Simulated Altitude via Re-Breathing Improves Performance in Well-Trained Cyclists

CARMEN SWAIN¹, TIMOTHY KIRBY¹, JAMES ALTSHULD²

¹Exercise Physiology Laboratory, Health and Exercise Science, The Ohio State University, Columbus, Ohio, USA, ²Quantitative Research, Evaluation and Measurement, The Ohio State University, Columbus, Ohio, USA

ABSTRACT

Swain CB, Kirby TE, Altschuld JW. Simulated Altitude via Re-Breathing Improves Performance in Well-Trained Cyclists. JEPonline 2010; 13(6):21-34. Commercially available re-breathing devices are now being used by athletes to instigate short bouts of extreme hypoxia in an effort to improve athletic performance. Scientific evidence to support this practice is lacking. Purpose: To perform a randomized controlled trial to examine the effect of this methodology on aerobic and anaerobic type work. Methods: Over 15 days, 18 well-trained male cyclists used a re-breathing device to instigate hypoxia (6 min) alternated with room air (4 min) and repeated for approximately 1 hr/day. Subjects were assigned to a constant exposure sham group, equivalent to 150 m (CON) or progressively increased hypoxic group equivalent to 3600-6300 m (TRT). The critical power protocol was used to examine power output in time trial efforts (TT’s). Performance was also investigated through measurements of blood lactate concentration, oxygen consumption (VO₂), and heart rate (HR). Blood characteristics were additionally measured. Results: There was a significant improvement for the TRT group in the 15 min TT (p=.004) and estimated 60 min TT (p=.024) compared to no improvement in the CON group. The TRT group improvement was 3-4.5% in average power output. There were no significant differences in the 3 min TT for either group. Nor were there significant differences in hematological measures for either group. A decreased VO₂ (p=.075) and HR (p=.026) was revealed for the TRT group. Conclusion: In competitive cyclists, intermittent hypoxic training using a re-breathing device resulted in improved performance for events which rely on aerobic power but none for anaerobic power. It is suggested that re-breathing intermittent hypoxic training may be utilized...
as an alternative to terrestrial or other forms of simulated altitude, in efforts to mediate performance gains in endurance type events.

**Key Words**: Athlete; Endurance, Cycling, Hypoxia, Exercise

**INTRODUCTION**

Although not yet the definitive solution, the most promising and presently the most accepted training method to improving endurance performance, for those not native to high altitude living, is the practice of live high and train low (5,8,12,13,26,27,31,35,38). This generally well accepted approach to achieve optimal endurance performance, particularly when the performance occurs at altitude, is not without practical drawbacks. Daily trips to lower altitudes are time consuming and difficult. Needless to say that living at altitude is impossible in many countries and prohibitive in many others.

In an attempt to solve these problems, novel technological approaches to providing “simulated” altitude have been implemented (18,25,26,29,36) and continue to be developed (42). While straightforward and less impractical than changing physical location daily, their effectiveness must be established through controlled investigation if they are to be credible and capable of eliciting the physiological changes needed to insure optimal performance. One such device, the AltO₂Lab®, dependent upon a re-breathing principle, has shown promise in pilot work and provided the simulated altitude exposure in this investigation.

Intermittent hypoxic training (IHT) via the re-breathing method involves spending a much shorter period in a state of extreme hypoxia (3600-6300m) alternated with bouts of room air (25,37,24). Does this dramatically different methodology combined with maintenance of near sea level training bring about performance adaptation? This study sought to answer the question through various measures of athletic performance and physiological characteristics of well-trained cyclists prior to and after exposure to simulated altitude via re-breathing.

The re-breathing device provides simulated altitude by creating a hypoxic environment (reduced amount of oxygen) to which the athlete is exposed while at rest. The technique has unique qualities which make it quite different from other forms of simulated altitude exposure. Most methods currently being employed for simulated altitude exposure rely on a chamber or tent-like structure, to create a hypoxic environment which is equivalent to moderate altitude (2,000 to 3,000 m). While at rest the athlete “lives” in this environment, for 6-12 hours at a time, usually on a daily basis. This provides the simulation for the “live high” aspect of the most common approach while training under normal sea level or near sea level conditions. Outside the chamber is the “train low” environment.

