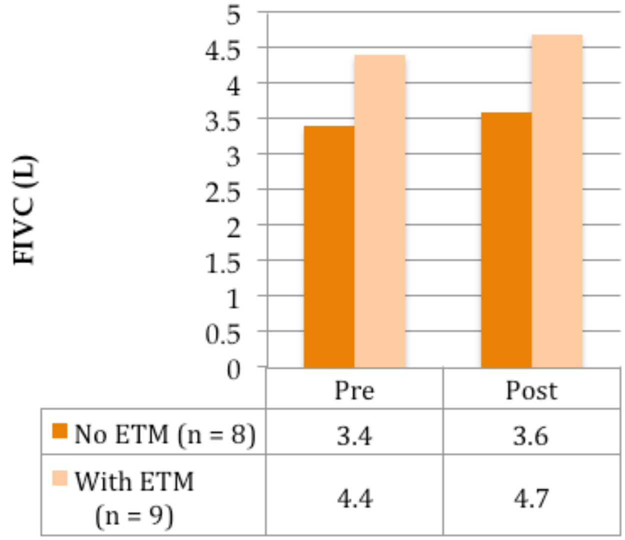

Figure 2. The FIVC mean values of the control versus the experimental group are shown from the pre-testing and post-testing results.

In addition, a 2x2 between groups ANOVA was utilized to look at the change between the control and experimental groups on FVC pre- to post-testing. There was not a significant difference in FVC between groups ($F(1, 17)= 3.562$, $p = 0.079$, partial ETA squared= .192) (see Figure 3 and Table 1).

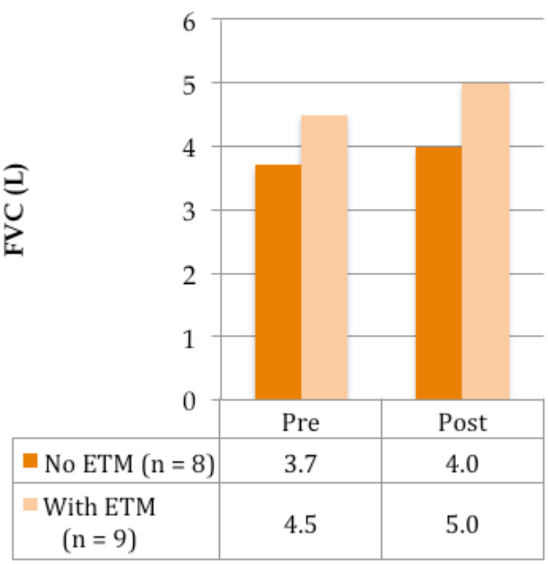

Figure 3. The FVC mean values of the control versus the experimental group are shown from the pre-testing and post-testing results.

A 2x2 within groups ANOVA was used to analyze the effects on predicted VO_2max over time on all of the subjects. A significant increase of predicted VO_2max was present within groups ($F(1, 17)= 7.376$, $p < 0.05$) (see Table 2). There was a large within group effect (partial eta squared= 0.330).

A 2X2 within groups ANOVA was used to compare pre- and post-test values of FIVC on individuals and revealed no significant differences ($F(1, 17)= .073$, $p > 0.05$, partial eta squared= 0.106) (see Table 2).

Table 2. Means (±SD) for within subjects comparison.

N = 17	Pre-test	Post-test	p value
VO_2max (ml/kg/min)	46.73± 4.63	48.87± 4.92	0.016*
FIVC (L/sec)	3.90± 1.32	4.17± 1.18	0.202
FVC (L)	4.14± 1.17	4.52± 1.09	0.025*

*p < .05

A 2x2 within groups ANOVA was also used to examine the change in FVC pre- and post-testing for all subjects. A significant increase in FVC took place pre- to post-testing ($F(1, 17)= 6.201$, $p < 0.05$) (see Table 2). Within groups FVC had a large effect size (partial eta squared= 0.292).

DISCUSSION

This study featured 17 healthy, active, college students that either wore an ETM or did not while participating in a 6-week HIIT protocol. All subjects were considered moderately trained based upon their current exercise level which subjects were allowed to maintain throughout the study. Individuals with various levels of training have all seen results with HIIT training programs (18, 20, 23). The results and discussion evaluate the addition of a HIIT program to individuals with an existing exercise program. Limitations of the study design are discussed later.

