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12-DAY ADVENTURE RUN-HIKE TRAINING AT ALTITUDE IMPROVES SEA LEVEL 5KM PERFORMANCE

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By

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12-DAY ADVENTURE RUN TRAINING AT ALTITUDE IMPROVES SEA LEVEL 5KM PERFORMANCE – A PILOT STUDY

This thesis by Andrew Maurice Jones is recommended for approval by the student's Thesis Committee and Department Head in the Department of Health and Human Performance and by the Assistant Provost of Graduate Education and Research.

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ABSTRACT

12-DAY ADVENTURE RUN-HIKE TRAINING AT ALTITUDE IMPROVES SEA LEVEL 5KM PERFORMANCE

By

Andrew Maurice Jones

Elite and recreational endurance athletes routinely seek strategies to enhance sea level (SL) performance. Altitude (ALT) training continues to be an appealing approach. The primary purpose of this study was to measure the effect of a 12-day adventure running camp at ALT on 5 km time trial (TT) performance at SL. Secondarily, we explored changes in select metabolic and blood variables. We hypothesized an improvement in TT at SL. A group of five well-trained individuals (2 females) volunteered. TT, maximal oxygen uptake (VO_2max), running economy (RE), and a complete blood count (CBC) were measured at SL before and after ALT. Natural ALT exposure occurred in Colorado where runners engaged in low-moderate intensity trail runs for 12 days. After 12 days, runners traveled to SL for post-testing 1 day (e.g., TT) and 3 days (i.e., VO_2max, RE, CBC) after return from ALT. Paired t-tests were utilized to describe differences between pre- and post-tests with $p \leq 0.05$ set for significance. Mean TT performance improved significantly from pre- to post-ALT (-3%, p=0.004). Moreover, significant increases occurred in red blood cell count (+5.6%, p=0.005), hemoglobin concentration (+8.4%, p=0.012), and hematocrit (+6.7%, p=0.012). There were no significant ($p > 0.05$) differences observed for VO_2max and RE. Since TT improved, our hypothesis was supported and positive blood changes (e.g., hematocrit) may have contributed to the enhanced 5km SL performance.

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This thesis follows the format prescribed by Medicine and Science in Sport and Exercise and the School of Health and Human Performance of Northern Michigan University.

TABLE OF CONTENTS

LIST OF SYMBOLS AN ABBREVIATIONS

ASL – Above sea-level

CBC – Complete blood count

Hb – Hemoglobin Concentration

Hct - Hematocrit

LHTH – Live high train high

LHTL – Live high train low

MCV – Mean cell volume

PV – Plasma volume

RBC – Red blood cell count

RE – Running economy

RPE-Rate of perceived exertion

TT – Time trial

VO_2 – Rate of oxygen uptake

VO_2max – Maximal rate of oxygen uptake

INTRODUCTION

This thesis follows the format prescribed by Medicine and Science in Sport and Exercise.

During the 1968 Olympic Games in Mexico City, Mexico, aerobic athletes did not achieve greater results compared to previous Olympic Games while anaerobic event athletes showed no change or improved. This was most likely due to the high altitude of Mexico City. Since the 1968 games, the effects of altitude on the human body have been studied extensively. Much of the research on the effects of altitude has taken place with elite endurance athletes and investigating changes in performance parameters. Notably, these athletes retreated to regions of high altitude to train for aerobic sports and reap specific physiological benefits gained by training in a high altitude environment.

The aim of this study was to assess the physiological effects of altitude training on sea-level performance parameters after short-term (i.e., 12 days) altitude exposure; including easy to moderate intensity workouts while driving to various cities at moderate to high elevation above sea level (ASL) (e.g., 2,133 to 3,048 meters ASL).

CHAPTER 1: JOURNAL MANUSCRIPT

INTRODUCTION

During the 1968 Olympic Games in Mexico City, Mexico, aerobic athletes did not achieve greater results compared to previous Olympic Games while anaerobic event athletes showed no change or improved. This was most likely due to the high altitude of Mexico City (19). Since the 1968 games, the effects of altitude on the human body have been studied extensively. Much of the research on the effects of altitude has taken place with elite endurance athletes and investigating changes in performance parameters (15, 24, 33, 35). Notably, these athletes retreated to regions of high altitude to train for aerobic sports and reap specific physiological benefits gained by training in a high altitude environment (36).

Initial altitude training protocols involved many athletes transitioning to a three to six weeks of live high, train high (LHTH) types of programs (14, 15, 33, 35). This involved the athletes moving to a high altitude environment (> 2,133 m) to live and train for a few weeks. The strategy of LHTH provided a stimulus to athletes which allowed physiological components in the body to adapt to lower barometric pressure. Based on the prior mentioned research, the body responded by enhancing the transportation of oxygen in the body through increased red blood cell count (RBC), increased mean cell volume (MCV), and greater hemoglobin concentration (Hb) (25). When the athlete returned to sea level, he or she potentially gained a better internal system for delivering oxygen, which may lead to increased aerobic performance. However, the LHTH style of training was proven to be equivocal in relation to improved running performance at sea level (8, 18).

Through the previous mentioned altitude training techniques, researchers understood that several important parameters related to aerobic performance were enhanced with altitude training (1, 7, 29). One such parameter was running economy (RE), which can be beneficial to the success of endurance athletes (7) as RE has been shown to have a positive effect on running performance (39). Saunders et al. showed a significant improvement of 3.3% in RE after 20 days of simulated live high, train low (LHTL) altitude protocol (33). This further supports training at altitude as likely to improve RE (9, 32, 33).

The oxygen carrying components of the blood also affect the performance or RE of endurance athletes (1). These components include Hb, RBC, and MCV. The aforementioned variables may be the limiting factors in maximizing an individual's maximal oxygen uptake (VO_2max) (1), rendering them valuable to improved performance. Altogether, improving RE, Hb, RBC, and MCV may provide important benefits to endurance athletes.

Researchers have also shown acute improvements to aerobic performance after only 45 hours at an altitude of 3,200m (4). Furthermore, some researchers demonstrated positive hematological changes and endurance performance improvements after only 12 days at altitude (37, 35). The aforementioned studies may hold very positive benefits for recreational endurance athletes who may not have more than two weeks to travel to altitude and train due to limited vacation time. Therefore, the purpose of this study was to assess the physiological effects of altitude training on sea-level performance parameters after short-term (i.e., 12 days) altitude exposure; including easy to moderate intensity workouts while driving to various cities at moderate to high elevation above sea level (ASL) (e.g., 2,133 to 3,048 meters ASL). We hypothesized 12-days of running/hiking at altitude would elicit improved 5km TT performance based on the aforementioned, short term altitude studies. A secondary hypothesis was 12-days of altitude exposure would elicit positive changes in Hb, RBC, MCV, and RE upon return to sea-level.

METHODS

The purpose of this study was to determine the effects of altitude on performance parameters (e.g., 5km TT) and hematological measures after short term exposure to altitude.

Experimental Design. A quasi experimental design with convenience sample was used to compare performance parameters of runners after 12 days training at altitude. The independent variable in this study was the time of the altitude training protocol. The dependent variables of the study, measured in a pre- and post-test format, were: 5km TT, VO_2max, RE, Hb, Hct, RBC, and MCV.

