Exercise Performance of Sea-Level Residents at 4300 m After 6 Days at 2200 m

CHARLES S. FULCO, STEPHEN R. MUZA, BETH BEIDLEMAN, JULI JONES, JANET STAAB, PAUL B. ROCK, AND ALLEN CYMERMAN

Residing for several days at a moderate altitude prior to ascending to a higher elevation or "staging" is a universally accepted acclimatization strategy (8,15,17,18). In general, an ideal staging altitude for unacclimatized sea-level residents (SLR) should be high enough to initiate physiological responses that induce beneficial changes such as an increase in arterial oxygen saturation, but not so high as to cause acute mountain sickness (AMS) or sleep disruption (15,18). The expectation is that the modest beneficial changes induced during staging will transfer to the higher altitude and thereby help avoid severe symptoms of AMS and large reductions in endurance exercise performance that would otherwise occur with rapid, non-staged ascent (8,10).

Broad guidelines exist that recommend various modalities at the higher altitudes to determine the success of a given staging strategy (8,9,12,21). Depending on factors such as the staging elevation(s) (e.g., 1500 to 2500 m) and duration (e.g., > 4 d), the reported effectiveness for reducing the incidence or severity of AMS at higher altitudes typically ranges from 20 to 100% (8,12,18,21).

The beneficial changes induced by living for several days at moderate altitude have long been known to be quite effective for attenuating the symptoms of AMS (8,12). Whether staging would also minimize the endurance performance decrement at high altitude is largely unknown. Consistent with a performance benefit are recent reports indicating that moderate-altitude residents who lived for 21 mo at 2200 m and who were considered fully acclimatized to moderate altitude did not experience AMS (16) or a decline in exercise intensity during endurance exercise (11) when rapidly exposed to 4300 m. Nevertheless, the effect of only partial acclimatization resulting from living for several days at moderate altitude on endurance performance at high altitude has been neither evaluated quantitatively nor assessed independently of changes in AMS. The primary objective of this study, therefore, was to determine for the first time the effectiveness of staging for 6 d at a moderate altitude of 2200 m on prolonged endurance performance at 4300 m without concomitant changes in AMS. It was hypothesized that the decrement in prolonged time-trial performance at high altitude would be attenuated by partial acclimatization resulting from staging at moderate altitude.

METHODS

The volunteers were 10 SLR who were active duty male military personnel assigned to the U.S. Army Natick Mountain Medicine Division, U.S. Army Research Institute of Environmental Medicine, Natick, MA.

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Soldier Center. All had been living at low altitudes (<1000 m) for at least 3 mo prior to the start of the study. The age, height, and weight of the volunteers were (mean ± SE): 21 ± 1 yr, 177 ± 3 cm, and 78 ± 4 kg, respectively. In addition to participating in Army physical training for 3-4 d · wk⁻¹ (e.g., running, calisthenics, backpacking), the men reported regularly participating for at least 1 h · d⁻¹ for 23 ± 5 d · mo⁻¹ in activities such as basketball, weightlifting, football, baseball, and competitive skateboarding. All provided verbal and written consents 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 U.S. Army Research Institute of Environmental Medicine (USARIEM), U.S. Army Medical Research and Materiel Command, Human Research Protection Office, and the U.S. Air Force Academy (USAFA).

Testing Phases, Facilities, and Experimental Design

Overview

This study was organized into three distinct phases at three different test facilities over a period of 12 wk in the following order: 1) a baseline sea-level and prestaging (ALT-1) high-altitude assessment phase at USARIEM, Natick, MA; 2) a moderate altitude acclimatization staging phase at the USAFA (Colorado Springs, CO; 2200 m); and 3) a post-staging (ALT-2) high-altitude phase at the summit of Pikes Peak (Colorado Springs, CO; 4300 m) (Fig. 1). The same equipment that was used at USARIEM also was used at the USAFA and on the summit. During all phases, the temperature and relative humidity during testing were 21 ± 3°C and relative humidity 45 ± 10%, respectively.

