Carbohydrate Supplementation Improves Time-Trial Cycle Performance During Energy Deficit at 4300 m Altitude


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ABSTRACT

Carbohydrate supplementation (CHOS) during prolonged cycling at sea level (SL) enhances glucose availability and oxidation, and allows sustained higher intensity exercise compared to no CHOS. This study determined if CHOS also improves performance while residing at high altitude (ALT, 4300 M) despite hypoxemia exacerbated by high intensity exercise. To simulate negative energy balance that typically occurs while living at ALT for 10 days, energy expenditure was increased (~500 kcal•d⁻¹) and energy intake was reduced (~750 kcal•d⁻¹) compared to SL. After an overnight fast, 2 groups of fitness-matched men performed a maximum effort, 720 KJ cycle time trial (TT) at SL and while living at ALT on days 3 (ALT3) and 10 (ALT10). 8 men drank a 10% CHO solution (0.175 g•kg⁻¹•bw; e.g., 14 g CHO, 56 kcals and 140 ml•serving⁻¹ for 80 kg bw) and 8 drank a placebo (PLA; double-blind) at the start of and every 15 min of the TT. All freely adjusted watts and drank water. Blood glucose and O₂ saturation (SaO₂) were measured at rest and during exercise. For all test days, resting glucose and SaO₂ were similar for both groups while glucose during exercise was higher (P<0.05) for CHOS than for PLA. At SL, TT duration (~59 min) and watts (~218 or ~61% of peak watts; %SL Wpeak) were similar for both groups. At ALT, TT duration was worse than at SL for both groups (P<0.01) but was better for CHOS than for PLA on ALT3 ((X±SE): 80±7 vs 105±9 min, P<0.01) and ALT10 (77±7 vs 90±5 min, P<0.01). At ALT, %SL Wpeak for both groups was reduced from SL (P<0.01) with the reduction on ALT3 larger for PLA (to 33±3%) than for CHOS (to 43±2%, P<0.05). On ALT3, SaO₂ fell similarly from 84±2% at rest to 73±1% during the entire TT for both groups (P<0.05) and on ALT10, SaO₂ fell more (P<0.02) during the TT for CHOS (91±1 to 76±2%) than for PLA (90±1 to 81±1%). There were significant inverse relationships between %SL Wpeak and SaO₂ during the TT for both groups at ALT3 (r = -0.76, P<0.03) and ALT10 (r = -0.90, P<0.01). It was concluded that despite hypoxemia exacerbated by higher intensity exercise, increasing availability of glucose as a metabolic fuel greatly improved TT performance during the first 10 days of ALT residence in which there was a negative energy balance.

Keywords: Endurance performance, glucose, hypoxemia, prolonged exercise, ergogenic
INTRODUCTION

Carbohydrate supplementation (CHOS) during prolonged (>2 hrs) exercise prevents declines in blood glucose concentration and carbohydrate oxidation (3; 11; 16; 17; 24), and typically reduces the time to complete tasks requiring that a fixed amount of work be completed as quickly as possible (e.g., maximum effort cycle time trial, TT) (3; 17; 36). The relationship between CHOS and prolonged exercise performance is well described at sea level (11) but not at high-altitude (e.g., 4300 M). Moreover, some physiological responses to intense exercise at high altitude make it difficult to determine *a priori* if CHOS will benefit TT performance at high altitude.

Mean power output during a prolonged TT at sea level can usually be maintained at a higher level during CHOS compared to placebo, thereby improving performance (3; 17). At high altitude, similar attempts to maintain a higher mean power output during exercise with CHOS will reduce arterial oxygen saturation (SaO$_2$) (34) and require compensatory increases in cardiac output, arterial oxygen content, muscle blood flow, and/or oxygen extraction across the working limbs to maintain oxygen transport to tissues (29; 30; 35). An increase in cardiac output, for example, will exacerbate an already widened alveolar to arterial PO$_2$ difference and result in more severe hypoxemia (35; 37) and perhaps a greater feeling of respiratory distress due to hyperventilation (33). Sustained time at higher power outputs, therefore, may be limited such that the durations of prolonged cycle TTs at high altitude may not be shortened by CHOS.

The purpose of this study was to determine if CHOS could improve cycling performance during prolonged TTs conducted on the third and tenth days while living at 4300 M. The TTs were performed while undergoing a daily energy deficit and weight loss that are common during high-altitude residence (38). It was hypothesized that the potential benefit of CHOS on TT performance
at altitude would be offset by hypoxemia exacerbated by attempts to increase mean power output during exercise.

**METHODS**

**STUDY DESIGN OVERVIEW**

The study used a double-blind, placebo controlled prospective design in which two groups of healthy men performed a two-segment endurance test at sea level and then on the third and tenth days of residence at 4300 M. Just prior to the sea-level endurance test, a staff member not directly involved with any exercise testing assigned the volunteers for the rest of the study to either a group receiving a carbohydrate supplement (CHOS; n=8) or a group receiving a placebo (PLA; n=8) that was similar in taste and appearance. Individuals between groups were matched as closely as possible (P>0.10) on age, body weight, height, and sea-level \( \dot{VO}_2 \) peak prior to the endurance tests, as illustrated in Table 1.

*** TABLE 1 ***

**VOLUNTEERS**

The men were recruited using advertisements and fliers placed in local newspapers and universities in and around the Palo Alto/San Jose, CA area (<50 M). In response to a questionnaire regarding daily physical activity, the men reported exercising 6.3 ± 0.3 d•wk\(^{-1}\) (median: 7 d•wk\(^{-1}\)) or 11.9 ± 1.9 hrs•wk\(^{-1}\) (median: 12 hrs•wk\(^{-1}\)) in activities such as bicycling (n=11), running (n=9), weightlifting (n=8), basketball (n=3), Stanford University varsity crew (n=2) or wrestling (n=1) team, rock climbing (n=1), and ultimate frisbee (n=1). All were nonsmokers, normal weight for height (i.e., body mass index = 20 to 27), able to perform strenuous cycle exercise for 1 hour at 75% of their age-predicted peak heart rate, and not born or residing within the previous six months at altitudes greater than 2000 M. All voluntarily provided verbal and written consents to participate.
after being fully informed of the nature of the study and its possible risks and benefits. The study was approved by the institutional review boards of the United States Army Research Institute of Environmental Medicine (USARIEM), The Office of the Surgeon General of the Army, Veterans Administration (VA) Palo Alto Health Care System, and The College of William and Mary. The investigators adhered to policies of the U.S. Code of Federal Regulations, Part 46 and U.S. Army Regulations AR 40-25 for the protection of volunteers.