Subjects. A total of five participants (n = 5), three male and two female, volunteered to participate in the study. Participants were sought using word of mouth. The mean age of participants was 26 ± 4 yrs. Each participant completed at least three months of running (3 – 7 days/wk) with a weekly volume of 1 – 2 hours prior to the start of the study. Thus, they were categorized as recreational runners. Participants were informed of the risks and benefits of the protocol and signed an informed consent before the study. Testing protocols were approved by Northern Michigan University's institutional review board (#HS15-643). Inclusion and exclusion criteria were established to narrow the focus of the analysis. Inclusion criteria were trained runners (≥ 1 hr·wk^{-1} of running and 3-7 day·wk^{-1} frequency of running) who trained for ≥ three months prior to the study. Exclusion criteria were any current acute injury causing a decrement to performance during running or training, pulmonary, cardiac, or metabolic disease, and greater than moderate risk for cardiac disease per the American College of Sports Medicine. Notably, a month prior to leaving for the trail running adventure camp to Colorado, we had 10 recruited participants. Due to unforeseen injury and time conflicts, five dropped out a week before departure.

Instrumentation. A Vmax 29 encore (CareFusion, San Diego, California) was used to measure oxygen uptake during the VO_2max and RE tests.

5k Time Trial Run. The performance run took place four days before departure to altitude (ALT) and the day after the return to sea-level. Prior to TT, individuals warmed up for about 10 minutes at a self-selected, sub-maximal pace of their choice. Subjects were instructed to jog slowly and perform some light stretching after the warm up, per their normal routine. All five subjects ran TT at the same time and on the same outdoor track at sea-level. Laps were counted by three individuals to ensure accuracy and time was measured using a handheld stopwatch. The conditions for both the pre and post TT were nearly identical with a temperature variation of less than ±1.67^{0}C and ~ 4.47 m·sec^{-1} wind coming from the south on both days.

Incremental VO_{2max} and RE Protocol. Baseline, incremental VO_2max and RE tests were completed two days after TT and one day before departure to altitude. Subject's height and weight were recorded. For the incremental VO_2max and RE tests, runners began by warming up for 10 minutes. The warm up consisted of a light jog at self-selected speeds of each person's choice and some stretching.

RE Stages. The subjects began the test by running at a speed about 31.8 $m \cdot min^{-1}$ slower than a pace determined by Jack Daniel's Running Formula (9). Individual paces were determined using 5kmTT time in conjunction with 'threshold pace' in a chart in Jack Daniel's Running Formula (9). The treadmill was set at a 1% grade to simulate running outdoors on a flat surface (20). After four minutes, treadmill speed was increased by 0.27 $m \cdot sec^{-1}$ and subjects ran at this pace for another four minutes. VO_2,was averaged over 60 seconds for the last minute of the second stage only to determine RE.

VO_2max Stages. After determining RE during stage 2, an incremental VO_2max protocol was initiated. The speed of the treadmill was dropped to the individual's starting speed of 31.8 $m^{-1} \cdot min^{-1}$ slower than a pace determined by Jack Daniel's Running Formula (9) and the grade was increased by 1% every minute until the subject achieved volitional exhaustion. VO_2 was measured and averaged every 30 seconds during this stage and the maximum value was recorded in both absolute ($L \cdot min^{-1}$) and body-weight relative values ($ml \cdot kg^{-1} \cdot min^{-1}$). Secondary criteria for VO_2max included a maximum heart rate within 10 beats of the individual's age predicted maximum heart rate, a respiratory exchange ratio of 1.10, and a rate of perceived exertion of 16-18 on the Borg scale. After completion of the tests, individuals were instructed to cool down by jogging lightly for ten minutes.

Blood Parameter. After a 12 hour, overnight fast, a CBC was obtained from each individual. The CBC was performed in the morning, prior to the incremental VO_2max and RE test. Blood was drawn from the antecubital vein of the left arm both pre- and post- altitude exposure. Four primary blood variables were used in this study: RBC, Hb, MCV, and Hct. Notably, RBC, Hb, MCV, Hct, and plasma volume (PV) were used to assess the oxygen carrying parameters of the blood. PV was measured to possibly explain significance in other blood parameters.

Location. The study took place in the state of Colorado in the United State of America. The group lodged in three different cities over the course of 12 days. These cities were Gunnison (2,347m), Buena Vista (2,427m), and Estes Park (2,292m). The average altitude of the three combined cities is 2,357 meters above sea-level. The group traveled to these elevations to ensure training above the mark of 2,194m which may be the most beneficial elevation for eliciting the best results for altitude training (37). Lodging was located near each city. Average lodging elevation was ~2,438m ASL. The group traveled to different areas and elevations around each city to train. Training elevations ranged from 2,346 – 4,326 m ASL. The list of training locations and maximum and minimum altitudes are located in Table 1.

Training Protocol. The intensity for all runs were to be ~60% heart rate max (34), or around a rate of perceived exertion (RPE) of 4 – 6, and was measured daily using RPE. Only one run/hike was scheduled each day with no further physical activity taking place. To reach this intensity, a mixture of running and hiking was used since many of the trails involved steep inclines. The average length of the daily runs was 2.95 ± 1.86 hours with the longest being seven hours and the shortest 30 minutes. The total time spent performing aerobic exercise over the 12 days was 29.5 hours. The daily training volume varied to ensure proper recovery after long bouts of aerobic exercise. Table 1 details the amount of time spent training each day of the study.

Statistical analysis. IBM SPSS statistics version 23 was used to assess statistical significance of all recorded data. A paired-sample, two tailed t-test was used to assess all pre and post measures during the study. Significance was set at $p < 0.05$.

RESULTS

Pre and post values for individuals are listed in Table 2. Individual weight pre (67.7 ± 12.4 kg) and post (66.8 ± 11.3 kg) was not significantly different ($t(4) = 1.748$, $p = 0.155$). There was a difference ($t(4) = 6.132$, $p < 0.004$) between the two 5km performance run results as pre 5km performance (21.5 ± 2.7 min) was slower than post (20.87 ± 2.7 min). Figure 1 shows pre and post 5km performance time trends for all individuals. RE did not change significantly ($t(4) = 1.075$, $p = 0.343$) before (47.03 ± 4.31 $ml \cdot kg^{-1} \cdot min^{-1}$) and after (46.01 ± 3.31 $ml \cdot kg^{-1} \cdot min^{-1}$) training. RBC increased significantly ($t(4) = -5.519$, $p = 0.005$) from pre (4.83 ± 0.47 x $10^6 \cdot \mu L^{-1}$) to post (5.1 ± 0.43 x $10^6 \cdot \mu L^{-1}$) values. Hb increased significantly ($t(4) = -4.366$, $p = 0.012$) from pre (13.88 ± 2.2 $g \cdot dL^{-1}$) to post (15.04 ± 2.08 $g \cdot dL^{-1}$) values in response to the study protocol. MCV did not show a significant ($t(4) = -1.79$, $p = 0.148$) increase from pre (87.44 ± 5.45 fL) to post (87.96 ± 5.89 fL) values. There was a significant ($t(4) = -3.25$, $p = 0.031$) increase in the Hct of the blood from pre (41.98 ± 5.6 %) to post (44.86 ± 5.8 %). PV did not elicit any significant ($t(4) = -0.173$, $p = 0.871$) changes from pre (8.48 ± 0.59 fL) to post (8.5 ± 0.45 fL) values; thus further validating Hct and Hb. VO_2max showed no significant change before ($t(4) = 1.429$, $p = 0.226$) and after training ($t(4) = 0.88$, $p = 0.425$), respectively. Fee figures1, 2, and 3 for individual pre- and post-5km TT, Hb, and RBC, respectively.

