Two-Day Residence at 2500 m to 4300 m Does Not Affect Subsequent Exercise Performance at 4300 m

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ABSTRACT

KENEFICK, R. W., B. A. BEIDLEMAN, S. P. ANDREW, B. S. CADARETTE, S. R. MUZA, and C. S. FULCO. Two-Day Residence at 2500 m to 4300 m Does Not Affect Subsequent Exercise Performance at 4300 m. *Med. Sci. Sports Exerc.*, Vol. 51, No. 4, pp. 744–750, 2019. **Purpose**: To determine the efficacy residing for 2 d at various altitudes while sedentary (S) or active (A; ~90 min hiking 2 d) on exercise performance at 4300 m. **Methods**: Sea-level (SL) resident men (n = 45) and women (n = 21) (mean ± SD; 23 ± 5 yr; 173 ± 9 cm; 73 ± 12 kg; $\dot{V}O_{2peak}$ = 49 ± 7 mL·kg^{-1}·min^{-1}) were randomly assigned to a residence group and, S or A within each group: 2500 m (n = 11S, 8A), 3000 m (n = 6S, 12A), 3500 m (n = 6S, 8A), or 4300 m (n = 7S, 8A). Exercise assessments occurred at SL and 4300 m after 2-d residence and consisted of 20 min of steady-state (SS) treadmill walking (45% ± 3% SL $\dot{V}O_{2peak}$) and a 5-mile, self-paced running time trial (TT). Arterial oxygen saturation (SpO_2) and HR were recorded throughout exercise. Resting SpO_2 was recorded at SL, at 4 and 46 h of residence, and at 4300 m before exercise assessment. To determine if 2-d altitude residence improved 4300 m TT performance, results were compared with estimated performances using a validated prediction model. **Results**: For all groups, resting SpO_2 was reduced (P < 0.01) after 4 h of residence relative to SL inversely to the elevation and did not improve after 46 h. Resting SpO_2 (~83%) did not differ among groups at 4300 m. Although SL and 4300 m SS exercise SpO_2 (97% ± 2% to 74% ± 4%), HR (123 ± 10 bpm to 140 ± 12 bpm) and TT duration (51 ± 9 to 73 ± 16 min) were different (P < 0.01), responses at 4300 m were similar among all groups, as was actual and predicted 4300 m TT performances (74 ± 12 min). **Conclusions**: Residing for 2 d at 2500 to 4300 m, with or without daily activity, did not improve resting SpO_2, SS exercise responses, or TT performance at 4300 m. **Key Words:** STAGING ALTITUDE, ALTITUDE ACCLIMATIZATION, ARTERIAL OXYGENATION

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Rapid and direct ascent of unacclimatized sea-level (SL) residents to terrestrial altitudes greater than 4000 m causes substantial reductions in endurance exercise performance (1). Acclimatization attenuates altitude-related declines in exercise performance (2–4); however, the relative effectiveness of various strategies to induce acclimatization remain unclear (5,6). “Staging” or residing at an intermediate altitude just before ascending to a higher, target altitude is an acclimatization strategy that is widely used in mountaineering and by the military (7). For staging to provide functional benefits, individuals must reside at an altitude high enough and long enough to initiate the acclimatization process. The expectation is that modest physiological changes (e.g., increased arterial oxygenation) induced during residence will be “carried over” to the target altitude and thereby attenuate the initial large reduction in endurance exercise performance and avoid severe symptoms of acute mountain sickness (AMS) that would otherwise occur during direct ascent to the same target altitude (8).

Despite staging being a universally accepted acclimatization strategy, no systematic scientific evaluation has been reported of the relative effectiveness of the many possible combinations of staging elevations, durations, and activity levels for improving endurance exercise performance outcomes during subsequent target altitude exposures. To our knowledge, only one investigation has experimentally evaluated the effect of staging (6 d at 2200 m) with rigorous physical activity on endurance exercise performance at a given target altitude, prestaging to poststaging. Fulco et al. (9) reported reduced HR and RPE and increased arterial oxygen saturation (SpO_2) during steady-state (SS) exercise, along with a significant attenuation of the decline in time trial (TT) performance at a target altitude of 4300 m. While that investigation (9) provided objective evidence that staging can be highly effective for improving endurance exercise performance at a target altitude, the effectiveness of other combinations of staging duration, staging elevation, or physical activity level remain unclear. Determination of the most effective acclimatization strategy combinations has important application to military,

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occupational, and recreational settings where factors, such as staging duration and activity, represent a logistical burden, potentially complicating planning and cost of a mission, project, or expedition. Given the scenario of minimal mission/project preparation time, we chose to study the impact of 2 d of residence at altitudes ranging from 2500 to 4300 m, with and without increased physical activity, on subsequent exercise assessments at a target altitude of 4300 m.

Increased physical activity during altitude residence has the potential to augment the altitude acclimatization process and endurance exercise performance during subsequent exposure to a target altitude. It has long been recognized that compared with rest, exercise at altitude exacerbates arterial hypoxemia primarily due to a pulmonary gas exchange limitation resulting from a reduction in the partial pressure of oxygen in ambient air (4,7,9,10). At an elevation of 2200 m, for example, SpO_2 in unacclimatized individuals is reduced from 94% at rest to 89% while exercising at a moderate intensity (9), which is the equivalent of being temporarily exposed to higher altitudes of approximately 3000 m without exercise (7). It is, therefore, reasonable to hypothesize that the additional hypoxia associated with physical activity (compared to no activity) while residing at given elevations may accelerate the ongoing acclimatization process resulting in a more improved endurance exercise performance outcome at the target altitude. However, this hypothesis has not been thoroughly field tested among multiple resident elevation/duration combinations.