Exercise assessments, AMS, and resting cardiorespiratory and blood measurements occurred on multiple occasions at USARIEM during the baseline phase at sea level (SL, P₀ = ~760 mmHg) or during two acute hypobaric chamber exposures (1 and 5 h) that were at the same P₀ as at the summit of Pikes Peak (i.e., 459 mmHg). Hypobaric chamber decompression from 760 mmHg to 459 mmHg took ~10 min. After all testing was completed at USARIEM the volunteers were flown nonstop via commercial airline to Colorado (~6 h) in groups of two on consecutive days to participate in the staging phase that was conducted over a 6-d period in the Human Performance Laboratory (HPL) and its surrounding rooms (~601 mmHg) at the USAFA. Sending only two volunteers at a time to Colorado allowed the subsequent high-altitude timing and sequence of procedures at ALT-2 to be maintained identically to those used at ALT-1 at USARIEM. The number of days between ALT-1 and ALT-2 testing ranged from 34 to 52 d (median: 46 d) among volunteers.

In addition to laboratory-based testing procedures, all volunteers participated in two to four supervised hikes (<3 h) on trails located on the USAFA base to simulate military scouting patrols. At 0600 of the 7th day at the USAFA, the volunteers were driven (~1.5 h) to the summit of Pikes Peak. The volunteers were instructed not to perform any non-study related leg exercise for 24 h before each test session. Volunteers were allowed to eat ad libitum throughout the entire study, except when they were provided with two commercially available energy bars and fruit juice (food composition = 510 kcal, 14 gm fat, 65 gm carbohydrate, 32 gm protein) at 1 to 2 h prior to the beginning of each of the long endurance performance assessments.

Procedures

Incremental, progressive exercise bouts to volitional exhaustion on an electromagnetically braked cycle ergometer (model: Excalibur, Lode BV, Groningen, The Netherlands) were used to assess peak oxygen uptake (V̇O₂peak) at USARIEM twice while at SL (1st practice/familiarization, 2nd definitive) and once during a 1-h hypobaric chamber exposure to 4300 m. Continuous measurements of O₂ uptake were obtained throughout the tests using a calibrated metabolic cart (True Max 2400, Parvo Medics, Sandy, UT). For each test, the volunteer began pedaling at ~80 rpm at 50 W for a 3-min warm up. The power output was then increased to 100, 130, and 160 W in 2-min increments. Thereafter, power output was increased by 15 W each min until O₂ uptake failed to increase or the volunteer could not continue despite strong verbal encouragement. Data from the V̇O₂peak tests were used to determine the steady-state power outputs during cycle maintenance training, the long endurance performance assessment, and to estimate the mean power output used during the time trial (TT) (1).

Cycle maintenance training was conducted using electromagnetically braked cycle ergometers (model: Corival, Lode BV, Groningen, The Netherlands) four times during the USARIEM baseline phase (SL only) and five times during the USAFA staging phase (days 1, 2, 4-6). Each training session consisted of 5 min of warm up at 50 W, 30 min of steady-state (SS) exercise at an individually
determined low-intensity fixed power output (44 ± 2% of SL $\dot{V}O_{2peak}$) and, after a 5 min break, a short (~15 min) 180 kJ TT segment (except on the last day at the USAAF to allow adequate rest prior to cycling at ALT-2 the next morning). The goal of the nine training sessions over the 12-wk study period was to maintain familiarity with the cycling procedures.

Long endurance performance was determined using an electromagnetically braked cycle ergometer (model: Excalibur, Lode BV, Groningen, The Netherlands) three times during the USARIEM baseline assessment phase (twice at SL and once beginning at ~2 h of exposure to hypobaric hypoxia) and once beginning at ~2 h of arriving at the summit of Pikes Peak. Each long endurance performance assessment consisted of two major segments after 5 min of warm-up at 50 W: 1) SS exercise for 20 min at ~44 ± 2% (low intensity) followed by 20 min at ~60 ± 2% (high intensity) of their altitude-specific $\dot{V}O_{2peak}$ and after a 5 to 10 min rest, 2) a 720-kJ maximum effort TT. The better TT performance at SL was used as the SL baseline value. For all tests and throughout the duration of each test, water was provided ad libitum. These procedures and the justification for their use have previously been described in detail (10).