Contrary to the more common simulated altitude methodologies, re-breathing utilizes a small apparatus that a subject breathes through for less than an hour per day. It is lightweight, extremely portable and consists of a mouthpiece and tube connected to an uncomplicated system, which allows for the re-breathing of a certain adjustable portion of expired air. This apparatus is capable of producing hypoxia simulating a high altitude environment (4,000 to 6,500 m) compared to the more moderate altitude environment of chamber/tent based simulated altitude methods. The advantages of the equipment used in the current study consist of relatively low cost and a time requirement of less than 1 hour per day. The assumption of the present study is that short-term exposure to simulated very high altitudes will result in physiological changes and performance enhancements equal to or more advantageous than those found in response to moderate altitude. Numerous moderately-high to high altitude investigations, terrestrial and simulated, have shown performance enhancements at low
Chronic exercise and metabolism in SHR

altitude (7,9,10,28,33,36). But, the duration of time exposed to altitude has been substantially greater than that for the treatment being tested here.

METHODS
Subjects
Eighteen well trained male cyclists, aged 24.1 ± 4.0 (SD) yr (weight = 171.8 ± 13.7 lbs; height = 180.6 ± 2.8 cm; 8.7 ± 3.5 %fat) provided written consent to participate in this study. Prior protocol approval was obtained from The Ohio State University Institutional Review Board. During this study all subjects were exposed to simulated altitude via a re-breathing device. Subjects were randomly assigned to either the constant or progressive simulated altitude group. The constant treatment (CON) was comparable to low altitude (400m). The TRT protocol for re-breathing was consistent with manufacturer instructions (Pharma Pacific), in which a progressive treatment comparable to exposure of a moderate altitude graduating to high altitude; (3600m – 6300m) was instituted over a period of 15 consecutive days.

Procedures
Subjects were given specific instructions and monitored for factors which may influence performance; detailed records of training, diet, overall health, and well-being were recorded on a daily basis. Subjects performed exercise performance tests on three occasions: a familiarization trial (FAM), a baseline trial before the simulated altitude sessions (PRE) and 5 days after the completion of the altitude exposures (POST). Hematological measurements include: hematocrit (HTC), red blood cell volume (RBC), and white blood cell volume (WBC).

Measured Physiological Parameters
Measured physiological parameters were: power output, heart rate, oxygen consumption and lactate. These measures were used to gauge physiological efficiency. Data was collected during each of the 3 exercise tests as described below.

Power Output
Performance in cycling is the primary dependent variable of interest in this investigation. Data were collected in each of the 3 exercise tests described later. Subjects completed the exercise test on their personal racing bikes, placed upon a computer regulated and calibrated stationary trainer (Computrainer) (32). Power output was measured in watts on a continual basis and averaged over the length of the TT effort, either 15 minutes (15m) or 3 minutes (3m) in length. Coyle et al. (10) has previously established power output in efforts of this nature to be highly reproducible. Power was displayed on a computer screen that was placed behind the subject and out of view. Subjects were prohibited from using power meters as a means of monitoring performance during testing.

Oxygen Consumption
A mouthpiece and nose clip were worn by the subject, which were connected to a laboratory metabolic cart (Med Graphics) to analyze expired gases with; oxygen consumption (VO$_2$) being ascertained on a breath by breath basis (3). As an indicator of VO$_2$ efficiency, the average amount of oxygen consumed (ml/kg/min) per watt$_{avg}$ was calculated PRE and POST. It was termed VO$_2$ index.

Lactates
Increased measures of blood lactate are indicative of a rise in the amount of anaerobic metabolism. To measure the amount of lactate at PRE and POST, the index finger of the subject’s left hand was the sample site. The skin was punctured with a sterile lancet, the first drop of blood was wiped away and the next drop of blood was drawn into an automatic handheld lactate analyzer (Accusport) (11). Data were collected serially at 3, 6, 9, 12, and 15 minutes of the 15m TT. Lactate values versus time
were plotted and quantified as a summary value, which accounts for the total area under the curve. For lactate efficiency the area under the curve is divided by the average watt achieved. This manipulation allows comparison of lactate accumulation for specific workloads.