**STUDY OUTLINE**

The volunteers initially participated in a seven-day “stabilization phase” at the Clinical Studies Unit at the VA Hospital (SL; 50 M) during which time they were fed a controlled and well-balanced diet to attain energy and nitrogen balance, and body weight stability. During the stabilization phase, a VO\(_2\)\text{peak} test and an endurance test were conducted using cycle ergometry on days 2 and 4, respectively. They remained on the diet and lived at the VA Hospital during the subsequent five days (“baseline phase”). During this time, a VO\(_2\)\text{peak} test and endurance test were repeated on days 9 and 10, respectively. The volunteers were told not to perform any non-study related leg exercise for 24 hours prior to each test session.

After completing the SL baseline phase, the volunteers were flown to Colorado Springs, CO (1800 M) where they spent the first afternoon and night in an apartment under staff supervision. To facilitate study needs, the volunteers traveled to Colorado Springs either singularly or in groups of two every one to three days. From the time they arrived until they departed the next morning to the USARIEM High Altitude Research Laboratory at the summit of Pikes Peak (4300 M), they breathed medical grade O\(_2\) (> 96%) via a nasal cannula connected to an O\(_2\) concentrator. Flow rate was adjusted to maintain SL SaO\(_2\) (i.e., >96%), as measured by finger pulse oximeter.
At 0530 h (day 1; ALT1), they were driven in about an hour to the laboratory while breathing from nasal cannulas connected to small O₂ tanks (100% O₂) with a flow rate that maintained SaO₂ >96%, as measured by the pulse oximeter. Supplemental breathing of O₂ was terminated upon arrival where the volunteers lived continuously without supplemental O₂ for 12 days. The volunteers performed VO₂ peak tests on days 2 and 9 of altitude residence (ALT2 and ALT9, respectively) and endurance tests on ALT3 and ALT10.

While living on the summit, they were asked to increase their energy expenditure by 30 to 40% more (or by 1200 to 1600 Kcal·d⁻¹) than their expenditure during the SL baseline phase when their body weight was stable. They also were asked to maintain energy intake throughout the SL and altitude phases. Such requirements helped simulate the increased expenditure and rate of weight loss that are typical of prolonged, outdoor activities in mountainous terrain (38). To facilitate the increased energy expenditure, a large heated tent (18’W x 36’L x 8.5’H) was set up next to the laboratory in which the volunteers had unlimited access to treadmills, cycle ergometers, rowing and ski machines, and barbells. They could also play basketball, soccer, and hacky sack, or play catch with a football, baseball, or frisbee just outside of the facilities. They also participated in 1 to 3 hikes lasting from 1 to 4 hours during their tenure on the mountain. The hiking routes were within 8 KM from the summit and were no less than 3600 M elevation.

**ENERGY INTAKE**

During the SL and altitude phases, volunteers were fed a standardized, healthy diet that consisted of whole foods and liquid supplements provided in individualized amounts. Each individual's energy intake was initially estimated during day 1 of the SL stabilization phase using the Harris-Benedict equation (20), corrected for typical activity level estimated by volunteer recall, and was then adjusted, if warranted, to maintain body weight (bw) which was measured daily.
Protein content of the diet was held constant (1.2-1.3 g•kg bw d⁻¹). Total energy intake was adjusted by adding or subtracting fat and carbohydrate containing foods so that the energy ratio of these nutrients remained at approximately 1:2, respectively. The diet provided approximately 14% of energy from protein, 23% from fat, and 63% from carbohydrate.

**ENERGY EXPENDITURE**

Daily energy expenditure was estimated from self-reported activity logs maintained in real time. Each volunteer recorded in 15 min segments all activities for each 24-hr period (midnight to midnight) throughout the study. Activities were estimated by the same investigator (1). On several occasions, heart rate (HR) for each volunteer was monitored for some activities (e.g., running, hiking) to more accurately assess energy expended. For all volunteers, total daily expenditures were corrected by actual measurement of basal metabolic rate (via open circuit spirometry) determined on the mornings of ALT2 to ALT6 and on ALT10. Volunteers were provided daily continuous feedback on energy expended so that they could adjust their activity levels as needed.

**ACUTE MOUNTAIN SICKNESS ASSESSMENT**

Acute Mountain Sickness (AMS) was assessed each morning using the Environmental Symptoms Questionnaire (ESQ). The ESQ is a self-reported 68-item inventory typically used to document symptoms induced by altitude. A 0 to 5 point weighted average of scores from "cerebral" symptom items (AMS-c) was used to determine AMS severity (0 = none to 5 = severe) and incidence (e.g., AMS-c > 0.7 indicates AMS), as previously described (32).

**PEAK OXYGEN UPTAKE**

An incremental progressive exercise bout to volitional exhaustion on an electromagnetically-braked cycle ergometer (Sensormedics Co., Model 800s, Yorba Linda, CA) was used to assess VO₂peak at SL and altitude. Volunteers pedaled at 70 to 100 rpm for two min at 50 W, 100
W, 150 W, and then in 30 W increments thereafter until O₂ uptake failed to increase or they stopped the test despite strong encouragement. During the \( \dot{V}O_2 \) peak test, O₂ uptake (via metabolic cart, True Max 2400, ParvoMedics, Salt Lake City, UT) and HR (via HR watch, Polar Corp, Hempstead, NY) were monitored continuously. Some of the results of the \( \dot{V}O_2 \) peak tests were used to determine peak heart rates, peak power outputs, 48% and 68% \( \dot{V}O_2 \) peak steady-state power outputs, and energy costs of the self-selected power outputs used during the time-trial performance assessment.

**BICYCLE ERGOMETER ENDURANCE TEST**

The endurance test consisted of two distinct segments: a fasting steady-state exercise segment having a low and high-intensity stage, and a CHO or PLA supplemented, self-paced maximal effort time-trial (TT) segment. Steady-state exercise was used to assure group similarity prior to CHO or PLA supplementation and to document physiological responses during exercise at SL and in response to altitude exposure and acclimatization. The TT segment was used to assess performance changes due to supplementation at SL and altitude, and those due to altitude exposure and acclimatization.