Briefly, the power outputs used for the low- and high-intensity steady-state exercise bouts were identical during ALT-1 and ALT-2. After the short rest period at the end of high-intensity SS exercise, the volunteers were asked to complete the 720-kJ TT as fast as possible. They were allowed to alter pedaling speed and adjust power output by any watt increment at any time. To minimize possible interference with volunteer concentration and cycling pace, $O_2$ uptake measurements and blood samples were not obtained during the TT. Volunteers were continuously informed of the volume of work performed and remaining (via computer screen); but not the time elapsed. The 720-kJ TT segment provided the primary outcome variable to determine if partial acclimatization acquired during staging improved endurance performance at high altitude.

Heart rate via HR watch (Polar Electro, Woodbury, NY), arterial oxygen saturation ($S_aO_2$) via noninvasive finger pulse oximetry (Model 8600, Nonin Medical, Inc., Plymouth, MN), and ratings of perceived exertion (RPE, 6 to 20 Borg scale (5)] were determined at the end of every stage of the $\dot{V}O_{2peak}$ tests, at 25 min during cycle maintenance training, at 15 min during SS exercise, and every 5 min during the TT.

AMS was determined from information gathered using a subset of the Environmental Symptoms Questionnaire (ESQ) and the Lake Louise AMS Scoring System (LLS) administered using a personal digital assistant (PDA; HP model: iPAQ). The ESQ was a shortened version (4) of the self-reported, 68-question inventory used to document symptoms induced by altitude (20). A weighted average of scores from nine symptoms (headache, lightheaded, dizzy, etc.) designated “AMS-C” was calculated. The weighted scores ranged from 0 (no symptoms) to 5 (severe symptoms). A weighted AMS-C score equal to or greater than 0.70 indicates the presence of AMS. The LLS consists of a six-question, self-reported assessment of AMS symptoms (19). Total LLS scores that include headache and are ≥3 (range: 0 to 18) are diagnostic of AMS. The questionnaires were administered during rest in the mornings at SL, ALT-1, USAAF, and ALT-2. The questionnaires were also administered within an hour of initiating each long endurance performance assessment.

Measures of resting partial pressures of end-tidal carbon dioxide ($P_{ETCO_2}$) and oxygen ($P_{ETO_2}$), $S_aO_2$, and heart rate (HR) were conducted with the volunteers awake, seated, relaxed, and fasting for at least 2 h. During these tests, the volunteers were connected for 15-20 min to a breathing circuit by a rubber mouthpiece and nose clip and to a finger pulse oximeter unit (Model 8600, Nonin Medical, Inc., Plymouth, MN) to record $S_aO_2$ and HR. $P_{ETCO_2}$ and $P_{ETO_2}$ were determined using a metabolic cart (Vmax 229, Sensormedics Inc., Yorba Linda, CA). All resting measurements were determined in the morning at SL and during ALT-1 and ALT-2 on the same days and just prior to the long endurance performance assessments.

Resting venous arm blood samples (5 ml) were obtained at SL, ALT-1, and ALT-2. Each 5-ml sample was analyzed immediately in duplicate for the measurement of hemoglobin concentration ([Hb]), hematocrit (Hct), and glucose using an iStat portable clinical analyzer (Abbott Diagnostics, Abbott Park, IL). Changes in [Hb] and Hct were used to estimate the percentage plasma volume reduction from SL resulting from staging (7). Arterial oxygen content ($C_aO_2$; ml ⋅ dl$^{-1}$) was calculated as the product of $S_aO_2$ (%), [Hb] (g ⋅ dl$^{-1}$), and 1.34 mlO$2$ ⋅ gHb$^{-1}$.

Analysis of variance with repeated measures on one factor (day) was used for performance, physiological, and blood values (Statistica v7.1, Statsoft, Tulsa, OK). Post hoc (Newman-Keuls) calculations were performed when appropriate. Regression analyses were used to determine relationships between physiological measures (e.g., $S_aO_2$) 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

Peak oxygen uptake declined 31 ± 2% from 3636 ± 215 ml ⋅ min$^{-1}$ at SL to 2693 ± 89 ml ⋅ min$^{-1}$ at 4300 m ($P < 0.01$). At $\dot{V}O_{2peak}$, there were also declines ($P < 0.01$) in $W_{peak}$ (283 ± 10 to 234 ± 7 W) and $S_aO_2$ (97 ± 1 to 75 ± 2%). In contrast, there was no difference in $HR_{peak}$ (186 ± 3 vs. 183 ± 3 bpm).