DISCUSSION

We showed short-term altitude exposure can improve performance at sea-level. In particular, we hypothesized a change in 5k TT performance at sea level after short term (i.e., 12 days) altitude exposure with unstructured training at an assumed low to moderate pace to best maintain current fitness. Our main hypothesis, 12 days of altitude exposure would increase 5km TT performance, was supported. Additionally, secondary metabolic and hematological variables were measured pre- and post-ALT. Metabolic variables included VO_2max and RE. Primary hematological indices were Hb, Hct, RBC, and MCV. Five individuals trained at low intensity for 12 days in a high altitude environment. Upon return, 5km TT results improved. Secondarily, RBC, Hct, and Hb improved with exposure to altitude while MCV, VO_2max and RE showed no change.

Five km TT improved significantly after 12-days at altitude. Notably, each day of the TT, weather conditions at the outdoor track were almost identical and ideal. Wind was a steady 10 mph out of the south and the temperature was within three degrees on both days. Since VO_2max and RE showed no change, the increase in performance may have been related several variables. Familiarity to the 5km TT may have played a role in improved performance on return to sea-level (27). The runners may have been in the taper period of training, per the assumption they maintained their current fitness with unstructured workouts and whereby overall fatigue was lessened, allowing return to sea-level performance to be potentially be enhanced (34). Lastly, the final VO_2max and RE data may be skewed as individuals may have been fatigued and/or lacked motivation on the final day of testing (34). Researchers have shown comparable changes in RBC, Hb, Hct and MCV, which may relate to improved sea-level performance after four weeks at altitude (23). While no change in MCV was illustrated in this study, RBC, Hb, and Hct all elicited greater response after the 12 days of altitude training. In support of this but with less time spent at altitude, the present investigators illustrated how short duration (12-days) altitude exposure may elicit a positive response in RBC, Hb, and Hct.

RE showed no change before and after altitude training. Previous studies showed improved RE as a benefit to altitude training (13, 17, 33). These studies also documented an improvement in running economy by about 3.3 – 3.5 % after altitude exposure in elite runners (17, 33). The present study presented a slight decrease overall in mean RE (-1.02 ± 1.89%) for the runners but the value is marginal and not statistically significant. This may have been due to the short stay at altitude as most studies show changes after at least 20 days of altitude training (15, 33) as well as the small sample size. Furthermore, not performing workouts to elicit gains in muscular power (e.g., interval training) may have also played a role into no change in RE in the current study. In partial support of this, another group of researchers found no change in RE in a control group only running low intensity endurance runs for nine weeks (28). Ultimately, the lack of change in RE in the current study was most likely due to low number of subjects and short study duration (i.e., 12-days). It is clear prior researchers have observed improvements in RE after training at altitude. While there are many variables which may account for the lack of significant RE change in the current study (i.e., short altitude exposure, lack of structured high intensity workouts), more research is needed on the topic of RE and altitude training.

In this study, hematological parameters showed changes after exposure to altitude. RBC improved after altitude training, which is a common outcome in altitude research lasting three to four weeks (5, 23). In the present study Hb and Hct also improved after altitude exposure. Some researchers showed the increase in Hb and Hct might be due to changes in PV (31). The present study showed no change in mean PV for individuals, suggesting changes in PV cannot account for any change in Hb and Hct. Ultimately, researchers suggest the oxygen carrying blood components may be the limiting factor for maximal aerobic performance (1). If this is the case, in the present study, increasing a person's ability to deliver oxygen is key (i.e., elevated Hct, Hb, RBC) and along with maintained VO_2max and RE, improved 5km time trial performance may be partially explained.

There was no significant difference in VO_2max from pre- to post-ALT training. VO_2max has been shown to increase after 28 days of intermittent hypoxia (38). Investigators showed high intensity aerobic training while at hypoxia, which is a possible mechanism for the increased VO_2max (9). The intended training in this study was unstructured and subjective; and as each subject was instructed to exercise at an RPE of 4-6 with no high intensity workouts, this was likely why there was no increase in VO_2max (9). Hence, VO_2max is not linked to an increased performance in the current investigation and our low number of participants may have masked any actual effects of VO_2max on performance.

Individual differences may have also contributed to the results of the study. Table 3 compares the changes in performance variables for the subjects who improved the least and the most for the 5km TT. This data was utilized to analyze the participant who improved the most vs. the one who improved the least on the 5km TT.

While most performance variables tended to move in a similar direction for each individual, VO_2max did not. The subject who improved least for the 5km TT elicited a 5% decline in VO_2max from pre to post while the subject who improved the most showed a 1% increase. Since VO_2max is highly correlated to performance, this may have been the reason for the lack of improvement.

In summary, 12 days of unstructured, low to moderate intensity training at altitude is enough to elicit a positive change in 5km TT performance. 12 days of altitude exposure also elicited an increase in RBC, Hb, and Hct. After 12 days of unstructured, low to moderate intensity training at altitude, no changes in RE, MCV, or VO_2max were observed. It is clear short term altitude exposure can have a positive effect on distance running performance. More research is needed to clarify specific mechanisms to this increase in performance.

CHAPTER II: LITERATURE REVIEW

The purpose of this study was to evaluate the effects of altitude components affecting running performance. The purpose of the literature review is to give insight into the sport of running and educate the reader on important components and terms related to running performance. This literature review will be separated into five sections: (a) brief history of altitude training, (b) running performance, (c) running economy, (c) VO_2max, and (e) blood composition.

Altitude Training

Altitude training can have a significant impact on athletic performance. At the 1968 Olympic Games in Mexico City, Mexico, aerobic endurance athletes showed a decrease in performance while anaerobic athletes showed improvements or stayed the same (19). Since Mexico City, Mexico is located at an elevation of 7500 ft above sea level (ASL), the high elevation was labeled as the culprit for the decreases aerobic performance. The 1968 games may have marked the beginning of high altitude training which has been prevalent among elite athletes and researchers alike (3, 5, 8, 15, 22, 37).

The primary mechanism for altitude effect on aerobic performance is the lack of oxygenation of the blood (25). At high altitude environments, the barometric pressure is markedly lower than sea-level. The air is less compressed, meaning lesser concentrations of oxygen are present in the atmosphere. In lieu of the lower atmospheric pressure, the partial pressure of oxygen (PO_2) is also reduced. Since the PO_2 is the main driving force of blood oxygenation, less oxygen is transported into the capillaries of the lungs and ultimately the blood (25).

Since decreased PO_2 allows less oxygen to be transported through the alveoli and into the blood stream, the body may adapt by enhancing the oxygen carrying capacity of the blood may be attained. The aforementioned enhancements can occur in different ways. Increased erythropoietin levels and augmentation of the production of red blood cells occurs in hypoxic conditions (16). These phenomena result from the activation of the hypoxic-inducible factor-1 pathway under hypoxic conditions (16). The augmentation of blood cell production leads to a greater number and size of red blood cells circulating throughout the body. As long as individuals ensure proficient iron intake, the oxygen carrying capacity of the blood can be enhanced. These hematological enhancements have prompted both researchers and athletes to develop altitude training modalities.

