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Changes in Running Economy, Respiratory Exchange Ratio and VO_2max in Runners following a 10-day Altitude Training Camp

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ABSTRACT

International Journal of Exercise Science 10(4): 629-639, 2017. Running economy (RE) and VO_2max are important predictors of endurance performance for elite and semi-elite endurance athletes, with RE being an appropriate predictor in a homogenous running population. Altitude training has been observed to change RE ($mL.kg^{-1}.min^{-1}$), and VO_2max due to alterations resulting from acclimatization. This study tracked changes in RE and VO_2max before and after a 10-day altitude training camp at 1828 meters. VO_2max, RE expressed calorically, and respiratory exchange ratio (RER), were measured below anaerobic threshold (AT) to observe differences between pre-and post-altitude training. Eight varsity cross-country runners between the ages of 18 and 22 years performed an incremental treadmill test, pre- and post-10-day altitude training. Paired samples t-tests were used to statistically analyze the data. Average RE (VO_2 $mL.kg^{-1}.min^{-1}$) improved following altitude intervention (M= 56.44 ± 4.28) compared to pre-altitude training (61.30 ± 7.56). These differences were statistically significant $t(7)$= 2.71, p =.014. RE expressed as $kcals.kg^{-1}.km^{-1}$ improved following altitude training (16.73 ± 2.96) compared to (18.44 ± 4.04) pre-altitude training and was statistically significant $t(7)$ =3.08, p = .008. RER taken during the last minute of steady-state was higher (0.97, ± .019) post-altitude training, compared to (0.90 ± .043) pre-altitude. These differences were statistically significant $t(7)$ -3.62, p =.008. VO_2max ($mL.kg^{-1}.min^{-1}$) was lower in 6 out of 8 participants (63.91, ± 8.65) post-altitude compared to (69.90, ± 10.80) pre-altitude and was statistically significant $t(7)$ = 2.33, p =.026. The observed improvements in RE may be beneficial for endurance athletes competing and/or training at moderate altitudes near 1828 meters.

KEY WORDS: Altitude, aerobic athletes, varsity athlete, cross country running, athletics

INTRODUCTION

Various physiological factors, including a high maximal oxygen uptake (VO_2max), and a low cost of energy required to run a specific speed, act together in order to achieve success in distance running (10). Measuring the amount of energy to run a specific speed is known as running economy (RE). RE is an important determining factor of aerobic ability and is a more appropriate predictor of performance than VO_2max in homogenous trained group of runners who possess similar VO_2max values (2, 6, 7, 9, 19). RE is trainable and is an important indicator of estimated performance (19). As a result, coaches and athletes seek various types of interventions in an attempt to improve RE (19). These interventions include: strength training, training in warm to hot environments, and altitude training.

For nearly half a century, the effects of altitude training on endurance sports performance have been frequently investigated (25). The common belief amongst athletes and coaches is that altitude training will improve endurance performance (8). Although the precise mechanisms responsible are not known (19), studies (4, 15) have established improvements in running performances at sea-level. The proposed mechanisms from these improvements include hematological changes and local muscular adaptations (13).

In a study conducted by Brooks and colleagues, it was established that central and peripheral adaptations take place as a result of altitude acclimatization (3). As a result, O_2 delivery and utilization is improved (20). These adaptations imply that an athlete's RE would improve as there would be a reduction in O_2 consumed at submaximal speeds (20).

Limited research has demonstrated altitude training's effects on RE and authors report mixed results (20). To the best of our knowledge, two investigations (15, 23) noted no change in O_2 consumption at submaximal efforts following altitude training. In contrast to those findings, two studies (14, 20) found improvements in trained runners' RE following altitude exposure, however, both studies used a simulated altitude (altitude tents) as opposed to a natural altitude.

An improved RE is beneficial to middle-distance and long-distance running performance as it reduces the utilization of O_2 to run at any given steady-state (3). Given that RE is an important and easily obtained parameter for researchers and coaches, it is frequently used as a prediction of running performance (19).

RE is typically represented as the relative VO_2 ($mL.kg^{-1}.min^{-1}$) at a known speed during a physiological steady-state (6, 7, 19). However, Fletcher and colleagues demonstrated that it is more appropriate to denote RE as the caloric unit cost to cover a known distance ($kcal.kg^{-1}.km^{-1}$), as this would allow the estimation of the substrates metabolized (10).