Endurance tests were performed using electromagnetically-braked cycle ergometers (Sensormedics Co., Model 800s, Yorba Linda, CA or Warren C. Collins, Inc., Pedalmate, Braintree, MA) on four separate days: twice at SL and on ALT3 and ALT10. Each volunteer was always tested using the same ergometer throughout the study. Volunteers were encouraged to provide maximum effort during the four TT performance tests. Water was provided *ad libitum* during all endurance tests.

During steady-state exercise, volunteers warmed up for 5 min at 50 W and then exercised for 20 min at a low intensity and 20 min at a high intensity of their altitude-specific \( \dot{V}O_2 \) peak (48 ± 5%
and 68 ± 5%, respectively). Because of the ~25% to 28% expected reduction in \( \dot{V}O_2 \) peak from SL to 4300 M (18), the work rate used for low intensity steady-state exercise at SL was calculated to become the work rate used for high intensity steady-state exercise at altitude. Doing so allowed SL to altitude comparisons at the same absolute work rates in addition to the same relative percentages of \( \dot{V}O_2 \) peak. After the steady-state segment, the volunteers had a 5 min rest period to allow bathroom use and “stretching out.” They then began the TT performance segment and were required to complete 720 KJ of total work as fast as possible. They were allowed to alter pedaling speed and to adjust their work rate at any time during cycling by any desired increment. All were provided real time feedback (via computer screen graphics) of total work performed and total work remaining. The volunteers were not informed of any of their TT performance durations until the study was completed. A TT performance test was chosen because of its high test-retest reproducibility and low coefficient of variance (22).

All four endurance tests were conducted using the same protocol. The only exception was during the first SL endurance test there were no blood samples drawn and, in the TT performance segment, in addition to \textit{ad libitum} water, the volunteers were required to drink water at the exact volume, times, and frequency that the CHO supplement or PLA would be consumed during the remaining three endurance tests.

The second endurance test was conducted during the SL baseline phase, and the third and fourth tests were conducted on ALT3 and ALT10, respectively. All three were conducted in the mornings after fasting overnight, placement of a forearm venous catheter, and the drawing of a resting fasting blood sample. Exercise blood samples were obtained during steady-state exercise (i.e., while fasting) and during CHO or PLA supplementation during the TT.
Carbohydrate and Placebo Supplementation

The CHO supplement was a previously tested and highly acceptable (26) tropical punch flavored blend of maltodextrin (mass•volume⁻¹, 9%), glucose (2%), and fructose (1%) (Ergo Drink, US Army Soldier Systems Command, Natick MA). Each powdered serving was reconstituted with water to a 10% CHO solution. At the start of the TT and every 15 min thereafter until completion, volunteers consumed either 0.175 g•kg⁻¹ bw (e.g., 80 kg bw = 14 g CHO, 56 Kcals and 140 mls•serving⁻¹) of reconstituted Ergo Drink or an equal volume of indistinguishable PLA having no nutritive value. A staff member not directly involved with the endurance tests mixed and assigned the CHO and PLA drinks. The volunteers and the investigators participating in the study remained blinded to the supplement assignment until the entire study was completed. The rate of CHO ingested during exercise (i.e., 56 g•hr⁻¹ for an 80 kg bw) was within established CHO supplementation guidelines (2).

To assure that the CHO supplemented group did not receive a disproportionate amount of CHO on the TT test days, each volunteer was required to receive the exact volume of the opposite supplementation after each TT. In other words, if a volunteer had four drinks of 13 g of CHO per drink (total of 52 g or 208 Kcals of CHO in 520 mls of H₂O), he would receive 520 mls of PLA and be required to drink it within an hour of completing the TT, and vice versa.

Blood Measures

Blood glucose, lactate, and glycerol (Analox GM7 Micro-Stat, Hammersmith, London, UK), and free fatty acids (Elan Diagnostics, ATAC 8000, Smithfield, RI) were determined at rest to validate a fasting state, and after 15 min of cycling at 48% and then at 68% of VO₂ peak during steady-state exercise to assure that all volunteers had normal metabolic responses to exercise. Blood samples also were obtained during the TT after the volunteer completed 25% (i.e., 180 KJ),
50% (i.e., 360 KJ), 75% (i.e., 540 KJ) and 100% (i.e., 720 KJ) of total work to validate CHO/PLA supplementation. For each endurance test, less than 10 ml of blood were withdrawn. Blood glucose and lactate were analyzed within minutes of collection; while glycerol and free fatty acids were frozen for later analyses.

**Other Measures**

During rest and all endurance tests, SaO₂ via noninvasive finger pulse oximetry (Model N-200, Nellcor, Pleasanton, CA.; measurement error: ±2% in the range of 70-100% SaO₂, validated against a hemoximeter as per manufacturer communication) and HR via HR watch (Polar Corp, Hempstead, NY) were recorded continuously for determination of possible between-group differences in hypoxemia level and exercise intensity, respectively. Ratings of perceived exertion [RPE; 6 to 20 Borg Scale (5)] were obtained every 5 min for determination of possible between group differences in perceived effort. Oxygen uptake data via metabolic cart (True Max 2400, ParvoMedics Salt Lake City, UT) were collected at rest and within the 10th to 15th minute during the 48% and 68% VO₂ peak stages of steady-state exercise to determine the O₂ cost of cycle exercise at the same absolute and relative exercise intensities at SL and altitude.

**STATISTICS**

A two-factor (days X group) or three-factor (days X times X group) analysis of variance with repeated measures on one (days) or two (days and times) factors was utilized for performance, physiological and blood values comparisons (Statistica v7.0, Statsoft, Inc, Tulsa, OK). All values collected during the TT were analyzed at 25%, 50%, 75% and 100% of TT work completion to assure intra- and inter-subject data compatibility among TTs and between groups. Post hoc analyses (Neuman-Keuls) were performed when appropriate. Independent t-tests were used to compare specific characteristics (e.g., age, height, etc) between groups. Regression analyses were
used to determine relationships between physiological measures (e.g., SaO₂) and exercise performance (e.g., TT duration). Statistical significance was accepted when P < 0.05. All values are expressed as means ± SE unless otherwise indicated.

RESULTS

ENERGY INTAKE AND ENERGY EXPENDITURE

There were no differences in mean daily intakes of energy, CHO, protein or fat, energy expenditure, energy deficit or body weight loss between the CHOS and PLA groups at SL or altitude. Throughout SL, body weight remained stable for all subjects at ~77.5 ± 2 kg due to the similarity in energy intake (3879 ± 91 Kcal\*d⁻¹) and energy expenditure (4057 ± 153 Kcal\*d⁻¹).