Two distinct altitude training modalities established are live high, train high (LHTH) and live high, train low (LHTL) (11). LHTH involves living and training at high altitude. LHTL has individuals living at high altitude but doing their training at lower altitudes. Since oxygen saturation of the blood and performance may be compromised at high altitudes, athletes travel to lower elevations to train at the high intensities needed to improve or maintain performance (3). Both LHTH and LHTL have shown enhancements in hematological components (11) but LHTL shows more positive effects in regards to sea-level performance (3, 23, 38). The increases in performance after LHTL may be primarily due to the maximum volume of oxygen uptake (11). LHTH and LHTL seem to both elicit hematological enhancements while LHTL allows for more performance related benefits (11).

A study by Brugniaux et al. detailed LHTL of 18 middle distance athletes (3). Athletes spent 14 hours per day in hypoxia and were tested before, immediately after, and 15 days post cessation of LHTL protocol. Individuals were required to supplement with iron pills during the training protocol. Athletes were tested for maximal oxygen uptake, ventilation threshold, and hemoglobin mass and red cell volume were measured (hemoglobin mass and red cell volume). Significant improvements for maximal oxygen uptake and maximal aerobic power were noted immediately following cessation of the training protocol. While hemoglobin mass significantly increased immediately post training, there was no significant increase in red cell volume. Fifteen days after cessation of training, blood parameters returned to pre-altitude training levels.

A study by Wilhite, Mickeborough, Laymon, and Chapman also illustrated changes to performance parameters with a LHTL protocol (38). Seven elite distance runners traveled to an elevation of 2,150m and followed a LHTL model. The athletes had begun supplementing ferrous sulfate into their diet four weeks prior to the trip. Athletes completed a maximal oxygen uptake test before and immediately following cessation of the LHTL protocol. Significant increases in VO_2max relatively to body mass were observed. All subjects also lost body mass while at altitude. A significant increase in ventilator exchange was also observed prior to the LHTL protocol.

One important aspect of altitude training is the ‘dose’ of altitude. ‘Dose’ can be defined here as the specific elevations and length of time spent at altitude. 2,000 to 2,500 m (6,561 – 8,202 ft) has been observed to be the best altitude to elicit both hematological and performance gains in athletes (5). Levine et al. showed living at altitudes higher or slightly lower (1,780 m) than 2,000 to 2,500 m did elicit hematological enhancements whereas no changes to performance occurred in these extreme regions (5). In this study, 48 collegiate distance runners were randomly assigned to four living altitudes (1,780, 2,085, 2,454, or 2800m) where they would live for 28 days. Participants completed hematological, metabolic, and performance measures at sea level, before and after altitude training. Athletes in this study also completed iron supplementations up to four weeks before training. The athletes reported 3 – 4 high intensity workouts per week at their respective elevations. Sea level 3,000m time trial significantly improved after altitude training for athletes at the two middle elevation but not for 1,780 and 2800m. VO_2max improved significantly for all groups except the 1,780m group. Erythropoietin concentration significantly increased for all groups at altitude but stayed increased up to 72 hours after altitude exposure only in the 2,800m group. Erythrocyte volume was also significantly increased in all groups from pre- to immediately post altitude. This study shows altitudes of 2,080 to 2,454 may be best for eliciting hematological and metabolic changes which may lead to increased performance.

In regards to the specific length of time, as little as three days of altitude exposure may have a positive effect on performance (4). Most research; however, involves at least 18 days (3, 15, 33) and up to around four weeks (11) living at altitude. Heinicke, Heinicke, Schmidt, and Wolfarth observed 10 athletes undergoing a 21 day training camp at a mean altitude of 2,050m. Subjects elicited significant improvements in hemoglobin concentration, hematocrit, and plasma concentration. Hemoglobin mass and red cell volume also increased at altitude but returned to sea-level values after 16 days. It seems the best elevations for altitude related performance gains are between 2,000 and 2,500 m. The best length of time to live at altitude may be 18 – 30 days.

The final element discussed in the altitude section of this review is normobaric vs. hypobaric hypoxia. Specialized chambers have been created which simulate the hypoxic conditions of altitude through two mechanism. A normobaric, hypoxia (NH) chamber increases the percentage of nitrogen in the air, ultimately decreasing the total percentage of oxygen available to subjects. A hypobaric, hypoxic (HH) chamber decreases barometric pressure in the chamber, simulating a 'true' altitude environment. Research of NH environments is equivocal (2, 10, 21), which may point to HH environments as being a more favorable training environment.

Berglund, Gennser, Ornhagen, Ostberg and Wide observed increases in blood components after exposure to NH (2). Seven subjects were confined to a NH chamber for 14 consecutive days. EPO, hemoglobin concentration, hematocrit, and ferritin concentration were assessed before and after the hypoxic confinement. All four blood parameters showed an increase from pre-NH protocol levels. This is contradictory to results observed by Julian et al. where fourteen elite distance runners (21). Participants underwent intermittent NH for 70 minutes, five times per week for four weeks. VO_2max, 3000m time trial performance, EPO, soluble transferrin receptors, and reticulocyte paramters. No significant changes were reported in any variables measured from pre- to post NH protocol.

Running Performance

Running performance can be defined as a runner's ability to cover a set distance in a certain amount of time (9). Generally, the faster the athlete covers this distance, the better the performance. While running performance is often the final result of a running program, there are numerous factors that play into the performance of a runner (7, 29, 30). This review focuses on three variables which affect runner's performance: the maximum volume of oxygen consumption (VO_2max), running economy (RE), and hematological indices.

Maximum Volume of Oxygen Consumption

The maximum volume of oxygen consumption is termed VO_2max and is highly correlated with aerobic performance (29). VO_2max is the maximum volume of oxygen the body can uptake at the muscular level. This is typically measured through an open-circuit gas analyzer in a laboratory setting. VO_2max is a function of cardiac output (Q) and the degree of extraction of oxygen from arterial blood, or arterio-venous oxygen difference (a-vO_2). Altitude affects this equation by lowering the amount of arterial oxygen available for use. The Fick equation for VO_2max is given below (25).

$$VO_{2max} = Q \times a\text{-}vO_2$$

There are two ways VO_2max is primarily measured: absolutely and relatively (34). Absolute VO_2max is measured typically measured in $L \cdot min^{-1}$ and is a measurement of power since it is related to time. Relative VO_2max is relative to an individual's body weight and is typically measured in $ml \cdot kg^{-1} \cdot min^{-1}$. VO_2max can be described relative to body weight by dividing by an individual's mass in kilograms. Measurement of VO_2max is typically done using an incremental protocol which gradually raises exercise intensity through grade, speed, or resistance, depending on the chosen exercise modality (6).

Since VO_2max is correlated to aerobic performance, many athletes plan training which will increase or maintain his/her current VO_2max. This style of training can be accomplished by training at intensities about 98% of heart rate max for durations lasting less than five minutes (9). These intervals are coupled with a 1:1 or less rest ratio to allow appropriate recovery. The main idea is to exercise at a high enough intensity to allow the body to reach VO_2max and then recover (34). Each repetition is repeated a number of times before the workout is complete. In this way, an individual can gain, or maintain their VO_2max (9).