Though research has been conducted on RE and altitude, to the best of our knowledge, no studies have examined RE following acute exposure to a moderate altitude (1828m) and no study has measured RE expressed as ($kcal.kg^{-1}.km^{-1}$) pre-and post-altitude intervention. Therefore, the principal purpose of this study was to examine the difference in RE pre- and post-moderate altitude exposure (1600 – 2500 meters) in varsity cross-country runners. Other physiological parameters investigated in the study were changes in respiratory exchange ratio (RER) and VO_2max.

METHODS

Participants

Following approval from the Lakehead University Research Ethics Board, 8 healthy participants aged 18-22 years were recruited. Each participant belonged to either a university or a high school varsity track and field and cross-country team. In total, there were five male and three female participants. Out of the five male participants one was in high school and four competed for the university. The female participants consisted of one high school level athlete and two university level athletes. Participants were included in the study if they were: 1) healthy, with no injuries; and 2) competitive runners who were currently training and competing for a varsity team. Additionally, all participants trained at the same altitude (183 meters) prior to attending the altitude training camp. Table 1 represents the anthropometric measurements of the participants.

Table 1. Anthropometric measurements of participants.

Age (years)	20.50 ± 1.77
Gender	5M, 3F
Height (cm)	171.18 ± 9.46
Weight (kg) Pre-Altitude	59.25 ± 6.53
Weight (kg) Post-Altitude	59.7 ± 6.46
Resting HR (bpm) Pre-Altitude	55.37 ± 4.62
Resting HR (bpm) Post-Altitude	54.75 ± 7.55

M= males, F=Females, cm = Centimeters, kg = Kilograms, HR= Heart Rate, bpm = beats per minute

Protocol

Testing took place in the School of Kinesiology, Lakehead University, Thunder Bay, Ontario, Canada (elevation 183 meters). Following the explanation of the purpose and methods of the study, consent to participate was obtained. Each testing session lasted approximately 1-hour. Testing sessions occurred within 10-days before leaving for the altitude training camp and within two days of being back to Thunder Bay, Ontario, Canada and were conducted in between the indoor and outdoor track seasons. Prior to testing, participants were asked to 1) not eat a substantial meal within 3 hours before the test; 2) abstain from alcohol 24 hours prior to the test; 3) abstain from coffee, tea, or other caffeine sources at least 1 hour before the test; and 4) abstain from vigorous training or high intensity physical work for 24 hours prior to the test. A Physical Activity Readiness Questionnaire (PAR-Q) (1), and a lab specific Maximal Testing Pre-Participation Screening Questionnaire, were completed to ensure that the participant was physically able to take part in the study. Upon completion of the required questionnaires, the participant had anthropometric measures (height, weight) taken and recorded using a My Weigh MD 500™ digital scale and a Tanita HR – 100™ stadiometer. Following these measures, participants had their resting heart rate (after 5 minutes in a supine position), resting blood pressure, and a resting blood lactate measured and recorded. Blood lactate was taken from each participant's fingertip using a calibrated Lactate Pro ™ Analyzer (Arkray, KDK Corporation, Kyoto, Japan) by the same clinician using the same technique for each participant. Participants then warmed up for 15 minutes on a treadmill at 9.65 kilometers per hour (K.P.H.) and completed 10 minutes of dynamic warm-up that focused on major muscle groups predominantly used during running.

Participants were then fitted with a Hans Rudolph Inc. 7940 series mask (Hans Rudolph Inc. Shawnee Mission, KS, USA) and hooked up to the AD instruments model ML206 Gas Analyzer (AD Instruments Pty Ltd, Castle Hill, Australia) metabolic cart and placed on the Woodway Inc. model ELG treadmill (Woodway Inc., Waukesha, WI, USA) set at an incline of 0% grade.

An incremental treadmill protocol was then initiated. Both men and women started the treadmill protocol with three, 3-minute stages. Following completion of the 3-minute stages, subjects entered 1-minute stages of increasing speed until exhaustion. This protocol was chosen as the early stages of 3 minutes allowed participants to achieve a steady-state. The one minute stages at an incline of 0% grade allowed for the speed of VO_2max and exhaustion to be known. Three male participants started at 14.16 K.P.H and two male participants at 15.93 K.P.H. (based on their most recent race results). All three of the female participants in the study started at 13.36 K.P.H. as they all possessed similar race results. Table 2 indicates the starting speeds and speed increases for each group.

Table 2. Treadmill protocol.