Heart rate
Heart rate was continuously monitored and recorded using a 12-lead electrocardiograph. Heart rate has been shown to rise linearly with workload and be extremely reproducible in adequately controlled conditions (40). Heart rate was divided by power output \(\text{watt}_{\text{avg}}\) to examine efficiency; which is called heart rate index.

**Exercise Performance Testing**
Measurements of performance were completed, in a regulated laboratory facility, three times for each subject: a familiarization trial, pre-treatment and post-treatment. Testing occurred at approximately the same time of day for each subject and they were instructed to eat high carbohydrate meals on the evening before and on the day of each test. The familiarization trial was included to deter performance improvements due to a learning effect. It was expected that the two initial performances would elicit similar results. If an adaptation occurred at post-test in the treatment group, the presence of the familiarization trial would provide evidence of its authenticity. Pre-treatment represents a baseline measurement, and was administered on the day prior to treatment. Post-treatment testing was administered five days post- treatment to allow for possible physiological adaptation to the altitude stimulus. Each subject was instructed to perform to the best of his ability.

Competitive cycling is a unique and challenging sport. In road racing; the course, conditions and competition varies dramatically from event to event. Races are a highly aerobic event; but also commonly require cyclists to put forth multiple, short-duration, extreme-intensity efforts utilizing anaerobic contributions. Whether it is an attack, chasing down a break-away, climbing an ascent, or in training; the durations of these efforts vary greatly depending upon variables pertaining to the specific competition and environment. It is highly desirable to utilize a testing protocol that simulates familiar racing experiences; as well as provides a prediction for actual cycling performance.

Previous examination of cyclists shows actual cycling performance, for a 40k TT on the road, to be highly correlated with average power elicited over 60 minutes (10). The Critical Power Cycling Protocol can successfully estimate average aerobic intermittent power for a period of 60 minutes by performing bouts of work that have highly anaerobic contributions (21,22,30). Jenkins and Quigley (22) indicated the Critical Power function closely reflects the ability to perform supra-maximal exercise. Given the altering nature of power output in racing, the Critical Power Protocol has been chosen to explore the various metabolic components of cycling. Specifically, the Critical Power Test is expected to: 1) match the type of efforts commonly associated with training and racing for road cyclists, 2) examine average power over different durations of time; which align to varying degrees of contribution from anaerobic and aerobic energy systems, and 3) determine the potential effects of the experiment on actual cycling performance by estimating average power output over 60 minutes.

As part of the Critical Power Protocol, subjects performed a 15 minute warm-up, followed by 2 separate TT’s in which subjects were asked to perform to the best of their ability. The first TT was 15 minutes long, followed by a 10 minute active recovery session. The second TT was 3 minutes in length. These 2 bouts of exercise were used to predict a 60 minute TT performance.

**Simulated Altitude Treatment**
Altitude was simulated by exposing a subject to a decreased concentration of oxygen than what is found in normoxic (20.99%). This was accomplished by the use of a device consisting of a breathing
tube attached to an open-ended silo containing soda-lime to absorb carbon dioxide (CO$_2$). Additional foam-filled silos were added to increase respiratory dead space and thereby increase the altitude stimulus. Subjects wore a nose clip to prevent nasal breathing and followed manufacturers suggested protocol for use by alternating 6 min of breathing through the simulated altitude device with 4 min of breathing room air, six times, for a total of 56 minutes. Peripheral oxygen saturation was continuously monitored using a pulse oximeter. Subjects performed treatment at a consistent time of day prior to their training session.

In the CON Group (control) saturation was held at 98% for 15 days of treatment; this saturation occurs with adaptation to altitudes of approximately 150 m (14). This short duration of exposure to the low altitude stimulus was not expected to lead to significant differences in measured physiological or hematological parameters. The low level stimulus was chosen in an effort to blind the subjects from the actual altitude treatment, such that the subject was aware of receiving an altitude treatment but blind to the gradation. In the TRT Group saturation was progressively reduced, starting at 90% on the first day and finishing at 76% on the last day; these saturations occur with adaptation to altitudes of approximately 3600 and 6300 m (14) and were chosen to imitate altitude levels as demonstrated in other studies that have shown physiological adaptation (33,42).