Running Economy

Runners who use less oxygen compared to other runners while running at the same speed are more economical (12). Running economy (RE) can be defined as the energy demand for a given velocity of submaximal running and is determined by measuring the steady-state consumption of oxygen (VO_2) (32). The lower the VO_2 at a certain speed, the better the RE of the individual. Using less oxygen at speeds ultimately translates to expending less energy at that same speed. This is why RE is an important physiological factor linked to running performance (7, 12).

Just like VO_2max, RE can be enhanced in runners through training as RE has been shown after simply beginning a running training program, RE improves naturally (27). As runners become more experienced, it becomes difficult to improve RE and more specific training modalities may need to be implemented. Explosive strength and power exercises have been shown to provide improved RE in individuals (28). This may due to neuromuscular adaptations to the strength and power exercises. Another training modality for RE is altitude training where investigators have also proved RE is enhanced after altitude training (33).

A study by Saunders et al. enhances in RE after 20 days of altitude exposure (33). In this study, elite runners participated in LHTL altitude training. Average VO_2 (L/min) was 3.3% lower across three running speeds pre to post altitude training. There was no decrease in ventilatory exchange meaning the improvements in RE could not be contributed to a lower energy cost of ventilation. There was also no increase in lactate concentration post altitude intervention, meaning the improved RE could not be explained by use of carbohydrates as a primary fuel source. The conclusions were that 20 days of LHTL improved the RE of elite distance runners.

The previous study is in agreement with other observations of improved RE after LHTL (17). Saunders et al. documented a drop in submaximal VO_2 by 3.2%. Similar to the study by Saunders et al., the specific mechanisms for improved RE are unspecified. What is clear is altitude training elicits an enhancement in RE. Since RE is linked to performance, the improvements of RE after altitude trainings adds another reason why athletes train at higher elevations.

Blood Composition

The final component covered in this literature review is the blood composition of runners. While blood is composed of a variety of substrates, enzymes, hormones, among other constituents, the focus in this review will be on mean red blood cell volume

(MCV), hemoglobin concentration (Hb), red blood cell count (RBC), and hematocrit (Hct). Each of these blood components is measured by a laboratory procedure termed complete blood count.

MCV has been shown to increase with altitude exposure (15). Heinicke et al. observed a significant increase in RBV after 20 days of altitude exposure (15). Six males and four females trained at altitude for 20 days. Blood measurements were obtained on day 1 and 20, as well as 16 days after return to sea-level. MCV as well as erythropoietin concentrations increased at altitude and returned to near sea-level values by day 16 after return to sea-level. This study shows an enhancement in RBC and erythropoietin after 20 days of altitude exposure, which seems to only last a short time (< 16 days).

RBC, Hb, and Hct also increase with altitude exposure in studies where individuals lived at altitude for an extended period of time (> 20 days) MCV, RBC, Hb, and Hct increased (15, 23). Xiaoxia et al. showed increases in RBC, HC, and Hct after 28 days of altitude exposure (23). 7 individuals were exposed to HH for 12 hours a day for four weeks while completing a LHTL regimen. RBC, Hb, and Hct reached peak levels after 19 days of altitude exposure. This study details further enhancements in blood oxygenation by increases in RBC, Hb, and Hct after altitude exposure.

Since oxygen uptake in the muscles may be limited by the amount of oxygen carried in the blood (1), increasing these parameters may hold performance benefits for athletes. HH signaling the HIF-1 pathway promotes EPO release by the kidney, leading to an increase MCV, RBC, Hb, and Hct (1).

Summary of Literature

Running is a simple sport with a complex, dynamic training approach. Altitude training has been a popular training modality since the 1968 Olympic Games (19). Runners all around the world choose high altitude locations because of the physiological benefits elicited by a hypoxic environment. These physiological changes include enhanced oxygen carrying-capacity of the blood (23) and improved RE (33), both which may provide improved performance on return to sea-level (7, 23). Much of the literature indicates at least 20 days of living at high altitude to elicit such results (14, 15, 33).

Running performance may be defined as the amount of time a specific distance is run in (9). Most athletes desire to improve performance. Factors linked to improved performance in runners are VO_2max, RE, and BC (7, 29, 31).

VO_2max is the maximal amount of oxygen the body can take up. VO_2max is a measurement of aerobic power, is correlated to running performance (29), and can be improved through specific training (9). Carefully programmed training usually focuses on improving or maintaining VO_2max in order to maximize performance (34).

RE is the amount of energy expended by a runner at a given speed (9). RE is directly linked to performance (7) and is trainable simply by beginning a running program (27). RE can be enhanced with altitude training (17, 33). This may be due primarily to decreased ventilation exchange or primary use of carbohydrates as a substrate (33).

Blood composition contains many proteins, enzymes, substrates, and other molecular compounds necessary for life. Of these compounds, hemoglobin and red blood cells are primarily in charge of delivering oxygen to necessary sites. And increase in size and number of red blood cells allows the attachment of more hemoglobin, which also contributes to greater oxygen delivery (23). Since oxygen delivery may be the key limiting factor of an individual's VO_2max (1), increasing these hematological parameters may lead to an increase in aerobic performance (23). Altitude training is one modality which is known to enhance these oxygen-carrying components (23).

CHAPTER III: CONCLUSIONS AND RECOMMENDATIONS

It is clearly shown altitude training is a vital part of many elite athletes training regimens (15, 35). The benefits of altitude to sea-level performance are numerous. Many of these benefits are said to be gained after three to six weeks of training (11, 15, 35). This length of time may not be feasible for the "weekend warrior". The current investigators showed physiological adaptations can occur with short-term (12 days) exposure and training at high altitude. 5km performance times were enhanced while RBC, MCV, Hb, and Hct showed increases. This study can hold much value and application to individuals with choosing to spend their limited free time training at altitude. This investigation does have some limitations. Inconsistencies in training for each subject prior to the study must be taken into account. Each subject had a given specific intensity, frequency, and weekly duration for training runs prior to the study. While all individuals gave word of mouth testimony to completion of the inclusion criteria, it is possible some subjects may have failed to meet the minimal training requirements. The lack of a control is another limitation to this investigation. Lastly, the small population (n = 5) of the research provides a limitation. Future studies are needed to better understand the benefits and mechanism which elicit these noted responses.

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TABLES

TABLE 1. Altitude Training Sites and Run/Hikes in Chronological Order

Location of run	**Elevation of run (min-max)**	**Duration of run/hike (hr:min:sec)**
Hartman Rocks Gunnison, CO	8,000 ft – 8,500 ft	2:00:00
Hartman Rocks Gunnison, CO	8,000 ft – 8,500 ft	2:00:00
Gothic Road Gothic, CO	9,700 ft – 10,722 ft	3:30:00
Deer Trail Crested Butte, CO	9,000 ft – 10,500 ft	5:00:00
Blue Mesa Dam Gunnison, CO	7,500 ft – 7,700 ft	0:30:00
Browns Canyon Buena Vista, CO	8,200 ft – 8,900 ft	2:00:00
Browns Canyon Buena Vista, CO	8,000 ft – 8,200 ft	1:00:00
Mount Yale Buena Vista, CO	9,900 ft – 14,196 ft	7:00:00
Lumpy Ridge Estes Park, CO	7,700 ft – 8,860 ft	4:00:00
Twin Sisters Peak Estes Park, CO	9,100 – 11,427 ft	2:30:00
	Average: 8,510 – 9,750 ft	Average: 2:57:00 Total: 29:30:00