Cycle Maintenance Training

Throughout the SL and staging phases, SS power output was maintained for 30 min at 116.0 ± 8 W (or 44 ± 2% of $\dot{V}O_{2peak}$, and 41 ± 2% of $W_{peak}$). There were no differences between SL and staging days for HR or RPE (Table 1). There also were no changes in 180-kJ TT performance times, HR, or RPE between SL and staging days. For both SS and 180-kJ TT exercise, $S_aO_2$ was lower...
on each staging day compared to SL and was lower on staging day 1 compared to each of the other staging days.

**Long Endurance Performance: Steady-State and 720-kJ TT**

Steady-state power outputs during the long endurance performance test were intentionally reduced ($P < 0.01$) from SL for ALT-1 and ALT-2 during low (1160 ± 8 to 725 ± 5 W) and high (1580 ± 7 to 1160 ± 8 W) intensity SS exercise to maintain an equivalent altitude-specific %VO$_{2peak}$ exercise intensities (at ~44% and ~60%, respectively) prior to the 720-kJ TT (10). Table II shows the HR, S$_{O_2}$, and RPE responses to the identical low (725 ± 5 W) and high (1160 ± 8 W) intensity SS exercise power outputs at high altitude during ALT-1 and ALT-2. Each of the measures was significantly improved or tended to improve from ALT-1 to ALT-2 for both intensity levels.

At ALT-1, two volunteers were unable to complete the entire 720-kJ TT of the long endurance performance test due to extreme leg fatigue. One completed 59% or 423 kJ and the other 49% or 351 kJ. Both volunteers (and all others) were able to complete the 720-kJ at SL and ALT-2. In order to meaningfully compare TT results for these two volunteers only, all their data collected at SL, ALT-1, and ALT-2 were compared only up to 423 kJ and 351 kJ, respectively. Thus, for the entire group, the mean TT completed in each phase was 653 ± 47 kJ. Time-trial performance durations were 61.0 ± 17% (38.1 ± 6 min) longer during ALT-1 and 26.0 ± 4% (18.7 ± 3 min) longer during ALT-2 compared with SL (Table III and Fig. 2). Moreover, the volunteers began the ALT-1 and ALT-2 long endurance performance tests with nearly identical resting blood glucose levels. These results indicate that 44.2 ± 8% of the initial TT deficit as measured during ALT-1 was eliminated by ALT-2. It is important to note that TT performance was improved for each of the 10 volunteers by an average of 19.5 ± 6 min at ALT-2 compared to ALT-1 ($P < 0.01$).

Mean power output used during the TT was lower ($P < 0.01$) during ALT-1 and ALT-2 compared to SL, but was 20% higher ($P < 0.01$) at ALT-2 compared to ALT-1. Power output expressed as %SL W$_{peak}$ also was similarly altered between test days. The values for changes in estimated VO$_2$ closely tracked the results for changes in watts used expressed either in absolute terms or as %SL VO$_{2peak}$. That is, from SL to ALT-1 or ALT-2, mean TT VO$_2$ values were reduced, but higher at ALT-2 than ALT-1 ($P < 0.01$).

TT S$_{O_2}$ was reduced ($P < 0.01$) from SL to ALT-1. S$_{O_2}$ tended to increase at ALT-2 ($P < 0.07$) compared to