When looking at the increase in maximal oxygen uptake in response to a HIIT protocol, the protocol was successful in increasing predicted VO_2max among all subjects of the study ($p < .05$). Both the experimental and control groups demonstrated an increase in VO_2max at the completion of the HIIT protocol. It was hypothesized that the ETM group would have a greater improvement compared to the non-ETM group. While the overall increase in VO_2max from pre- to post-testing was larger in the ETM group, the difference between the groups was not statistically significant. This was observed in measurements of both FIVC and FVC values, as well. Improvements or changes were not significant, but larger improvements were seen in the ETM group compared to the non-ETM group. Furthermore, analyzing the data within subjects (pre- to post-test measurements) revealed a change on an individual basis. Individually, a significant increase of predicted VO_2max and FVC was present pre- to post-testing for all individuals regardless of intervention type. There were no significant changes individually with FIVC values. The within subjects data supports previous research (18, 20, 23), that the addition of a HIIT training program to an existing exercise program will improve VO_2max of healthy, active, young adults, regardless of their training level. However, the addition of an ETM mask to a HIIT protocol did not garner additional significant improvement.

When training aerobically at altitude, physiologically, the body undergoes some significant changes when exposed to moderate to high altitudes over a period of time (19). Hypoxia-induced training, whether or at altitude or not, can replicate some of the same physiological benefits (12). Previous research has drawn conclusions that training at altitude can increase the aerobic capacity of athletes by increasing the body's ability to uptake oxygen (3, 19). In this study, though not statistically significant, a larger increase in VO_2max in the ETM group could support the use of a simulated altitude device. Although altitude cannot be perfectly simulated (hypobaric and hypoxic), some of the changes in the body can be replicated via the use of simulated altitude exposure, or normobaric hypoxic conditions (9, 21). Research has indicated that a specific simulated altitude of 2000-3000 meters (about 7000-10,000 feet) is preferred to provide the greatest physiological changes and improvements aerobically (9).

This study specifically analyzed the effects of simulated altitude combined with HIIT, as opposed to sprint interval training (SIT) or running performance as a whole, which has shown little to no improvement of aerobic capacity has produced negative results in regards to what was previously hypothesized (7, 16). This study produced similar results meaning that although not statistically significant, there was an increase in VO_2max the hypoxia-induced and normoxic group of subjects.

One specific aerobic adaptation while completing a HIIT protocol is increased ability of the body to uptake oxygen (23). Additionally, to a HIIT protocol this study also used ETM(s), significant results were seen within the individual in regards VO_2max and the use of HIIT. Furthermore, this study contributed to previous research indicating that HIIT does improve maximal oxygen consumption (18, 20, 23).

Looking specifically at research in regards to FVC and exercise, FVC can decrease with normal aerobic exercise (6). However, additional research supports the use of higher intensity training to elicit an increase in FVC (11, 13). Data from this study shows a statistically significant increase in FVC within subjects from pre- to post-testing, supporting the use of HIIT training for improving respiratory function. However the change between the ETM and non-ETM was not significant. Aerobic training at altitude does not dramatically influence overall lung volumes including FVC (14, 22). Substitution of altitude training with a simulated altitude device also does not appear to significantly influence lung volumes.

Limitations to this study primarily are a small subject population (n=17). A type II statistical error could be the contributing factor for no significance between groups. A larger sized group, not to be confused with effect size, could show significant results and would be an excellent point of further research. All three of the variables demonstrated a greater increase with the ETM and therefore implementing a research study with a much larger population may cause the data to have significant results.

Despite attempts to appropriately randomize subjects into groups with and without the ETM, the subjects in the group using the ETM displayed higher starting VO_2max values than those in the group not using the ETM. This difference may have had some impact on results as there is a physiological ceiling for VO_2max and improvement slows as individuals near their ceiling. In future studies, subjects should be randomized after pre-testing data, according to their VO_2max in an effort to better control this limitation.

Additionally, subjects were allowed to continue their existing exercise programs. Considering their current exercise level participation it is unlikely that the addition of a 6-week HIIT program would result in an overtraining effect yet replacing the current exercise program with HIIT programing would eliminate this as a possible limitation of the results.

This study could have utilized the ability to increase simulated altitude by use of the various altitude settings on the ETM. Although statistically the use of an ETM to improve aerobic fitness was inconclusive within this study, the ETM was not used to its full potential. The ETM can be set for 24,000 feet of simulated altitude, whereas this study utilized the ETM at 9,000 feet. Given, a larger sample size may change the statistical significance, increasing the replicated altitude of the ETM may also aid in the statistical significance of this study. Looking at FVC and FIVC, a larger sample size may be utilized for further research, however it is unknown if an increased simulated altitude with the ETM will alter FVC or FIVC. It can be inferred, based on this study and greater increase in the ETM data compared to control group, that if an ETM is used to its full potential, over time overall aerobic fitness will improve. It will most likely be more beneficial for an untrained population to use this product to see a more exponentially positive result than a trained population.

Overall, the findings of this study suggest that HIIT training does elicit an increase in VO_{2max} and FVC. However the addition of the ETM masks did not produce the effect of training at altitude, and failed to simulate altitude effectively. As previous research has shown, the masks did not elicit a response on improving cardiorespiratory fitness (10). Purchasing these masks with the hopes of improving VO_2max is not recommended based on the findings of the study. However, increasing the altitude of the mask may elicit an improvement, thus future research on this change is warranted.

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