TABLE 2. Pre and post values for all performance parameters

Variable	**Pre**	**Post**	**P-value**
Weight (kg)	67.72 ± 12.41	66.82 ± 11.28	0.155
5 km performance time (min)	21.5 ± 2.73	20.86 ± 2.7*	0.004
RE ($ml \cdot kg^{-1} \cdot min^{-1}$)	47.03 ± 4.31	46.01 ± 3.31	0.343
RBC (x $10^6 \cdot \mu L^{-1}$)	4.83 ± 0.47	5.1 ± 0.43*	0.005
Hb ($g \cdot dL^{-1}$)	13.88 ± 2.2	15.04 ± 2.08*	0.012
MCV (fL)	87.44 ± 5.45	87.96 ± 5.89	0.148
Hct (%)	41.98 ± 5.6	44.86 ± 5.8*	0.031
PV (fL)	8.48 ± 0.59	8.5 ± 0.5	0.871
Absolute VO_2max ($L \cdot min^{-1}$)	4.02 ± 1.12	3.87 ± 1.24	0.226
Relative VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$)	58.58 ± 8.0	57.12 ± 10.05	0.425

Note: *Denotes significance at $p < 0.05$ vs. pre-test.

TABLE 3. Individual differences of the two subjects on each extreme of the 5km performance

Performance Variables	Δ Least Improved (Δ%)	Δ Most Improved (Δ%)
5 km time (min)	-0.33 (-1%)	-0.91 (-5%)
VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$)	-3.1 (-5%)	+0.6 (+1%)
RE ($ml \cdot kg^{-1} \cdot min^{-1}$)	+2 (+5%)	-1.3 (-2%)
RBC ($x\ 10^6 \cdot \mu L^{-1}$)	+0.2 (+4%)	+0.23 (+5%)
Hb ($g \cdot dL^{-1}$)	+0.8 (+5%)	+0.9 (+6%)
MCV (fL)	+0.5 (+1%)	+0.1 (0%)
Hct (%)	+2.1 (+4%)	+2.1 (+5%)
PV (fL)	-0.3 (-3%)	+0.4 (+5%)
Body Weight (kg)	-1.3 (-2%)	-0.9 (-1%)