During the re-breathing procedure, subjects as noted before were separated by a screen from the oxygen saturation device. Subjects were continuously monitored during treatment. If oxygen saturation fell below the targeted value, the subject was instructed to disengage from the mouthpiece and breathe room air. This methodology of exposure was beneficial in that the altitude stimulus could be immediately withdrawn and through exposure to room air, symptoms (e.g., dizziness, light headedness, disorientation) related to hypoxia were promptly dissipated.

**Statistical Analysis**

**Sample Size**

Based upon previous research by Hodges et al. (19) it was estimated that a sample size of 8 subjects per group would be required to detect significant F-ratios with adequate power (power = 0.8) in efforts to detect change in a steady state performance test with exercise. This analysis was performed by calculating the change in VO$_2$ during steady-state cycling. Meeuwsen et al. (29) shows a subject size of 8 cyclists to exhibit adequate power when investigating cycling TT performances after intermittent hypobaric hypoxia. Analysis measured change in both watts and maximal oxygen consumption.

**Study Variables**

Descriptive statistics describe: subject characteristics, training characteristics, dietary characteristics, performance variables, and hematological features described as means ± S.D. Subject characteristics include: age, height, weight, and body composition.

Training characteristics portray time spent riding per week and intensity described as rating of perceived exertion, which are combined to create a training index. There was an effort to have subject’s maintain training (time and intensity) over the duration of the study. So, training was examined within groups using Repeated Measures MANOVA by week over the four weeks of the study. Dietary characteristics recount the subject’s kilocalories, carbohydrate, protein, and fat intake and then average values for a summary daily intake. Diet characteristics between groups were compared using MANOVA.

Repeated Measures MANOVA was used to examine the effects of re-breathing simulated altitude on cycling performance, hematological and physiological variables in subjects that had been randomly assigned to a treatment or a control group. The subjects in the treatment and control group performed
3 testing sessions (FAM, PRE and POST). At each of these testing sessions subjects were measured on: 15m TT, 3m TT, and Estimated 60m TT performance. At PRE and POST subjects were measured on the above parameters as well as: VO2, HR, Lactate, HTC, RTC, and Fe.

Multivariate subset tests were also examined in an effort to determine the effect of a specific dependent variable in the model. Assumptions for data (i.e., distribution) were checked. Statistical power is reported for supported hypothesis. Alpha level was set a priori at p < 0.05.

RESULTS

Subject Traits

The overall features of the TRT and CON groups can be described as typical of what would be expected for competitive cyclists. No significant differences in subject traits were found between the groups. Daily kilocalories (TRT: 3078.8 ± 703.3; CON = 2765.0 ± 666.8), % carbohydrates (TRT: 43.1 ± 11.2; CON = 37.9 ± 8.3), % fats (TRT: 40.0 ± 10.6; CON = 35.6 ± 12.5), and % protein (TRT: 16.9 ± 3.9; CON = 17.7 ± 3.8) were not significantly different between groups, as determined via dietary recall (Multiple Pass Method) with a registered dietician.

Training volume and intensity were combined to create a Training Index for each subject. There was no significant difference in training from week to week as a result of Time (week 1, week 2, week 3, week 4) or Time interaction with Group (TRT or CON). These findings indicate the training index was held constant within both groups (TRT: 25.7 ± 1.9 wk 1, 26.1 ± 2.7 wk 2, 25.7 ± 3.8 wk 3, 25.7 ± 2.3 wk 4; CON = 22.1 ± 4.0 wk 1, 22.0 ± 3.0 wk 2, 22.3 ± 4.5 wk 3, 20.9 ± 3.6 wk 4), an important objective when examining performance adaptations. Both groups met the minimum criteria for training (6 hours of moderate to high intensity cycling per week) and maintained it consistently over the duration of the study.

Performance Variables

Power outputs for the 15m, 3m and estimated 60m TT are presented in Table 1. Significant effects (p = .05) were found for Time (FAM to PRE to POST) and Group (TRT or CON) interaction and also between Groups (p=.038). The improvement in the 15 and 60m TT at POST is noted in the TRT group, but not in the CON group.

Table 1. Exercise performance test results in 15m, 3m and 60m time trial (TT).