Time (Minutes)	Male Group 1 Speed (K.P.H.)	Male Group 2 Speed (K.P.H.)	Female Speed (K.P.H.)
3	14.16	15.93	13.36
6	**16.25**	**17.21**	**14.16**
9	17.54	18.50	14.96
10	18.35	19.31	15.61
11	19.15	20.11	16.25
12	19.95	20.92	16.90
13	20.76	21.73	17.54
14	21.56	22.5	18.19

Displays Speed in K.P.H at the various times (minutes), for all three of the groups. The male participants in Group 1 had three participants in it, the male Group 2 had two participants in it. The male participants in Group 2 started slightly faster (based off of most recent race results). All three of the female participants started at the same speed. All of the participants continued until they were no longer able to do so. The bold section indicates when RE was calculated.

Expired gases were collected using an AD instruments model ML206 Gas Analyzer metabolic cart (AD Instruments Pty Ltd, Castle Hill, Australia), and recorded in real time using Power Lab 26T (AD Instruments Pty Ltd, Castle Hill, Australia), and analyzed using the software lab chart version 7 (AD Instruments Pty Ltd, Castle Hill, Australia). Expired gases were analyzed in order to measure RE and VO_2max. Upon conclusion of the incremental treadmill test, subjects had a blood lactate level taken and a rate of perceived exertion taken and recorded using a 6-20 Borg Rate of Perceived Exertion Scale. Blood lactate was also measured at intervals of 2, 4, 6, and 8 minutes post-incremental treadmill test.

The subjects were tested within 10-days prior to attending an altitude training camp for a 10-day duration in Lead, South Dakota, USA, at an elevation of approximately 1828 meters (6000 feet). At altitude, the subjects' training resembled their typical training when in Thunder Bay, ON, (183 meters above sea-level), and they recorded their training sessions in a daily log. The daily log asked athletes to note how much they ran each day (time and distance), the type of run that was accomplished (interval, fartlek, long steady run) and how they subjectively felt during each individual training session. Additionally, the athletes recorded the amount of hours that they slept and their general feeling each day. The information obtained in the daily log was used to confirm each individuals training sessions and how they felt during each training session.

Following the altitude training camp subjects were re-tested within 3-days of returning to sea-level using the same equipment and procedure as pre-altitude testing. Room temperature (° Celsius) and barometric pressure (mmHg) were recorded prior to every testing session.

Upon conclusion of the test, the researchers analyzed the expired gases in order to measure RE ($mL.kg^{-1}.min^{-1}$) and VO_2max. The breath-by-breath VO_2 was averaged every minute. RE ($mL.kg^{-1}.min.^{-1}$) was estimated by analyzing the steady-state oxygen consumption at the conclusion of 3-minutes of running at the same speed. It has been suggested that 3-minutes is enough time for a steady-state to be achieved, especially in a trained population (17). Furthermore, a steady-state was declared if the increase in O_2 was <100 ml over the last minute of each stage (10). VO_2max was estimated using the highest achieved oxygen uptake that occurred during the test (21).

Running Economy was also expressed as the gross caloric unit cost ($kcal.kg^{-1}.km^{-1}$). The average RER over the last minute was used to calculate the caloric equivalent of the VO_2 (kcal/l O_2) (10). The same method used by Fletcher, Essau, and MacIntosh was used to calculate the caloric unit cost ($kcal.kg^{-1}.km^{-1}$), where VO_2 is estimated in liters per minute, speed is in meters per minute, body mass is in kilograms, and km is equivalent to 1,000 meters (10). However, the proposed estimation is limited as it often ignores the role that protein plays in providing energy (10).

Statistical Analysis

The software IBM SPSS Statistics Data Editor 20 was used to analyze the data. One categorical independent variable (pre-altitude exposure and post-altitude exposure) and four continuous dependent variables (running economy ($mL.kg^{-1}.min$), running economy (kcals/min), RER (VCO_2/VO_2), and VO_2max) were examined. The data were analyzed using paired samples t-tests to examine the effect of a 10-day altitude training camp intervention on the dependent variables. The rejection criteria was set at an alpha level $p < .05$.

RESULTS

As the incremental treadmill test described above served the purposes of measuring both RE and VO_2max, participants started at different speeds based off of recent race results and performance. As a result, RE was measured at different speeds for different participants.

Running economy (mL.kg^{-1}.min^{-1}) improved in 6 out of 8 participants following the altitude intervention. The average RE changed from (M=61.30 ± 7.56 mL.kg^{-1}.min^{-1}) compared to (M= 56.44 ± 4.28 mL.kg^{-1}.min^{-1}) post-altitude intervention. These results were statistically significant $t(7)$=2.71, p=.014. This can be seen in figure 1.