FIGURES

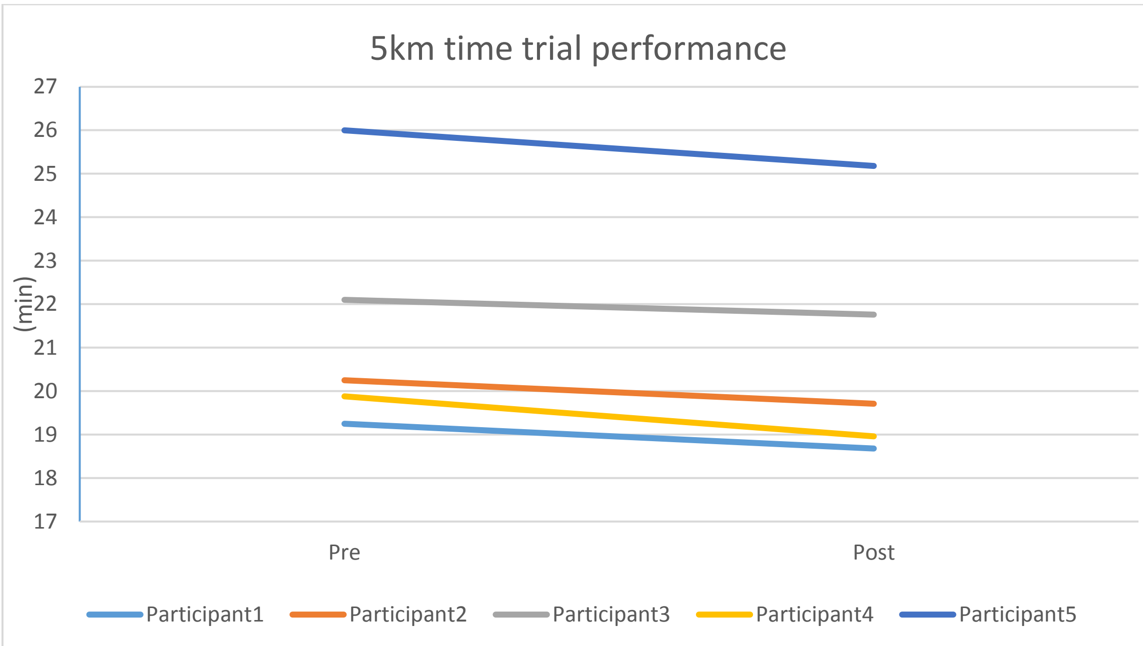

Figure 1. Pre and post 5km time trial performance results for all subjects

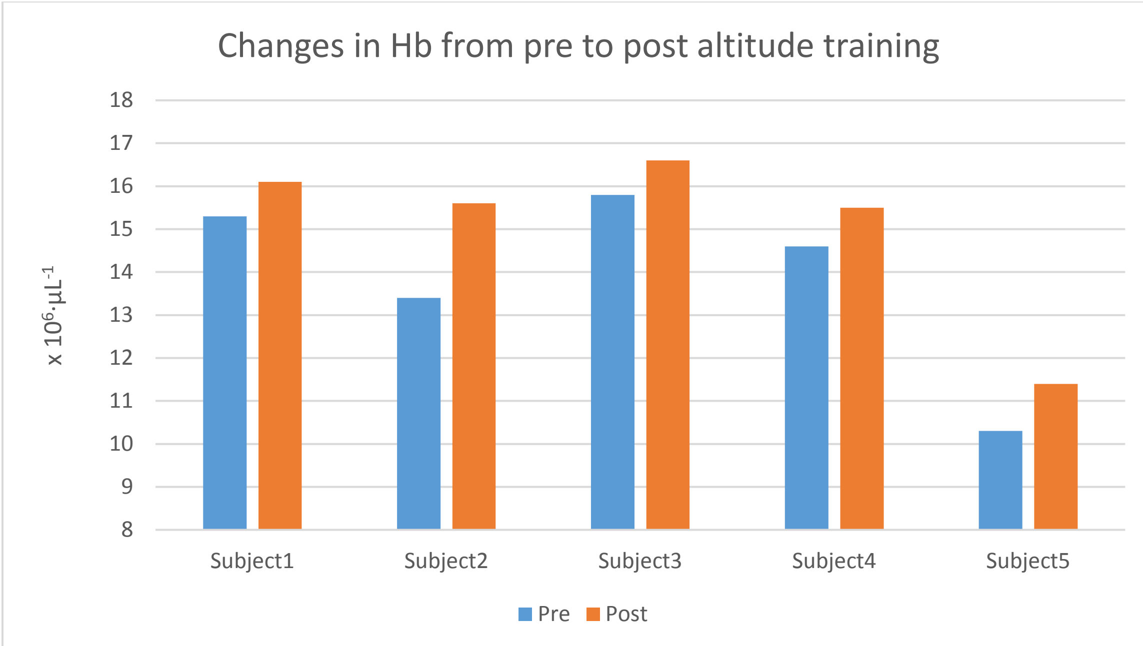

Figure 2. Pre and post Hb values for each subject

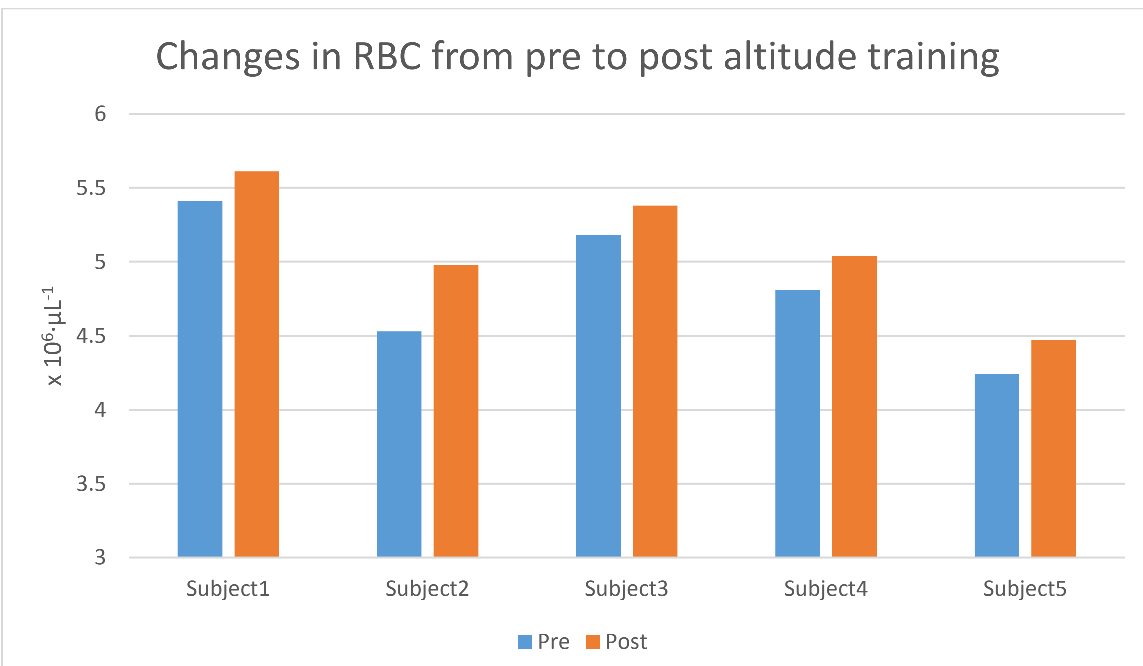

Figure 3. Pre and Post RBC values for each subject

APPENDIX A

NORTHERN MICHIGAN UNIVERSITY

DEPARTMENT OF HEALTH AND HUMAN PERFORMANCE

CONSENT TO ACT AS A HUMAN SUBJECT

Subject Name (print):________________________________ Date __________

1. I hereby volunteer to participate as a subject in exercise testing. I understand that this testing is part of a study entitled: "The effects of altitude training on physiological components of running performance during the final two weeks of a running training program." The purpose of this study was to examine the effects of altitude training on physiological components of running performance during the final two weeks of a running training program.

   I hereby authorize Andrew Jones, Scott Drum, and/or assistants as may be selected by them to perform on me the following procedures:

   (a) I understand that I will perform a VO_{2max} test and Running Economy Test on a treadmill.

   (b) I understand that I will be required to perform a 5 km run for time.

   (c) I understand that blood will be drawn for analysis.

   (d) I understand I will be required to train at high altitude for two weeks.

2. The procedures outlined in paragraph 1 [above] have been explained to me.

   I understand that the procedures described in paragraph 1 (above) involve the following risks and discomforts: musculoskeletal injuries including but not limited to; muscle strains, and ligament sprains, initial discomfort due to acute mountain sickness.

In order to prevent any of the above-mentioned risks, I understand that the examiners shall adopt the necessary measures to prevent them such as: using physical tests in accordance with my athletic conditioning. However, I understand that I can terminate any testing at any time at my discretion. I should stop any test if I experience any abnormalities such as dizziness, light-headedness, pain, or shortness of breath, etc.

3. I have been advised there could be educational benefits for training and injury reduction in the future, but there are no direct benefits to me at this time.

4. I understand that Andrew Jones, Scott Drum and/or appropriate assistants, as may be selected by them, will answer any inquiries that I may have at any time concerning these procedures and/or investigations.

5. I understand that all data, concerning myself will be kept confidential and available only upon my written request, unless the IRB board requests the review of my data. I further understand that in the event of paper publication, no association will be made between the reported data and myself.

6. I understand that there is no financial compensation for my participation in this study.

7. I understand that in the event of physical injury directly resulting from participation, compensation cannot be provided. However if injury occurs, emergency first aid will be provided and the EMS system activated if necessary.

8. I understand that I may terminate participation in this study at any time without prejudice to future care or any possible reimbursement of expenses, compensation, or employment status.

9. I understand that if I have any further questions regarding my rights as a participant in a research project I may contact Dr. Brian Cherry (906-227-2300) bcherry@nmu.edu, Assistant Provost of Graduate Education/Research of Northern Michigan University. Any questions I have regarding the nature of this research project will be answered by Dr. Scott Drum sdrum@nmu.edu or Andrew Jones andrjone@nmu.edu.

Subject's Signature:____

Witness:_______________________________________ Date:________

APPENDIX B

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	**Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	2.	**Do you feel pain in your chest when you do physical activity?**
☐	☐	3.	**In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	4.	**Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	5.	**Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	6.	**Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	7.	**Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ____________________

SIGNATURE ____________________ DATE ____________________

SIGNATURE OF PARENT ____________________ WITNESS ____________________
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

continued on other side...

APPENDIX C

Intake survey for well-trained runners

"The effects of altitude exposure on physiological components directly relating to improved distance running performance"

Name:____

Age: __________ Gender: M F Height (cm):__________ Weight (kg):__________

Please list personal bests from the last 5 years in any of the running events listed below

800m: _______ 1500m: _______ Mile:_______ 3k: _______

2 mile: _______ 5k: _______ 10k: _______ Marathon: _____

How many years of competitive running experience have you had prior to the survey?

____

Do you have any current injuries which will prevent you from running for the next 3 months?

Yes No

If yes, please explain.

____

____

____

Do you have a heart or metabolic condition that will prevent you from running for the next 3 months? Yes No

If yes, please explain.

____

____

APPENDIX D

Altitude Study Journal

Date: 6/8/2015 Days at Altitude: 1

Location: Gunnison, CO Elevation: ≈ 8000 ft Time: 8:00 a.m. MT

Temperature: 73^0 F Conditions: Sunny Run Length: 2:00:00

Notes

We ran today at Hartman Rocks recreational area. The majority of the run was spent on double track roads winding through the land with about 20% of the run taking place on single track trails which zigzagged along steeper and rockier portions of the terrain. The beginning of the run was very easy with the pace increasing slightly after the 1 hr mark. Toward the end, the group split up a little to run at individual paces. The only adverse effects of the run was sunburn due to lack of sunscreen. Altitude was noticed, especially on the hills. Some members of the group complained of a headache today.

Date: 6/9/2015 Days at Altitude: 2

Location: Gunnison, CO Elevation: ≈ 8000 ft Time: 8:00 a.m. MT

Temperature: 75^0 F Conditions: Sunny Run Length: 2:00:00

Notes

The run today also took place at Hartman Rocks recreational area. The run today took place mostly on single track trails. We chose a steeper, rocker course to begin our run. The latter portion of the run was spent on easier terrain which moved easily through the land. Altitude was definitely noticed on the steep portions of today's run. The majority of the first part of the exercise was spent walking up steep sections to avoid too high of a heart rate. The pace was quickened to a run once we got back to easier terrain. Some members of the group were a bit dehydrated today after the run. There was no complaining of headaches from anyone. Sunscreen was worn to avoid sunburn.