<table>
<thead>
<tr>
<th></th>
<th>TRT</th>
<th>CON</th>
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<tr>
<td>15m TT (watts)</td>
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</tr>
<tr>
<td>FAM</td>
<td>322.6 ± 35.0</td>
<td>295.7 ± 30.1</td>
</tr>
<tr>
<td>PRE</td>
<td>325.0 ± 34.4</td>
<td>295.9 ± 23.3</td>
</tr>
<tr>
<td>POST</td>
<td>335.0 ± 33.6**</td>
<td>289.9 ± 30.5</td>
</tr>
<tr>
<td>3m TT (watts)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FAM</td>
<td>395.5 ± 45.1</td>
<td>362.0 ± 31.1</td>
</tr>
<tr>
<td>PRE</td>
<td>409.0 ± 43.9</td>
<td>360.0 ± 20.4</td>
</tr>
<tr>
<td>POST</td>
<td>402.5 ± 29.6</td>
<td>346.3 ± 40.4</td>
</tr>
<tr>
<td>60m TT (watts)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FAM</td>
<td>307.9 ± 35.5</td>
<td>283.2 ± 31.4</td>
</tr>
<tr>
<td>PRE</td>
<td>300.1 ± 28.4</td>
<td>275.2 ± 29.1</td>
</tr>
<tr>
<td>POST</td>
<td>322.4 ± 36.1**</td>
<td>279.4 ± 29.9</td>
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</table>

Abbreviations: TRT: treatment group, CON: control group. Values are means ± S.D. Significant differences are indicated (** P<0.01 )

15 Minute Time Trial

The CON group data for FAM, PRE and POST changes little between trials, whereas, the TRT group data increases at POST when compared to FAM and PRE scores. As expected, the FAM and PRE scores were similar within groups (TRT: FAM = 322.6 ± 35.0 watts and PRE = 325.0 ± 34.4 watts; CON: FAM = 295.7 ± 30.1 watts and PRE = 295.9 ± 23.3 watts). This finding suggests that the 15m TT performance was likely to be reproducible among subjects. Although this does not constitute a full measure of reproducibility, it does point to this conclusion. At POST the TRT group improved
performance (PRE = 325.0 ± 34.4 watts, POST = 335.0 ± 33.4 watts) and there was a decrease performance in the CON group (PRE = 295.9 ± 23.3 watts, POST = 289.9 ± 30.5 watts).

Based upon within-subject analysis there was a significant interaction (p = .004, and observed power of .890) between Time and Group. The average 3% improvement in power output, in the 15m TT performance in the TRT group may be attributed to the progressive re-breathing simulated altitude treatment. The treatment may significantly improve performance in an event at or near sea level which relies heavily upon aerobic power.

3 Minute Time Trial
The similarity of scores within the TRT and CON group for the 3m TT can be observed in Table 1. The TRT group consistently scores higher than the CON group, as noted between groups. Between group analysis shows there was a significant difference (p = 0.002) for 3m TT performance, confirming that the TRT group achieved significantly higher outputs than the control group.

A key concern for all the performance trials was the within-subjects effect. There was no significant effect as a result of Time (FAM, PRE, or POST) or interaction of Time and Group (TRT or CON). In the sample of well-trained cyclists, the findings are that the re-breathing form of simulated altitude does not significantly affect performance in an event at sea level which relies heavily upon anaerobic power.

60 Minute Time Trial
Similar to the 15 and 3m TT, TRT scores are regularly higher than CON scores in the estimated 60m TT. TRT scores appear noticeably higher at POST compared to CON scores which remain relatively steady over time. Subsequent analysis confirms there was a significant difference (p = .035) between CON (FAM = 283.2 ± 31.4 watts; PRE = 275.2 ± 29.1 watts; POST = 279.4 ± 29.9 watts) and TRT (FAM = 307.9 ± 35.5 watts; PRE = 300.1 ± 10.0 watts; POST = 322.4 ± 12.8 watts) scores. There was a significant (p = .002) within-subjects effect of Time. That is, all of the subject's performances, regardless of group, were affected by the time of the measurement. Both the CON and the TRT group scores declined at PRE (CON = -2.8%; TRT = -2.5%), and then improved at POST, although it is noted that the CON group did not score higher than at FAM. There was also a significant effect (p = .023) of Time interaction with Group (CON or TRT).