| TABLE II. STEADY STATE EXERCISE VALUES DURING THE LONG ENDURANCE TEST AT HIGH ALTITUDE BEFORE AND AFTER STAGING AT MODERATE ALTITUDE. |
|-----------------|----------------|----------------|----------------|----------------|----------------|
| **Activity**    | **Measurement** | **SL**         | **STG1**       | **STG2**       | **STG4**       |
| Low Intensity Exercise | HR (bpm) | 122.8 ± 5 | 118.5 ± 4 | 118.5 ± 4 | 118.5 ± 4 |
| (72.5 ± 5 W)     | S$_{O_2}$ (%) | 73.5 ± 2 | 77.2 ± 1 | 77.2 ± 1 | 77.2 ± 1 |
| (58% VO$_{2peak}$) | RPE     | 8.4 ± 1 | 7.4 ± 1 | 7.4 ± 1 | 7.4 ± 1 |
| High Intensity Exercise | HR (bpm) | 147.8 ± 5 | 140.1 ± 5 | 140.1 ± 5 | 140.1 ± 5 |
| (116.0 ± 8 W) | S$_{O_2}$ (%) | 75.6 ± 2 | 76.8 ± 1 | 76.8 ± 1 | 76.8 ± 1 |
| (60% VO$_{2peak}$) | RPE     | 11.7 ± 1 | 9.2 ± 1 | 9.2 ± 1 | 9.2 ± 1 |

Values are means ± SE; SL- ALT-1 = 5-h hypobaric chamber exposure before staging; ALT-2 = 5-h Pikes Peak exposure after staging; VO$_{2peak}$ = peak oxygen uptake; HR = heart rate; S$_{O_2}$ = arterial oxygen saturation; RPE = ratings of perceived exertion. * $P < 0.01$ compared to ALT-1; † $P = 0.068$ compared to ALT-1.

| TABLE III. STEADY STATE EXERCISE VALUES DURING THE LONG ENDURANCE TEST AT HIGH ALTITUDE BEFORE AND AFTER STAGING. |
|-----------------|----------------|----------------|----------------|
| **TT Duration (min)** | **SL**         | **ALT-1**       | **ALT-2**       |
| 73.2 ± 6         | 111.4 ± 6 | 91.9 ± 7*        |
| Power Output (W) | 150.0 ± 5 | 100.4 ± 10*     | 120.2 ± 7*     |
| Power Output (%SL W$_{peak}$) | 52.9 ± 2 | 37.9 ± 4*        | 45.4 ± 3*     |
| VO$_2$ (ml · min$^{-1}$) | 2280 ± 147 | 1478 ± 167 | 1765 ± 131*† |
| VO$_2$ (%SL VO$_{2peak}$) | 59.2 ± 2 | 37.2 ± 3*        | 45.3 ± 3*     |
| S$_{O_2}$ (%) | 96.5 ± 1 | 74.1 ± 1*        | 75.7 ± 1*     |
| RPE | 13.2 ± 1 | 15.5 ± 1*        | 13.0 ± 1     |
| HR (bpm) | 160.3 ± 5 | 147.7 ± 6*       | 148.4 ± 4*    |
| HR (%SL HR$_{peak}$) | 85.4 ± 2 | 78.9 ± 3*        | 79.1 ± 2*    |

Values are means ± SE; SL = sea level; ALT-1 = 5-h hypobaric chamber exposure before staging; ALT-2 = 5-h Pikes Peak exposure after staging; W = watts; VO$_2$ = oxygen uptake; %SL W$_{peak}$, %SL VO$_{2peak}$, %SL HR$_{peak}$ = percentage of SL$_{peak}$ values for watts, oxygen uptake, and heart rate, respectively; that was used during the TT. * $P < 0.01$ from SL; † $P < 0.01$ from ALT-1; ‡ $P < 0.04$ from SL and ALT-1; †† $P < 0.05$ from SL.
ALT-1 and ALT-2. There were no statistically significant
relationships between changes in TT performance and
RPE or HR from ALT-1 to ALT-2.

Acute Mountain Sickness
At SL and during each of the 6 staging days, the mean
AMS-C value of the ESQ and the mean LLS value were
always below the AMS criterion scores of 0.70 and 3.0,
respectively. On an individual basis, the ESQ deter-
mained that none of the volunteers had AMS during stag-
ing, whereas the LLS determined that there was mild
AMS in four volunteers on staging day 1 (scores: 3,3,4,6),
in three volunteers on staging day 2 (scores: 3,4,9), and in
two volunteers on staging day 3 (scores: 3,4). After stag-
day 3, no volunteers reported having AMS regard-
less of the scoring system used.