On the summit, unlimited and convenient access to a wide variety of physical activities resulted in daily energy expenditures at altitude being consistently higher than at SL. Energy expenditure at altitude averaged 4567 ± 169 Kcal\*d⁻¹ (or ~500 Kcal\*d⁻¹ more than at SL, P<0.01). At altitude, despite strong encouragement to maintain daily energy intake similar to that at SL, energy intake was voluntarily reduced to an average of 3140 ± 165 Kcal\*d⁻¹ (or ~750 Kcal\*d⁻¹ less than at SL, P<0.01). At ALT compared to SL, CHO consumption was reduced by 102 g\*d⁻¹ (662 ± 33 to 560 ± 19 g\*d⁻¹, P<0.01) or by 1.0 g \*kg⁻¹\*d⁻¹ (8.6 ± 0.01 to 7.6 ± 0.01 g \*kg⁻¹\*d⁻¹, P<0.02). The resulting energy deficit contributed to the body weight decline from 77.0 ± 2 kg on ALT3 to 74.7 ± 2 kg on ALT10 (P<0.01).

ACUTE MOUNTAIN SICKNESS

Five volunteers in the PLA group and 5 volunteers in the CHO group had AMS prior to the TT on ALT3. Because the AMS-c score was 1.38 ± 0.52 for the PLA group and 1.26 ± 0.35 for the CHO group, the severity of AMS was determined to be equal and "slight" for both groups. Prior to
the TT on ALT10, none of the volunteers had AMS. Thus, the incidence and severity of AMS for
volunteers in both groups were nearly identical prior to each of the TTs.

PEAK OXYGEN UPTAKE, PEAK WATTS, AND PEAK HEART RATE

Both groups --- matched on \( \dot{V}O_2 \text{peak} \) at SL --- had similar declines in \( \dot{V}O_2 \text{peak} \) and peak
watts (Wpeak) resulting from altitude exposure. For both groups, \( \dot{V}O_2 \text{peak} \) and Wpeak declined
\(-25\% \) from SL to ALT2 (P<0.01) and did not change (P>0.05) with continued exposure (\(-26\% \) on
ALT9; Tables 2 and 3). Peak HR was lower on ALT2 (177 ± 2 b•min\(^{-1}\)) compared to SL (187 ± 2
b•min\(^{-1}\); P<0.01). It was also lower on ALT9 (156 ± 3 b•min\(^{-1}\)) compared to ALT2 and SL
(P<0.01). These results are consistent with normal altitude acclimatization (18).

*** TABLES 2 and 3 ***

BICYCLE ERGOMETER ENDURANCE TEST

Steady-State Exercise Responses

Because volunteers were matched as closely as possible at SL on \( \dot{V}O_2 \text{peak} \) and other
physical characteristics, it was anticipated that there would be no between-group differences during
the fasting, steady-state exercise for work rate or \% \( \dot{V}O_2 \text{peak} \), or for any of the other measurements
made. Our results indicate that there were no between group differences in wattages, \% \( \dot{V}O_2 \text{peak} \),
HR, \%SaO2, RER, RPE, and blood values for glucose, lactate, free fatty acids, or glycerol used at
the low (48\% \( \dot{V}O_2 \text{peak} \)) and high (68\% \( \dot{V}O_2 \text{peak} \)) steady-state exercise intensities at SL, or on
either test day at altitude. The steady-state exercise data were then pooled to confirm that the values
obtained on ALT3 and ALT10 were typical for SL residents undergoing normal acclimatization to
4300 M (18; 19).
From SL to ALT3, power outputs were reduced during low intensity exercise (48% $\dot{V}O_2$ peak, 142 ± 6 to 94 ± 4 W, P<0.01) and high intensity exercise (68% $\dot{V}O_2$ peak, 205 ± 9 to 142 ± 6 W, P<0.01). Doing so allowed low intensity and high intensity steady-state exercise to be conducted at similar (P>0.05) altitude-specific relative exercise intensities, respectively. Since identical individual steady-state low and high power outputs were used on ALT3 and ALT10, and Wpeak did not change with time at altitude (see Table 3), the low and high relative exercise intensities remained similar during steady-state exercise between testing days.

Heart rate for both intensities was higher on ALT3 than for either SL or ALT10 (P<0.01). Heart rate during exercise was maintained approximately 25 b•min$^{-1}$ higher at 68% $\dot{V}O_2$ peak than for 48% $\dot{V}O_2$ peak throughout the study (P<0.01). There was a reduction (P<0.01) in HR for both exercise intensities of ~15 b•min$^{-1}$ from ALT3 to ALT10. Steady-state exercise SaO$_2$ decreased from SL (97 ± 0.3%; range: 94 to 99%) to ALT3 (73 ± 1.6%; range: 63 to 83%; P<0.01) and then increased on ALT10 (81 ± 1.2%; range: 68 to 89%, P<0.01), but remained lower compared to SL (P<0.01). For each of the altitude test days, SaO$_2$ during 68% $\dot{V}O_2$ peak was ~ 2% lower than during 48% $\dot{V}O_2$ peak (P<0.03). For 48% $\dot{V}O_2$ peak, RER decreased from 0.91 ± 0.01 at SL to 0.81 ± 0.01 on ALT3 (P<0.01) and to 0.80 ± 0.01 on ALT10 (P<0.01). There was no difference between the two altitude test days. Similar changes occurred for 68% $\dot{V}O_2$ peak from SL to ALT3 (0.93 ± 0.01 to 0.85 ± 0.01, P<0.01) and to ALT10 (0.84 ± 0.01, P<0.01), with no difference from ALT3 to ALT10. There also was no difference from SL to altitude in RPE. Steady-state exercise at 48% $\dot{V}O_2$ peak was rated as a ~ 10 to 11 (“fairly light”) and that at 68% $\dot{V}O_2$ peak as a 13 to 14 (“somewhat hard” to “hard”) throughout the study.
Blood glucose was higher during exercise on ALT3 (5.69 ± 0.16 mmol•L⁻¹) compared to SL (5.02 ± 0.13 mmol•L⁻¹) and ALT10 (5.16 ± 0.11 mmol•L⁻¹) (P<0.01). On all test days, blood lactate was higher at 68% \( \dot{V}O_2\) peak (3.69 ± 0.46 mmol•L⁻¹) compared to 48% \( \dot{V}O_2\) peak (1.94 ± 0.52 mmol•L⁻¹, P<0.01). Lactate during exercise also was higher (P<0.03) on ALT3 (3.61 ± 0.42 mmol•L⁻¹) than at SL (2.78 ± 0.44 mmol•L⁻¹) or ALT10 (2.06 ± 0.14 mmol•L⁻¹). Free fatty acids were higher on ALT3 (0.68 ± 0.05 mmol•L⁻¹) and ALT10 (0.59 ± 0.06 mmol•L⁻¹) compared to SL (0.30 ± 0.05 mmol•L⁻¹, P<0.01) but were not affected by a change from 48% \( \dot{V}O_2\) peak (0.55 ± 0.07 mmol•L⁻¹) to 68% \( \dot{V}O_2\) peak (0.49 ± 0.06 mmol•L⁻¹) on any testing day. Glycerol was higher for ALT3 (0.22 ± 0.03 mmol•L⁻¹) and ALT10 (0.21 ± 0.03 mmol•L⁻¹) compared to SL (0.11 ± 0.02 mmol•L⁻¹, P<0.01) and also was higher at 68% \( \dot{V}O_2\) peak (0.22 ± 0.03 mmol•L⁻¹) compared to 48% \( \dot{V}O_2\) peak (0.14 ± 0.02 mmol•L⁻¹, P<0.01).