Subjects in the TRT and CON group performed differently. The CON group did not improve performance at POST as opposed to the quite large increase in the TRT group. From the best preliminary performance, the CON group was an average 1.3% lower at POST whereas the TRT group improved an average 4.5%. This type of improvement could be represented as an average speed improvement from 22.3 mph to 23.5 mph in a 20km TT. The implication is that the re-breathing form of simulated altitude has a significant effect on longer aerobic events at sea level. CON boredom with the study is also not a likely cause since they did not report recognition of being in the placebo condition.

Hematological Variables
Subjects' blood characteristics (HTC, RTC, Fe) at PRE and POST are presented in Table 2. There were not any significant differences in the blood characteristics between or within subjects. Serum Fe levels were maintained in both groups over the period of the investigation. This confirms that the lack of red cell growth was not due to a lack of necessary iron in the blood. It appears the re-breathing form of simulated altitude has little to no effect on blood parameters after 15 days of exposure.
Efficiency Variables
Means and S.D’s of VO₂ Index, Lactate Index, and HR Index are presented in Table 3. There was a significant between groups difference (p=.012) in these variables. This finding is probably linked to the previous findings between groups, that is, a higher level of fitness in the TRT group as compared to the CON. Higher levels of fitness correspond to lower sub-maximal levels in such physiological measures. There was not a significant effect of Time within subjects, but Time (PRE to POST) combined with Group neared significance at p = .075.

There were no significant effects for the variable Lactate within or between subjects. There was a significant effect (p=.026) of Time interaction and Group in HR index within subjects and also a significant between subjects effect (p=.014). The notable difference exhibited in VO₂ Index does not quite reach significance (p = .075).

An improved HR efficiency, or a lower HR at the same level of work, is apparent in the TRT group following 15 days of re-breathing simulated altitude treatment (p = .026, and observed power of .641) as a result of the interaction of Time (FAM, PRE, POST) and Group (TRT and CON). There also appears to be a decline in oxygen consumption in the TRT group following 15 days of the re-breathing treatment. These findings may shed some light on the possible or contributing mechanisms for improved performances.

It is known that steady state measurement of these variables produce reliable quantification of physiological processes. A reduction in HR and VO₂ given the same workload, leads one to assume a more efficient delivery of oxygen. Direct measures of this phenomenon were not made in this investigation. But there are other potential explanations. A variety of possible scenarios which may have attributed to the improved physiological efficiencies and the direction for future research will be discussed in the following section. The findings of this investigation support improved physiological efficiencies to be a mechanism for improved performance, but not hematological adaptation.

In the TRT group, aerobic performance measures show a notable improvement (3 – 4.5%) in average power output, following the simulated altitude treatment. There was no change in anaerobic performance measures. There were no significant effects on hematological characteristics. Heart rate was found to be significantly more efficient and VO₂ Index exhibited a strong trend toward improved economy at POST in the TRT group.

<table>
<thead>
<tr>
<th>Variable</th>
<th>TRT</th>
<th>CON</th>
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<tbody>
<tr>
<td>HTC</td>
<td>43.25 ± 2.100</td>
<td>42.68 ± 1.480</td>
</tr>
<tr>
<td>RTC</td>
<td>0.035 ± 0.006</td>
<td>0.048 ± 0.015</td>
</tr>
<tr>
<td>Fe</td>
<td>73.9 ± 27.51</td>
<td>152.9 ± 136.3</td>
</tr>
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Values are means ± S.D.

<table>
<thead>
<tr>
<th>Variable</th>
<th>TRT</th>
<th>CON</th>
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<tbody>
<tr>
<td>VO₂ Index</td>
<td>.176 ± .032</td>
<td>.159 ± .017</td>
</tr>
<tr>
<td>PRE</td>
<td>.165 ± .016</td>
<td>.163 ± .022</td>
</tr>
<tr>
<td>POST</td>
<td>.152 ± .023</td>
<td>.170 ± .021</td>
</tr>
<tr>
<td>Lactate Index</td>
<td>.346 ± .039</td>
<td>.433 ± .146</td>
</tr>
<tr>
<td>POST</td>
<td>.406 ± .030</td>
<td>.433 ± .146</td>
</tr>
<tr>
<td>HR Index</td>
<td>.584 ± .072</td>
<td>.635 ± .094</td>
</tr>
<tr>
<td>FAM</td>
<td>.564 ± .044</td>
<td>.631 ± .094</td>
</tr>
<tr>
<td>POST</td>
<td>.544 ± .053*</td>
<td>.646 ± .091</td>
</tr>
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</table>

Values are means ± S.D, * denotes a significant within subjects effect p<0.05.