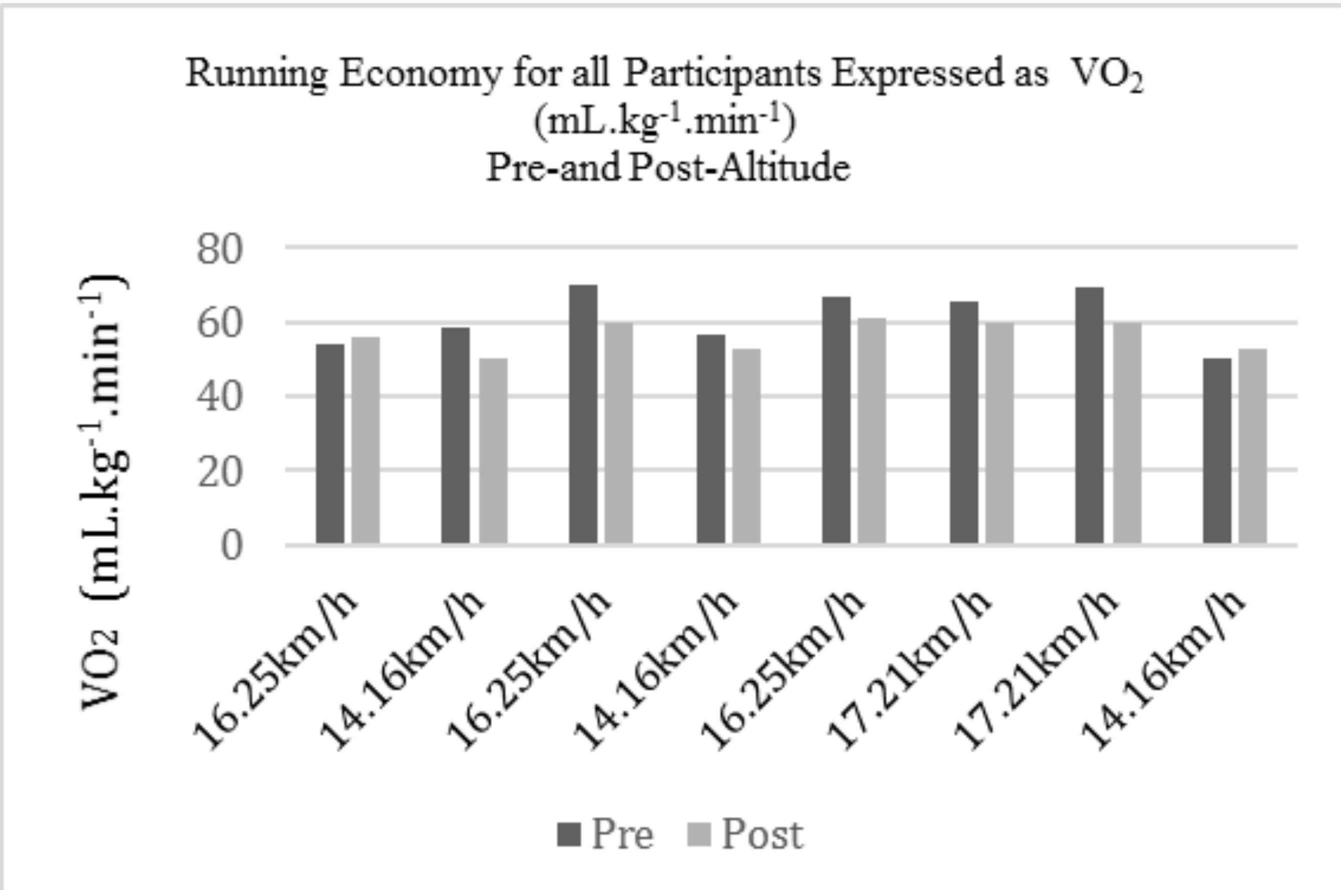

Figure 1. Depicts the speed that the running economy was measured at and the result of the RE expressed as VO_2 (mL.kg^{-1}.min^{-1}) for participants 1-8.

Running economy expressed as the caloric cost (kcal.kg^{-1}.km^{-1}) improved post-altitude intervention (M=1.08 ± .208 kcal.kg^{-1}.km^{-1}) compared to the pre-altitude values (M=1.16 ± .131 kcal.kg^{-1}.km^{-1}). These differences were statistically significant $t(7)$ 2.57, p=.018.