At high altitude, the mean group AMS-C score calcu-
lated from the ESQ indicated that there was an absence
of AMS prior to the start of exercise during ALT-1 (0.27 ±
0.11) and ALT-2 (0.31 ± 0.17). Similar group results
were obtained using the LLS: 0.55 ± 0.31 during ALT-1
and 0.64 ± 0.37 during ALT-2. On an individual basis,
the ESQ indicated that the same volunteer had AMS
just prior to exercise at ALT-1 (AMS-C score = 1.094)
and ALT-2 (AMS-C score = 1.649.) The LLS also identi-
fied that volunteer as having AMS (score = 3), but at
ALT-2 only.

Resting Cardio-Respiratory Measures and Blood Analyses
From ALT-1 to ALT-2, there were decreases in resting
$P_{ ET\ CO_2}$ and HR, and increases in $P_{ ET\ O_2}$ and $S_a\ O_2$ (Table
IV). Both [Hb] and Hct were slightly higher ($P < 0.05$) at
ALT-2 (15.3 ± 0.3 g • dl⁻¹; 45.1 ± 1%) than at SL (14.7 ±
0.2 g • dl⁻¹; 43.1 ± 1%) or ALT-1 (14.8 ± 0.3 g • dl⁻¹;
43.5 ± 1%). The increased values for [Hb] and Hct were
associated with an estimated % plasma volume reduc-
tion ($P < 0.01$) of 7 ± 2% from SL to ALT-2 (7). Arterial
oxygen content was reduced ($P < 0.01$) from SL (19.1 ±
1.0 ml • dl⁻¹) to ALT-1 (15.9 ± 1.4 ml • dl⁻¹) and
ALT-2 (17.1 ± 1.1 ml • dl⁻¹), and was higher ($P < 0.01$)
on ALT-2 compared to ALT-1. Resting blood glucose
just prior to exercise was not different from ALT-1
(5.37 ± 0.2 mmol) to ALT-2 (5.36 ± 0.2 mmol).

DISCUSSION
To our knowledge, this study is the first to present a
quantitative appraisal of the effect of staging at a moderate

**TABLE IV. RESTING CARDIO-RESPIRATORY MEASURES BEFORE AND AFTER MODERATE ALTITUDE STAGING.**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>ALT-1</th>
<th>ALT-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR (bpm)</td>
<td>71.6 ± 2</td>
<td>65.1 ± 2*</td>
</tr>
<tr>
<td>$P_{ ET\ CO_2}$ (mmHg)</td>
<td>39.1 ± 1</td>
<td>32.8 ± 1*</td>
</tr>
<tr>
<td>$P_{ ET\ O_2}$ (mmHg)</td>
<td>47.7 ± 1</td>
<td>50.2 ± 1*</td>
</tr>
<tr>
<td>$S_a\ O_2$ (%)</td>
<td>80.1 ± 1</td>
<td>83.1 ± 1*</td>
</tr>
</tbody>
</table>

Values are means ± SE; ALT-1 = 5-h hypobaric chamber exposure before staging; ALT-2 = 5-h Pikes Peak exposure after staging; $P_{ ET\ CO_2}$ and
$P_{ ET\ O_2}$ = partial pressure of end-tidal CO$_2$ and O$_2$, respectively; $S_a\ O_2$ = arterial oxygen saturation. * $P < 0.01$ compared to ALT-1.
altitude on prolonged endurance performance at a higher elevation. Our results clearly indicate that living for only 6 d at 2200 m enhanced TT performance of each of 10 previously unacclimatized SLR during exposure to 4300 m. Compared to the TT duration of 73 min at sea level, the TT at 4300 m took about 38 min longer to complete before staging, but only about 19 min longer after staging. This finding shows that partial acclimatization resulting from staging at 2200 m eliminated nearly half of the initial TT impairment at 4300 m. Moreover, two individuals who completed only ~55% of the TT at 4300 m before staging completed the entire TT after staging. It is also important to emphasize that the TT performance results at high altitude were not confounded by changes in the incidence or severity of AMS symptoms and that there was only mild AMS in a few individuals during early exposure to 2200 m. Collectively these findings indicate that the staging elevation and duration combination used provided a highly effective means for attenuating the large endurance performance decrement during early exposure to 4300 m.