Collectively, the volunteers had typical and expected physiological responses to the steady-state exercise segment at SL and altitude. Also, the decreases in HR and RER, the increase in SaO₂, and the blood value responses from ALT3 to ALT10 during exercise at the same power output, %W\( \text{peak} \), and %\( \dot{V}O_2\) peak on both days are consistent with a normal pattern of altitude acclimatization (6; 19).

**TIME-TRIAL PERFORMANCE**

**Carbohydrate Supplementation during the Time Trial**

The total amount of energy provided by CHO during the TT was a function of body weight and TT duration. While the calories in each drink ingested every 15 min were similar among TT testing days (52 ± 1.3 kcal at SL, 52 ± 1.6 kcal on ALT3, and 51 ± 1.6 kcal on ALT10), total calories consumed during the TTs differed. Total energy intake was 200 ± 16 Kcal at SL, 290 ± 16
Kcal on ALT3 (P<0.01 from SL), and 262 ± 17 Kcal on ALT10 (P<0.01 from SL or ALT3). At SL, the amount of CHO consumed during the TT was, as a percentage of daily CHO intake, 8 ± 1% at SL, 13 ± 1% on ALT3 (<0.01 from SL), and 12 ± 1% on ALT10 (P<0.01 from SL).

**Time-Trial Performance Durations**

Carbohydrate supplementation made no difference in TT performance at SL but improved performance at altitude (Figure 1). During the SL stabilization phase (in which none of the volunteers was yet supplemented), the TT was completed by the "CHOS" group in 56.3 ± 5 min and by the "PLA" group in 60.7 ± 5 min (P = 0.55). During the SL baseline phase, the TT was completed by the CHOS group in 55.3 ± 5 min and by the PLA group in 62.0 ± 5 min (P = 0.36). The coefficient of variation (CV, standard deviation • mean⁻¹) from the stabilization phase to the baseline phase was 5.2% for the CHOS group and 4.6% for the PLA group (and 4.9% for both groups combined). These values are close to the 3.4% CV previously reported for trained cyclists completing TTs of similar durations (22). These results clearly indicate that the test-retest variation in TT performance was small for each group and that there was no within or between groups effect of CHO supplementation on SL performance.

Performance durations were impaired (i.e., completion time was longer) for both groups (P<0.01) on ALT3 and ALT10 compared to SL. There was no significant relationship between the decline from SL in VO₂ peak and performance duration either for ALT3 (r = 0.26) or for ALT10 (r = 0.22). Performance duration and mean power output during the TTs were, however, similarly inversely related at SL (r = -0.93, P<0.001), ALT3 (r = -0.91, P<0.001), and ALT10 (r = -0.97, P<0.001). Also for both groups, performance time was improved on ALT10 compared to ALT3 (main effect, P<0.01). The data also indicate that the time on ALT3 for the PLA group was much longer (i.e., performance worse) than for the CHOS group (104.9 ± 9 vs. 80.1 ± 7 min, P<0.01).
From ALT3 to ALT10, performance time for the PLA group improved (P<0.01) whereas that for CHOS group did not improve (P>0.05). Despite the performance improvement of the PLA group from ALT3 to ALT10, their time on ALT10 was still worse than that of the CHOS group (89.8 ± 5 vs. 76.5 ± 7 min, P<0.01).

**FIGURE 1**

![Graph showing the performance times for Placebo Group and Carbohydrate Group from SL Stabilization to Day 10, ALT.](http://jap.physiology.org/)

There was no statistically significant difference between groups in self-selected, altitude-specific % \( \dot{VO}_2 \) peak used during the TT performance tests between SL baseline and ALT3 for either group (**Table 4**). By ALT10, both groups exercised at a higher altitude-specific % \( \dot{VO}_2 \) peak compared to SL baseline (P<0.03) and ALT3 (P<0.01).

The difference in altitude-specific % \( \dot{VO}_2 \) peak used during the TTs for the eight matched pairs of CHOS and PLA volunteers was 2% at SL baseline but increased to 14% on ALT3 (P<0.03), due to those in the CHO group tending (P = 0.061) to exercise at a higher % \( \dot{VO}_2 \) peak than those in the PLA group. The matched pair difference in altitude-specific % \( \dot{VO}_2 \) peak by ALT10 tended to
be lower than on ALT3 (P=0.06) but similar to SL baseline. Since a similar inverse relationship between altitude-specific % \( \dot{V}O_2 \) peak used during the TT and performance duration existed for both groups at SL (\( r = -0.79, P<0.01 \)), ALT3 (\( r = -0.74, P<0.01 \)), and ALT10 (\( r = -0.82, P<0.01 \)), those who were able to maintain a higher altitude-specific % \( \dot{V}O_2 \) peak completed the TT more quickly. Overall, these findings are consistent with the TT performance times.