Respiratory exchange ratio was higher following the 10-day altitude intervention (M= 0.97 ± .019), compared to (M= 0.90 ± .043) pre-altitude. These differences were statistically significant

$t_{(7)}$ -3.62, p=.008, indicating that the altitude intervention did affect the mix of substrate metabolized at the same running pace pre- and post-intervention.

The average VO_2max value was lower following the altitude intervention (M= 69.90 ± 10.80 (mL.kg^{-1}.min^{-1}), compared to (M= 63.91 ± 8.65 (mL.kg^{-1}.min^{-1}) post-altitude intervention. These differences were statistically significant $t_{(7)}$ = 2.33, p =.026.

DISCUSSION

This investigation examined the effects of a 10-day altitude training camp at approximately 1828 meters on the physiological parameters of RE expressed as VO_2 (mL.kg^{-1}.min^{-1}), RE expressed as caloric cost (kcal.kg^{-1}.km^{-1}), RER, and VO_2max. The results observed indicate that 6 out of the 8 participants experienced positive results in every parameter explored. Although it is not known why 2 participants did not experience an increase in the parameters explored post-altitude, it may be a result of some athletes not physiologically responding well to the altitude (25).

The results show that on average, the RE improved significantly following the altitude intervention. These differences were observed in 6 out of the 8 participants and were statistically significant. The rapid improvement of RE suggests an acute improvement in distance running performance (19).

The observed improvements in RE corresponds with findings of two previous studies (14, 20), as these studies also concluded that an altitude intervention could improve RE. However, both of these studies utilized hypoxic training tents, which suggest that their observations were based off of a simulated altitude. In contrast to our findings, two investigations (15, 23) noted no change in VO_2 consumption at submaximal efforts following altitude training. These differences may be due to the fact that Levine & Stray-Gunersen utilized a live-high, train-low, approach to their study, as opposed to the live moderate, train moderate approach utilized in this investigation. Telford and colleague's investigation was more in line with our current study as they had participants live and train at 1700m-2000m, however, they concluded with no significant benefits to RE or sea-level performance. The different results in the studies may be attributed to the fact that Telford et al., used elite male athletes only, and that the duration of the altitude intervention was 4-weeks.

The improvement in RE may be a result of an improved O_2 carrying capacity as a result of an increase in hemoglobin mass (11). In a recent study, Garvican-Lewis and colleagues suggested that an altitude of 1800m is enough for distance runners to experience an increase in hemoglobin mass. The increase in hemoglobin mass could have improved the amount of O_2 delivery, thus, improving RE (11). Another reason for the improved RE following altitude could be that different substrates are utilized while running at the same speed, an idea that is further elaborated on below.

It is imperative that the intensity of running during the estimation of RE be under the maximal lactate steady-state, as it is believed that the slow component of VO_2 commands that physiological steady-states are most likely unable to be attained (10). Additionally, Fletcher, Essau, and MacIntosh state that when running at speeds above the lactate steady-state, nonaerobic metabolisms add to the cost of energy (10).

The incremental treadmill test used during performance testing was chosen as it allowed for a steady-state to be achieved while the participant was at an intensity below the lactate steady-state, as well as it allowed for the estimation of VO_2max. This was verified as the participants ran three, 3-minute stages when the RER was under 1.0. Both the amount of time and the RER imply that the participant ran long enough, and at an intensity below the lactate steady-state (17, 22). Following the three, 3-minute stages, the speed increased by a set amount every minute until exhaustion, thus, allowing for the calculation of VO_2max (21).

The results show that on average, the RE expressed calorically improved significantly following the altitude intervention. These differences were observed in 6 out of the 8 participants and were statistically significant.

Typically, studies express RE as the relative VO_2 ($mL.kg^{-1}.min^{-1}$) required to run at a known speed (6, 7, 19). However, Fletcher and colleagues argued that a more appropriate method of quantifying RE was by expressing it calorically as ($kcal.kg^{-1}.km^{-1}$), as it is a more sensitive and appropriate means of estimating RE. Additionally, Saunders et al., stressed that performance in distance running moderately relies on an individual's ability to utilize fat as the primary source of fuel at intense work rates, thus, sparing the carbohydrate (10, 19). It has long been established that the RER can be used to estimate the percentage of carbohydrate and fat used, and allows for the conversion of VO_2 into units of energy (caloric unit cost (10, 16)).