Table 2. Hematological measurements

Table 3. Physiological efficiency variables
DISCUSSION

Performance

Performance in well-trained cyclists improved an average of 3-4.5% in aerobic natured events. This is a meaningful improvement in athletic accomplishment for a highly trained individual. A 1-3% increase in various endurance athletic performances as a result of acclimatization has been well-established when spending 8-20 hours per day for weeks at a time at moderate altitude (2,8,23,26). The data from this study reveals that exposure to simulated high altitude for a much shorter period of time (less than an hour per day) elicits at least similar and quite possibly larger gains in performance adaptations. The improvement found in the 15m TT performance in the TRT group is similar to that reported in previous literature. In well-trained runners, Levine & Stray-Gunderson (38) confirmed improved 5k running time that ranged from 1-3%. Other authors have also reported similar performance adaptations (2,8,23). The current finding of an average 3% improvement in 15m TT power output is in good agreement to the previously reported athletic adaptations that occur as a result of acclimatization.

The finding of an average 4.5% improvement in the 60m TT was substantially better than what has been reported for athletic improvements as a result of moderate altitude stays for several weeks. Longer events, such as the 60m TT, tend to mimic endurance race conditions and are not often reported in the literature. It was deemed necessary to include such a measure because laboratory testing is often criticized for lacking relationships to real world performance. The Critical Power Protocol allows for such inferences. This protocol predicts 60 minute average power output by using the average power from two different intensities and times to completion as predictor values.

Coyle (10) has previously observed a high correlation between 60 minute power output and 40k TT performance \( r = -0.88; P < 0.001 \). Our results indicate the TRT group significantly improved their average 60 minute power output at POST by an average of 20 watts. This is a nearly 5% increase in power output from initial performance scores. Even on the conservative side of performance adaptation, the AltO2Lab® (device used in this study) elicits a sizeable improvement in aerobic performance from athletes who are well-trained in their sport.

There was no improvement in performance which relied heavily on anaerobic power. The 3m TT effort was utilized in this investigation, as it requires a large energy contribution from anaerobic means. We found no difference within subjects (FAM, PRE, POST) in the TRT or CON group following the re-breathing form of simulated altitude. A recent publication (42) has suggested that events that are highly anaerobic powered may be improved by simulated altitude exposure. This was not found in this investigation.

It is with confidence these findings in performance may be generalized to other well-trained male competitive cyclists between the ages of 18-35. This statement is based upon our findings of an adequate sample size, small individual differences within the groups and the large observed effect size. It may also be considered likely, that other well-trained athletes of a similar age, who participate in highly aerobic athletic events, may also improve their performances via a simulated re-breathing device for 15 days.

Mechanism of Change

It was the aim of secondary and tertiary hypotheses to identify possible mechanisms underlying performance gains. This study provides some indication, but not a conclusive one with respect to clarifying the mechanisms responsible for change. Indicators of erythropoiesis (HTC, RTC) and
measures of physiological efficiency (VO\textsubscript{2} Index, Lactate Index, HR Index) were examined as the probable candidates for this mechanism of change.

**Hematological Characteristics**

It appears that the re-breathing form of simulated does not spur an enhanced erythropoiesis after 15 days of exposure. Measurements of erythropoiesis (HTC, RTC), the making of new red blood cells, resulted in no significant changes for either group from PRE to POST. Using a hypobaric chamber, other investigators have also found significant improvements in cycling power outputs following exposure to 1-2 hours of intermittent hypoxia for 10-15 days, accompanied by no significant changes in red blood cell parameters (18,29,41).

There are issues which may be account for the inability to achieve such changes. It is possible that an exposure period longer than 15 days may be necessary to elicit hematological changes, as many of the terrestrial altitude studies which report hematological changes are exposed for 3-4 week periods.