### *** TABLE 4 ***

#### Exercise Intensity and \( \text{SaO}_2 \)

Exercise intensity (expressed as %SL \( \text{W}\text{peak} \)) and \( \text{SaO}_2 \) measured during the TT are illustrated in the top and bottom panels, respectively, of Figure 2. Both groups exercised at a lower exercise intensity at altitude than at sea level (\( P<0.01 \)), with the CHOS group exercising on ALT3 and ALT10 at a higher %SL \( \text{W}\text{peak} \) than the PLA group (\( P<0.05 \)). For the CHOS group, there was no difference between ALT3 and ALT10 in %SL \( \text{W}\text{peak} \) whereas for the PLA group %SL \( \text{W}\text{peak} \) was lower on ALT3 than on ALT10 (\( P<0.03 \)). Arterial oxygen saturation did not differ between groups at SL (PLA: 96 ± 0.4%, range: 94 to 98%; CHO: 96 ± 0.5%, range: 95 to 99%) and ALT3 (PLA: 74 ± 1.9%, range: 64 to 79%; CHO: 72 ± 2.0%, range: 65 to 79%) but was reduced similarly for both groups from SL to ALT3 (\( P<0.01 \)). However, throughout the TT on ALT10, \( \text{SaO}_2 \) was lower (\( P<0.01 \)) for the CHOS group (76 ± 1.7%, range: 68 to 83%) than for the PLA group (81 ± 0.6%, range: 78 to 83%). For both groups \( \text{SaO}_2 \) was inversely related to %SL \( \text{W}\text{peak} \) throughout the TTs on ALT3 (\( r = -0.76, P<0.03 \)) and ALT10 (\( r = -0.90, P<0.01 \)). Time trial duration and mean absolute level of \( \text{SaO}_2 \) during the TT were not, however, related at ALT3 (\( r = -0.18, P=\text{ns} \)) and ALT10 (\( r = 0.17, P=\text{ns} \)). Collectively, these results indicate that \( \text{SaO}_2 \) level closely tracked changes in exercise intensity throughout the TTs at altitude but had little impact on overall TT performance.
FIGURE 2

PLA Group

CHOS Group

Percentage of SL Wpeak

SaO2 (%)

TT Completion (%)
Heart Rate and RPE

Percentage of HR peak (%HRpeak), and RPE are illustrated in Figures 3 and 4, respectively, for SL baseline, ALT3, and ALT10. In general, % HRpeak and RPE differed between groups during exercise, with the CHOS group having higher values for % HRpeak and RPE compared to the PLA group.
Blood Measures

Figures 5 to 8 show blood glucose, lactate, free fatty acids, and glycerol values, respectively, for the PLA and CHOS groups at rest and during the TT. For several of the volunteers during the TT segment on each testing day, we were unsuccessful in drawing all samples after approximately 50% of the TT duration due to problems such as blood clotting and catheter displacement. For these volunteers, blood sampling was postponed until the completion of exercise. Therefore, data represented are the fasting, pre-TT resting values and exercise values after 25%, 50%, and after completion of the TT at SL baseline, ALT3, and ALT10.

Throughout the study, resting values were similar for both groups. In contrast, exercise values for glucose and lactate were generally higher and values for free fatty acid and glycerol were generally lower for the CHOS group compared to the PLA group.
FIGURE 5

PLA Group

CHOS Group

FIGURE 6

PLA Group

CHOS Group
DISCUSSION

The results clearly indicate that CHO supplementation enhances cycle TT performance of SL residents during the first 10 days at 4300 M that is accompanied by negative energy balance. Performance on ALT3 compared to that at SL was reduced by 73% for the PLA group but only by 46% for the closely matched CHOS group. By ALT10, the between-group performance gap had narrowed but was still 9% better for the CHOS group. It is noteworthy that performance improved from ALT3 to ALT10 for the PLA group but not for the CHOS group. These results are consistent with the notion that TT performance for the CHOS group may have been optimized at altitude and that it was influenced more by CHO supplementation than the salutary physiological effects associated with the first 10 days of altitude acclimatization.

Arterial oxygen saturation during the TTs was reduced similarly for both groups on ALT3 and was lower for the CHOS group than for the PLA group on ALT10. Yet, during the TTs for both days at altitude, exercise intensity, HR, and RPE for the CHOS group were higher than those for the PLA group. These results are interpreted to mean that CHO supplementation enabled exercise to be performed voluntarily at a higher intensity despite severe hypoxemia. Thus, contrary to our hypothesis, the magnitude of the exercise-induced hypoxemia sustained during the TTs at altitude is inconsequential relative to the performance benefit resulting from CHO supplementation.

At least four major experimental design and measurement outcome features of this study provide assurance that such a difference in performance at altitude between groups was related directly to CHOS during exercise. First, matching groups on SL \( \dot{VO}_2 \) peak minimized the possibility that the performance disparity could be attributed to differences in fuel utilization linked to a difference in fitness level (7). Moreover, the similar altitude-induced decline in % \( \dot{VO}_2 \) peak and fall in HRpeak from SL to altitude indicated that aerobic capacity of both groups was affected equally at
altitude. Second, both groups began the steady-state segment of the endurance tests after an overnight fast in order to minimize the acute effects of the last meal on exercise metabolism and performance. Third, there were striking similarities of physiological (e.g., HR, RER, and SaO₂), perception (e.g., RPE), and metabolic (e.g., blood glucose and lactate) responses to steady-state exercise on each testing day at altitude. Such results strongly indicate a similar rate of altitude acclimatization for both groups. And fourth, experimental bias in favor of the CHOS group was avoided by having a disinterested third party make the volunteer assignments to each group. Results of the group assignments were not revealed to the other staff or volunteers until the entire study was completed. Moreover, while at altitude, volunteers from both groups lived together, participated jointly in the same activities, and ate the same foods.

Previous studies at SL reported that when resting muscle glycogen stores are replete, the rate of total CHO oxidation is similar for the CHOS and PLA or control groups for up to about two hours of cycling at ~70% ₪ VO₂ peak (15). After this exercise duration, with no CHOS, muscle glycogen stores are reduced about 60% and plasma glucose levels decline relative to resting levels (10; 14). Throughout the SL phase of the present study, energy intake nearly equaled energy expenditure and the diet was high in CHO (i.e., 63% of total energy or 8.6 g CHO•kg⁻¹•d⁻¹). This suggests that at the start of the endurance performance tests for both groups, resting muscle glycogen stores were not greatly reduced from fully replete levels. In addition, each group exercised at more than 60% ₪ VO₂ peak for less than a total of 1½ hours (i.e., 20 min at 68% ₪ VO₂ peak during the steady-state segment and TT segment combined), and, for the PLA group, blood glucose was maintained at resting levels throughout the endurance test. In such a scenario, CHO availability is not limiting to SL performance, and CHOS during exercise may not enhance exercise performance (4; 9; 16). The lack of change in the intra- and inter-group performance at SL
in the present study is consistent with this interpretation. In contrast, however, there are other
reports indicating that CHOS improves cycle TT performance of 1 hr duration; though the
mechanism has not been established (8; 21).