Residence at a given altitude induces a variety of physiological compensatory adjustments characteristic of altitude acclimatization that minimize the impact of hypoxemia and that are generally proportional to the altitude and time spent at that elevation (6, 17, 22). In the current study, traditional ventilatory and blood markers of acclimatization such as $P_{ET}CO_2$, $P_{ET}O_2$, $S_aO_2$, and [Hb] (22) were monitored at rest or during standardized exercise before, during, and after 6 d of staging. The $P_{ET}CO_2$ reduction, $P_{ET}O_2$, and $S_aO_2$ increases and the small but statistically significant hemoconcentration observed in response to 4300 m after staging indicate that at least partial acclimatization occurred while living at moderate altitude (6, 13, 17). Additional evidence of the benefit of moderate altitude acclimatization was manifested as generally lower RPE or HR and ~2–3% higher $S_aO_2$ for the same (i.e., SS exercise) or higher (i.e., maximal-effort 720-kJ TT) power output during exposure to 4300 m after staging compared to before staging. The lack of change in HR and RPE during cycle maintenance training (both SS exercise and 180-kJ TT) as well as no change in the 180-kJ TT performance duration during the staging phase and in comparison to SL suggests also that the endurance fitness level of the volunteers was maintained and not improved while living at the USAFA.

Ventilatory acclimatization and hemoconcentration help raise arterial oxygen content which, in turn, facilitates oxygen transport and delivery to metabolic active tissues, reduces the physiological strain and perceived exertion during SS exercise, and improves exercise tolerance (14). The significant association between improved TT performance and changes in exercise $S_aO_2$ compared to a lack of association with changes in [Hb] suggest that ventilatory acclimatization was the more beneficial factor resulting from staging, as has been previously proposed for relatively short exposures to altitude (17, 22). Ventilatory acclimatization also has been implicated as a major factor responsible for the much lower incidence and severity of AMS and improved endurance performance at 4300 m for both acclimatized SLR (2, 3, 10) and moderate altitude residents (MAR) (11, 16) compared to initially unacclimatized SLR.

The large TT performance improvement at 4300 m was associated with an increased capability to perform at a higher mean exercise intensity (i.e., higher $%VO_{2peak}$) after staging compared to before staging (45% vs. 37%) that was independent of changes in AMS symptoms. However, even after partial acclimatization resulting from staging, exercise intensity at 4300 m remained much lower than the 59% of $VO_{2peak}$ observed at SL. In contrast, MAR who lived for nearly 2 yr at 2200 m and who likewise performed the 720-kJ cycle TT within hours of exposure to 4300 m (11) did not experience any reduction in exercise intensity (~58% at both elevations). Exercise $S_aO_2$ at 4300 m also was significantly higher ($P < 0.05$) for the MAR (80%) than for the SLR even after staging (76%). Unfortunately, between-study differences such as resident altitude and fitness level do not allow exact comparison of changes in TT performance between the MAR and staged SLR after rapid ascent to 4300 m. Nevertheless, at 4300 m, a lack of reduction in exercise intensity and a higher $S_aO_2$ for the MAR indicate that while the degree of acclimatization and the TT improvement experienced by the staged SLR in the present study were significant, they likely were less than complete.

In summary, staging of previously unacclimatized SLR at a moderate altitude of 2200 m for 6 d greatly improved TT performance during subsequent exposure to 4300 m. The improvement in TT performance occurred independently of changes in AMS. The elevation and duration of the moderate altitude sojourn used were not so high to significantly raise the incidence and severity of AMS, yet were sufficient to induce beneficial changes that subsequently improved TT performance at high altitude. The association between improved TT performance and changes in exercise $S_aO_2$ suggest that ventilatory acclimatization was the major factor contributing to the improvement. Moderate altitude staging would be useful for military personnel or search and rescue teams who may be required to perform physically demanding tasks immediately on insertion to higher elevations.

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the investigators adhered to policies of applicable Federal Law CFR 46. Human subjects participated in these studies after giving their free and informed consent. Investigators adhered to AR 70-25 and USAMRMC Regulation 70-25 on the use of volunteers in research. Any citations of commercial organizations and trade names in this report do not constitute an official Department of the Army endorsement of approval of the products or services of the organizations.

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