Date: 6/10/2015 Days at Altitude: 3

Location: Crested Butte, CO Elevation: ≈ 9100 ft Time: 11 a.m. MT

Temperature: 66^0 F Conditions: Cloudy/Rainy Run Length: 3:30:00

Notes

Today's run took place on Gothic Rd. just north of Crested Butte. We ran up to Schofield pass before road conditions became 'un-runnable' due to snow. The majority of the run was spent on a dirt road winding through the mountains and up to the pass. Once we reached our cars after returning from the pass, we continued to run and found a trail winding up the side of a mountain to the west. As we approached the top of the mountain, conditions turned for the worst and a cold, heavy ran set in. We chose to turn back and finish the run 1.5 hours early. The pace today was smooth and consistent. We started easy due to the length of the run and finished hard with a hillier route. Other than the rain, there were no complaints of headache or dehydration. This is probably due to the mild temperature and lack of sunlight we received in the mountains. Everyone felt a bit fatigued at the end of today's run.

Date: 6/11/2015 Days at Altitude: 4

Location: Crested Butte, CO Elevation: ≈ 9000 ft Time: 8:00 a.m. MT

Temperature: 68^0 F Conditions: Rainy then Sunny Run Length: 5:00:00

Notes

We ran deer trail, which is just east of Crested Butte. The trail began with a gradual climb up into the forest of the surrounding mountains. The trailed continued to climb through the forest for a few miles. Once we were toward the top of the mountains, the trail opened up to stunning vistas of the surrounding land and held fairly fat for a number of miles. We turned around at the 2:30:00 mark and ran/walked the same trail back to the parking lot. Although tired, the run today was by far the most beautiful of the trip, which seemed to lifts everyone's spirit a bit. We are quite exhausted today and in need of some good rest. A very consistent, solid effort today for the entire length of the run.

Date: 6/12/2015 Days at Altitude: 5

Location: Gunnison, CO Elevation: ≈ 7500 ft Time: 11:00 a.m. MT

Temperature: 70^0 F Conditions: Sunny Run Length: 30:00

Notes

Today's run was very easy totaling only 30 minutes. The run took place at Blue Mesa Reservoir. The run was held on a dirt road with wound up a steady incline. At the 18 minute mark, the runners turned around and completed the rest of the run back to the car. Today's run was only 30 minute due to some members feeling a bit of fatigue and due to a day of travel to Buena Vista.

Date: 6/13/2015	Days at Altitude: 6	
Location: Buena Vista, CO	Elevation: ≈ 8200 ft	Time: 2:00 p.m. MT
Temperature: 76^{0} F	Conditions: Sunny	Run Length: 2:00:00

Notes

The today took place on a dirt road which wound steadily uphill into the surrounding mountains. The area around here is mostly dry, brown rock with evergreen trees strung around them. The land opens to the west and across the valley rises the collegiate peaks which seem to be teaming with storms this time of year. Today's weather is warm and the run up the road is steady and enjoyable. Our legs and minds are restored a bit after the easy day yesterday and today's run seems more enjoyable for that reason. We wind up the road until the one hour and ten minute mark before we turn around and trod back to camp. Everyone's legs seemed to feel great today and the majority of the time was spent running easily. The long, slow downhill back to camp with the astounding view of the collegiates helped as well.

Date: 6/14/2015	Days at Altitude: 7	
Location: Buena Vista, CO	Elevation: ≈ 8000 ft	Time: 6:00 p.m. MT
Temperature: 70^{0} F	Conditions: Sunny	Run Length: 1:00:00

Notes

Today's run was fairly easy due to the hard day we have tomorrow. The entirety of the run was spent on a flat railroad grade which followed the Arkansas River and wound through old rock tunnels made in the early part of the last century. The run was very enjoyable and allowed us to open our stride up a little. The intensity was kept the same as every other run and is another good day for our legs to do some recovery. We will need it for our adventure of Mount Yale tomorrow morning.

Date: 6/15/2015 Days at Altitude: 8

Location: Mount Yale, CO Elevation: ≈ 9900 ft Time: 7:30:00 a.m. MT

Temperature: 45^0 F Conditions: Sunny Run Length: 7:00:00

Notes

Today's adventure took us up Mount Yale, the 3rd tallest of the four collegiate peaks near Buena Vista, Colorado. The trail began by sloping moderately up and winding through the mountains for two or three miles. At this point we reached the tree line and the real work began. The trail was buried under snow and at this point, we chose to take the road less traveled, or the road with less snow. We began snaking our way up the side of the mountain on the path of least resistance. Our trail was very rocky and steep. We climbed up and over a few false summits before reaching a flat area where we could see the true summit of the mountain. After a brief break where a local hiker lent us some sunscreen, we began to climb premade steps up a wall of rock and snow toward the top. We inched our way along until we finally reached the spine of the mountain. From here, we carefully made our way with precise steps up the final incline and to the apex of Mount Yale. After another short break to look around and take some pictures, we grudgingly turned around and headed back down the way we came. The trail back was much harder as we were hardly prepared for the melting slow and extremely steep incline. We managed to make it down in one piece and during the entirety of the hike we had few moments where our hearts were not beating out of our chest. We definitely felt the altitude today, especially towards the top. Once we got back down and got some water in us, we felt much better. Today's hike was long and grueling and by far the toughest, and most enjoyable experience of the trip. After arriving to our cars, we drove back to Buena Vista to pack our bags and drive to Estes Park.

Date: 6/16/2015 Days at Altitude: 9

Location: Estes Park, CO Elevation: ≈ 7700ft Time: 11:00 a.m. MT

Temperature: 77^0 F Conditions: Cloudy/Rainy Run Length: 4:00:00

Notes

Today's run took place around a section of Rocky Mountain National Park called 'Lumpy Ridge'. The name is fitting as the area is shaped with many large, round rocks. The trail did not involve too much climbing and circled the ridge for a length of about 11 miles. The final section of trail was the steepest and most challenging. The tougher terrain proved worth it as the surrounding scenery of Estes Park is extraordinarily beautiful and picturesque. All in all, we were very glad to be done with today's run and get some rest. Pace was consistent, with some challenging sections toward the end of the hike. Our legs are pretty tired and we could feel the culmination of yesterday's beating from the get go of today's run.

Date: 6/17/2015	Days at Altitude: 10	
Location: Estes Park, CO	Elevation: ≈ 9100 ft	Time: 11:00 a.m. MT
Temperature: 83^0 F	Conditions: Sunny	Run Length: 2:30:00

Notes

Today is the last run of our adventure running camp. We chose to climb the 11,428 foot Twin Sisters Peak located just inside of Rocky Mountain National Park. The trail is fairly steep and rocky from the get go and switchbacks continuously from start to finish. The majority of the first part of the hike was spent walking. We made it up swiftly, then turned back around to finish the day. The last half of the hike was spent at a slight jog. We made it down the peak much faster and ended the run 30 minutes short of our desired time. Our legs were so exhausted at this point, we felt it okay to finish the day up early and go home.