Peak oxygen uptake at altitude was reduced from SL for both groups and, as a result, the
self-selected power outputs that could be used during the TT performance tests also were reduced
from SL (18). Since the total amount of work performed at SL and altitude was identical at 720 KJ,
the duration of the TT was necessarily longer at altitude than at SL for both groups. However, in
contrast to the similarity in performance between groups at SL, the performance of the CHOS group
was superior to that of the PLA group on both test days at altitude. It appears there are several
factors that, when combined, could at least partly explain this difference.

One factor is the observed SL versus altitude difference in energy balance and its
relationship to resting muscle glycogen stores. At SL, both groups were nearly in energy balance
whereas at altitude both groups had greatly increased energy expenditures and reduced energy
intakes that amounted to a daily energy deficit of approximately 1250 Kcal·d⁻¹ compared to SL.
Significantly increasing daily energy expenditure likely increased muscle glycogen utilization (12).
Moreover, it is important to note that to expend the necessary extra amount of daily energy required
20% to 40% more time at 4300 M altitude than it would have at SL (18) and therefore reduced the
daily rest time available for muscle glycogen restoration (23). Furthermore, the reduced daily
energy intake may have been insufficient to provide adequate CHO for full muscle glycogen
repletion (13) despite the daily CHO intake remaining relatively high at altitude (560 g·d⁻¹ or 7.6 g
CHO·kg⁻¹·d⁻¹). Thus it is possible that muscle glycogen was lower at altitude than at SL prior to
each TT.
In addition to the possibility that both groups at altitude started exercise with less than optimal resting muscle glycogen stores and with a greater proportion of fat being oxidized (based on lower steady-state exercise RER values), each group exercised via their own volition at approximately similar % \( \text{VO}_2 \text{peak} \) at SL and altitude during the TT performance tests. Since muscle glycogen utilization is related more to % \( \text{VO}_2 \text{peak} \) than absolute work rate (31) and the volunteers exercised for longer periods of time at altitude than at SL, it is likely that muscle glycogen stores fell to lower levels at altitude than at SL during the TT. The implication is that as muscle glycogen progressively declined during the prolonged TT, the reliance on blood glucose to maintain total CHO oxidation steadily increased (11).

In the present study, blood glucose level for the CHO group was higher than for the PLA group during the TTs at SL and altitude, and performance was superior for the CHO group at altitude. Since glucose is transported via facilitated diffusion down a concentration gradient (25), and glucose is the most O\(_2\) efficient fuel under conditions of acute and chronic hypoxia (28), our findings are consistent with the notion that CHO supplementation increased glucose availability that resulted in increased glucose utilization during the TTs at altitude. Previous studies at sea level have shown that when endogenous CHO stores are less than optimal and/or if exercise duration is two hours or longer, CHOS typically benefits performance (3; 11; 17; 27; 36). From this perspective, the benefit of CHOS on prolonged intense exercise may not appear to be unique to altitude exposure. However, what was difficult to determine \textit{a priori} was whether the severe hypoxemia resulting from maximal effort exercise during the first 10 days of high-altitude exposure would minimize or even mask the performance benefits otherwise associated with CHOS. We conclude that despite hypoxemia exacerbated by higher intensity exercise, increasing availability of
glucose as a metabolic fuel greatly improved TT performance during high-altitude residence in which there was a negative energy balance.

In summary, two groups of eight men closely matched by SL VO$_2$peak, age, body weight, and height, performed cycle endurance tests at SL and on days 3 and 10 while living at 4300 M altitude and experiencing daily negative energy balance and weight loss. The endurance test consisted of two distinct parts: a steady-state exercise segment (i.e., 20 min each at 48% and 68% VO$_2$peak) that assessed physiological changes due to altitude acclimatization while fasting and a 720 KJ TT segment that assessed the effects of CHOS (10% solution, 0.175 g·kg$^{-1}$ bw every 15 min) on prolonged, maximal effort performance. Both groups had similar physiological responses to the steady-state exercise segment at SL and high altitude, and acclimatized similarly with altitude residence. In contrast, TT exercise performance at altitude was far superior for the CHOS group than for the PLA group despite hypoxemia exacerbated by higher intensity exercise. We conclude that increased availability of glucose as a metabolic fuel greatly improved endurance performance in SL residents during the first 10 days at altitude that was accompanied by a daily negative energy balance and weight loss.
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FIGURE LEGENDS

FIGURE 1: Time trial performance at sea level and altitude. $^A$P<0.01 from SL; $^*$P<0.01 between groups; $^B$P<0.01 reduced from Day3, ALT

FIGURE 2: Percentage of sea level peak power output used to complete the time trial (Top Panels) and SaO$_2$ (Bottom Panels) during the time trials. For each group, the percentage of SL peak power output (%SL Wpeak) used during the time trial (TT) on ALT3 (■) and ALT10 (▲) was lower than at SL (●) ($^*$P<0.01). While there was no difference between groups at SL, %SL Wpeak was higher for the CHOS group than for the PLA group on each altitude day ($^C$P<0.05). %SL Wpeak also was lower on ALT3 than on ALT10 for the PLA group ($^D$P<0.03) but not for the CHOS group. For each group, arterial oxygen saturation (SaO$_2$) during the TT on ALT3 and ALT10 was lower than at SL ($^*$P<0.01). SaO$_2$ also was lower on ALT10 compared to ALT3 for the PLA group ($^**$P<0.01) but not for the CHOS group. There was no difference during the TT in SaO$_2$ between groups at SL or ALT3. However, throughout the TT on ALT10, SaO$_2$ was lower for the CHOS group (76.4 ± 2%) than for the PLA group (81.3 ± 2%, $^E$P <0.01). There were significant inverse relationships between %SL Wpeak and SaO$_2$ for both groups during the TT at ALT3 (r=0.76, P<0.03) and ALT10 (r=0.90, P<0.01).

FIGURE 3: Percentage of peak heart rate used during the time trial. Overall, the CHOS group used a higher %HRpeak than the PLA group (main effect, $^A$P<0.01). For both groups, a higher %HRpeak was used on ALT10 (▲) compared to SL baseline (●) and ALT3 (■) ($^B$P<0.01). Also for both groups, for all test days (with the exception of the PLA group on ALT3), the % HRpeak used was higher towards the end of exercise compared to the beginning of exercise ($^C$P<0.01).