Another possibility for failure to improve the erythropoietic response may be linked to the timing of measurement. Hamlin and Hellmans (17) reveal a minimal increase in HTC at 2 days post-acclimatization compared to more substantial increase at 12 days post (1.5 ± 3.1 day 2 and 3.6 ± 4.1 day 12) acclimatization. This investigation looked at HTC values at 5 days post-acclimatization. This period of time may have been insufficient to produce forth significant changes in HTC or RTC values.

Or, quite possibly, the re-breathing form of simulated altitude does not stimulate an increase in red cell volume. Regardless of the reason for which hematological changes did not occur, the fact remains that performance was improved, but it can not associated with an enhanced erythropoiesis.

**Efficiency Characteristics**

Physiological efficiency measures offered a promising look into mechanistic properties of change associated with the re-breathing form of simulated altitude. Of the 3 variables examined, 2 exhibited noticeable adaptation in the treatment group compared to the control group.

**VO\textsubscript{2} Index**

Reductions in submaximal VO\textsubscript{2} may indicate an improved cycling efficiency following acclimatization via re-breathing. In high intensity steady state exercise, the relative VO\textsubscript{2} per watt decreased in the TRT group compared to the CON group, p=.075. Significant reductions in submaximal VO\textsubscript{2} have also been reported in elite runners following acclimatization to moderate altitude (35), indicative of an improved running efficiency following acclimatization.

This physiological reduction is likely attributed to an adaptation of the VO\textsubscript{2} components. According to the Fick equation, maximal VO\textsubscript{2} is the product of cardiac output and the difference between arterial and venous oxygen content (a-vO\textsubscript{2} difference). Therefore, if VO\textsubscript{2} declines, it must be in direct relation to a decrease in either cardiac output and/or extraction of oxygen from the working muscles.

Each of the VO\textsubscript{2} components, cardiac output and a-vO\textsubscript{2} difference, is a potential candidate for improving efficiency. Cardiac output is the amount of blood pumped per minute and is expected to increase linearly with increasing levels of work. A-vO\textsubscript{2} difference is the measure of oxygen extracted by the musculature; this value also typically increases with workload. Neither measure was directly recorded in this study. However, related research findings and indications from the current research may provide some clue as to the likelihood that either of these variables may be part of a mechanistic property of change.
HR Index
An improved HR economy, suggests a more efficient delivery of oxygen, as the mechanistic reasoning for an enhancement in performance. HR and stroke volume are the constituents that make up cardiac output. If it is assumed that SV remains unchanged while HR decreases, then it must be deduced that the TRT group had a lower cardiac output following the simulated altitude treatment. A decrease in VO\textsubscript{2} could be related to the finding associated with the variable HR Index. When examining the physiological variable HR, a significant effect of the altitude treatment was evident in the TRT group. The average HR per watt decreased after simulated altitude acclimatization via rebreathing, or, the efficiency of HR was improved in the TRT group. At POST a lesser HR was required to perform the same workload. Other researchers have also found that submaximal HR decrease after acclimatization to altitude (5,6,13).

We have observed the TRT group to improve performance and become more efficient in HR response, assuming a lower cardiac output. This result suggests a more efficient delivery of oxygen as the mechanistic reasoning for an enhancement in performance.

CONCLUSIONS
The findings of this study warrant the use of a re-breathing device (AltO\textsubscript{2}Lab\textsuperscript{®} as employed in this investigation) as an alternative to terrestrial altitude or other forms of simulated altitude to mediate performance gains in events that rely heavily upon aerobic power. In fact, the re-breathing form of simulated altitude could possibly become the preferred method of simulating altitude. The significant performance gains associated with minimal time of exposure and considerably less cost as compared to other forms of simulated altitude makes this device quite a noteworthy and possibly preferred methodology.

ACKNOWLEDGMENTS
This study was supported by the General Clinical Research Center at The Ohio State University, Grant M01-RR00034 from the National Center of Research Resources of the NIH.

Address for correspondence Carmen B. Swain, Ph.D., Health and Exercise Science, The Ohio State University, A046 PAES Building, 305 W. 17\textsuperscript{th} Avenue, Columbus, OH 43210. Phone (614) 292-5959; Fax (614) 688-3432; Email swain.78@osu.edu.

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