Respiratory exchange ratio was examined during the last minute of the steady-state stages used to measure RE. Respiratory exchange ratio was higher in 6 out of the 8 participants following the 10-day altitude intervention, which suggests that carbohydrates may have been more utilized as a fuel source following the altitude training (10). However, Goedecke and colleagues established that RER can be highly variable and that a number of factors can have an influence on it including diet, hormone concentrations, and muscle fiber composition. Pre-exercise diet was controlled, however, could not be verified and could have influenced the RER values. Additionally, it is possible that the altitude training camp altered the muscle fiber composition, and the concentration of hormones (25). Fletcher et al., argued that the variability in RER, and thus, substrate use, affects VO_2, however, does not affect the energy needed to physically perform the task. Additionally, the altitude training camp could have influenced other physiological mechanisms like the bicarbonate buffering systems of hydrogen ions, which would affect the CO_2 levels exhaled during the exercise, and ultimately affect the RER as it is measured as VCO_2/VO_2 (25).

The oxidation of a molecule of Carbohydrate was assumed to follow the trend as presented in the equation below:

Oxidation of a molecule of Carbohydrate: $6\ O_2 + C_6H_{12}O_6 \Rightarrow 6\ CO_2 + 6\ H_2O + 38$ ATP. RER = $VCO_2/VO_2 = 6\ CO_2/6\ O_2 = 1.0$

Although the changes were statistically significant, Fletcher and colleagues stated that the change in RER from 0.87 to 0.95 is only 2% regarding the energy per liter of oxygen required. However, using the RER allowed for the calculation of the amount of energy needed to run at a given pace. If carbohydrates were utilized more compared to fats following altitude, this may explain why the RE expressed as relative VO_2 improved post-altitude as carbohydrates require less oxygen to metabolize than fats (10).

VO_2max decreased in 6 out of the 8 participant's post-altitude intervention. This is in contrast to a study conducted by Burtscher et al., that observed a VO_2max increase in amateur runners following a moderate altitude intervention. However, these changes occurred after an altitude training camp that involved interval training at an altitude of 2315 m. It is possible that the decrease in VO_2max reported in this study, is directly related to the improvement in RE (10, 17, 18). Previous researchers support the idea that RE becomes worse as VO_2max increases (10, 17, 18). Costill et al., explored the notion that runners with greater VO_2max values require a greater oxygen carrying capacity as they would have a greater dependence on fat as the primary substrate being used (5). As a result, a runner's RE could appear as "mediocre" or "below average" as extra oxygen is needed to metabolize fat compared to carbohydrates (10). This would also make sense with the rest of the results as RE improved, and the RER revealed that a shift in substrates being metabolized (more carbohydrates than fats) occurred following the altitude intervention. As a result of carbohydrates being used early as a fuel source, it is possible that less oxygen was required to metabolize the carbohydrates compared to the fats. The improvement in RE could have been the cause of the lower VO_2max values following altitude as it is suggested that an inverse relationship may exist (10, 17, 18).

Limitations of this study include a small amount of participants (n=8), and a small age range (18 – 22). An additional limitation can be associated with the design of the study. A one-group pre-test post-test design was used and future studies may consider including a control group. It is important to note that there were no significant environmental changes in the laboratory between pre and post-test. Additional limitations exist when converting RE from VO_2 to a caloric equivalent (10). Using the RER does provide some insight into how the RE (expressed calorically) is affected, however, this conversion is limited as the role of protein is still not fully understood (9). Measuring the RER involves analyzing the O_2 and CO_2, and thus, it is possible that some of the CO_2 would derive from the bicarbonate buffer system, and thus confound the attribution of CO_2 from fats or carbohydrates (10).

Altitude training has been a popular training intervention since the 1968 Mexico City Summer Olympics. Although altitude training has been extensively researched, controversy exists between the best techniques for use (Train-High Live-High; Live-High Train-Low, Moderate living and training), the potential physiological benefits, the exact timeline that physiological changes occur, and its overall effectiveness for endurance athletes. The findings of this study suggest RE improves following a 10-day altitude intervention at approximately 1828 meters. Additionally, this study suggests that 10-days of altitude training at approximately 1828 meters may be enough to alter physiological parameters such as improved RE and quicker carbohydrate utilization. An acute improvement in RE would imply a rapid improvement in performance and could be beneficial prior to athletic competition. Further study is required, and could expand upon the current findings.

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