FIGURE 4: Ratings of perceived exertion during the time trial. For both groups at SL and altitude, RPE increased progressively with exercise duration ($^C$P<0.05). For each group, RPE did not differ
among test days (P>0.05). However, at all time periods after 25% completion of the time-trial, the CHOS group reported higher RPE values than the PLA group for both altitude days (\(^{A}P<0.01\)).

**FIGURE 5:** *Blood glucose during the time trial.* At SL and altitude, blood glucose during exercise was higher for the CHOS group than for the PLA group (\(^{A}P<0.03\)). Blood glucose for the PLA group did not differ from rest (P>0.05) whereas for CHOS group, blood glucose was always higher throughout exercise compared to rest (\(^{C}P<0.02\)). When the data were pooled, blood glucose was higher on ALT3 (■) compared to SL (●) and ALT10 (▲) (main effect, \(^{F}P<0.01\)). In addition, blood glucose was higher on ALT10 compared to SL (main effect, \(^{G}P<0.01\)).

**FIGURE 6:** *Blood Lactate During the Time Trial.* At SL and altitude, blood lactate was higher for the CHOS group than for the PLA group (\(^{A}P<0.04\)). Pooled data indicate that blood lactate during exercise was similar at SL (●) and ALT3 (■), but was lower on ALT10 (▲) (\(^{H}P<0.01\)). While blood lactate tended to rise with exercise duration (P<0.07), that for the CHOS group rose to a higher level compared to the PLA group (\(^{C}P<0.03\)).

**FIGURE 7:** *Free Fatty Acids During the Time Trial.* At SL and altitude, blood FFA for the CHOS group was lower than for the PLA group (\(^{A}P<0.01\)). For pooled data, blood FFA was higher on ALT3 (■) compared to SL (●) and ALT10 (▲) (\(^{I}P<0.01\)). Also, blood FFA was highest at the end of exercise compared to rest and 25% and 50% completion (\(^{C}P<0.01\)). However, at SL and altitude, FFA for the PLA group was higher during exercise compared to rest (\(^{C}P<0.01\)) in direct contrast to the CHOS group whose level was lower during exercise than at rest (\(^{I}P<0.01\)).
FIGURE 8: Blood Glycerol During the Time-Trial. There was no overall difference in blood glycerol between groups during rest or exercise at SL or altitude. For pooled data, blood glycerol was higher on ALT3 (■) and ALT10 (▲) than at SL (●) ($F,Gp<0.01$), and, for each test day, higher during exercise than at rest ($CP<0.01$). While blood glycerol rose with exercise duration ($P<0.04$), that for the PLA group rose to higher levels compared to the CHOS group ($Ap<0.01$).
TABLES

TABLE 1. Baseline physical characteristics of the volunteers.

<table>
<thead>
<tr>
<th>Group</th>
<th>Age (yrs)</th>
<th>Weight (kgs)</th>
<th>Height (cm)</th>
<th>VO2 peak (ml•min⁻¹•kg⁻¹)</th>
<th>VO2 peak (ml•min⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLA</td>
<td>25.1 ± 6</td>
<td>79.8 ± 11</td>
<td>176.8 ± 6</td>
<td>54.0 ± 6</td>
<td>4270 ± 504</td>
</tr>
<tr>
<td>CHOS</td>
<td>25.3 ± 6</td>
<td>75.1 ± 6</td>
<td>180.6 ± 6</td>
<td>58.4 ± 6</td>
<td>4395 ± 682</td>
</tr>
</tbody>
</table>

N=8, Values are means ± SD, PLA = Placebo Group; CHOS = Carbohydrate supplement group

TABLE 2. Peak oxygen uptake (VO2 peak) change at altitude

<table>
<thead>
<tr>
<th></th>
<th>Day 2</th>
<th>Day 9</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VO2 peak (ml•min⁻¹)</td>
<td>SL (%)</td>
</tr>
<tr>
<td>PLA</td>
<td>3134 ± 79</td>
<td>74 ± 1</td>
</tr>
<tr>
<td>CHO</td>
<td>3211 ± 193</td>
<td>73 ± 2</td>
</tr>
</tbody>
</table>

Values are means ± SE. PLA = Placebo Group; CHO = carbohydrate supplement group; SL = sea level, ALT2, ALT9 = 2nd and 9th days at Pikes Peak

TABLE 3. Peak power outputs (Wpeak) at sea level and altitude.

<table>
<thead>
<tr>
<th></th>
<th>SL Wpeak (watts)</th>
<th>ALT2 Wpeak (watts)</th>
<th>ALT2 Wpeak (%SL Wpeak)</th>
<th>ALT9 Wpeak (watts)</th>
<th>ALT9 Wpeak (%SL Wpeak)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLA</td>
<td>349 ± 19</td>
<td>259 ± 13</td>
<td>75 ± 3</td>
<td>251 ± 11</td>
<td>73 ± 4</td>
</tr>
<tr>
<td>CHO</td>
<td>364 ± 20</td>
<td>270 ± 14</td>
<td>75 ± 3</td>
<td>266 ± 14</td>
<td>74 ± 3</td>
</tr>
</tbody>
</table>

Values are means ± SE. PLA = Placebo Group; CHO = carbohydrate supplement group; SL = sea level, ALT2, ALT9 = 2nd and 9th days at Pikes Peak; Wpeak = Peak wattage determined during VO2 peak test.
TABLE 4: Percentage $\dot{V}O_2$ peak During The Time-Trial Performance Segment

<table>
<thead>
<tr>
<th>Group:</th>
<th>SL Stabilization</th>
<th>SL Baseline</th>
<th>Day 3, Altitude</th>
<th>Day 10, Altitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Placebo</td>
<td>61.3 ± 4</td>
<td>60.3 ± 4</td>
<td>55.1 ± 5*</td>
<td>66.0 ± 3*</td>
</tr>
<tr>
<td>Carbohydrate</td>
<td>65.2 ± 3</td>
<td>64.9 ± 3</td>
<td>66.9 ± 3</td>
<td>71.8 ± 4*</td>
</tr>
<tr>
<td>Matched Pair Difference</td>
<td>4 ± 4%</td>
<td>2 ± 5%</td>
<td>14 ± 5%*</td>
<td>6 ± 6%</td>
</tr>
</tbody>
</table>

Values are means ±SE. *P<0.03 from sea level; aP<0.01 from day 3; bP=0.06 from day 3; P = 0.061 from Carbohydrate, Day 3
Reference List