Thus, the primary purpose of the present study was to determine the efficacy of residing for a shorter duration (2 d) using altitudes of 2500, 3000, 3500, and 4300 m to attenuate the decline in TT performance at a given target altitude of 4300 m. Relatedly, TT performance was estimated for direct and rapid ascent (≤4 h) to 4300 m using a validated algorithm (11) to determine if endurance exercise performance could be improved at the target altitude as a result of living for 2 d at any of the four elevations. A secondary purpose was to determine whether a difference in activity level while residing at altitude further benefits TT performance outcomes at the target altitude. We hypothesized that residing for a shorter duration but at higher elevations (vs 2200 m) would result in improvements in a key acclimatization index (e.g., increased resting SpO_2) and that the degree of resting SpO_2 increase would be directly related to the increase in resident elevation. Furthermore, we hypothesized that altitude-mediated improvements in SpO_2 would be associated with TT performance improvements at the target altitude (4300 m). We also hypothesized that within each of the four altitude resident groups, resting SpO_2 values would be greater for each active versus sedentary subgroup resulting in better TT performance outcomes at the target altitude of 4300 m.

METHODS

Volunteers

Sixty-six healthy unacclimatized, SL native men and women participated in this study (Table 1). All were born at altitudes <1500 m and lived at altitudes <1000 m for >3 months before the start of the study. 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 US Army Research Institute of Environmental Medicine (USARIEM) and the Human Research Protection Office, US Army Medical Research and Materiel Command. Investigators adhered to DoD Instruction 3216.02 and 32 CFR 219 on the use of volunteers in research.

Study Design

Four independent groups (each divided into a sedentary or active subgroup) resided for 2 d at terrestrial elevations of 2500, 3000, 3500, or 4300 m, just before assessing TT performance at 4300 m. This was accomplished in three distinct phases over approximately 3 wk. The first phase was conducted in a week at the USARIEM Hypobaric Chamber Facility in Natick, MA (50 m, SL). Volunteers were familiarized with all equipment, personnel and procedures, and SL baseline data were collected.

After familiarization and baseline testing at SL, volunteers were flown from USARIEM to CO Springs, CO (2000 m) where they stayed overnight and breathed supplemental oxygen to maintain finger pulse oxygen saturation level at ≥96%. At 5:00 AM the next morning, the volunteers were awakened and inhalation of supplemental oxygen ceased.

The second phase began when the four volunteer groups were transported by automobile (60–120 min transit) to their respective resident sites for 2 d. Three groups of volunteers camped within the Pikes Peak National Forest region at elevations of 2500 m (561 mm Hg; n = 19), 3000 m (526 mm Hg; n = 18), and 3500 m (494 mm Hg; n = 14). A fourth group of volunteers ascended directly to the Pikes Peak Laboratory to reside at a geographical elevation of 4300 m (462 mm Hg; n = 15).

TABLE 1. Physical characteristics.

	All Volunteers	2500 m	3000 m	3500 m	4300 m
Volunteers (*n*)	66	19	18	14	15
Age (yr)	23.4 ± 5	23.3 ± 7	24.5 ± 5	23.9 ± 4	21.6 ± 2
Height (cm)	173.0 ± 9	173.3 ± 10	173.3 ± 10	172.8 ± 7	172.5 ± 8
Weight (kg)	73.4 ± 12	74.3 ± 14	75.1 ± 13	71.9 ± 11	71.5 ± 11
$\dot{V}O_{2peak}$ (mL·min^{-1}·kg^{-1})	49.4 ± 7	48.5 ± 6	49.5 ± 7	49.3 ± 5	50.5 ± 8
Activity (*n*; A/S)	36/30	8/11	12/6	8/6	8/7
Sex (*n*; men/women)	45/21	14/5	12/6	11/3	8/7

Values are means ± SD or counts.

Phase 3 of the study began early in the morning of the third day after each group had resided at their respective site for 2 d. Volunteers from each of the three campsites were driven (60–180 min transit) to the Pikes Peak Laboratory. Arrival time for the three campground-staged groups was between 7:30 AM and 10:00 AM. The fourth group, already in residence at 4300 m for 2 d, was tested early to midmorning on their third day of residence at 4300 m.

Activity Levels

Volunteers were randomly assigned to participate in either a sedentary (S) or high activity (A) subgroup while residing at each of the four altitudes. To verify differences in activity levels, daily energy expenditures (kcal·d^{-1}) were assessed via a one-directional accelerometer (Actical; Philips Respironics, Murrysville, PA) that volunteers wore on their ankle throughout their participation in the study. Those in the S subgroup engaged only in sedentary living tasks (reading, board games, etc.). Those in the A subgroup also participated in supervised, 1.5- to 2-h trail hikes twice each day between the hours of 8:00 AM and 4:00 PM. During all other times of day, the S and A volunteers commingled at the campgrounds/laboratory and remained sedentary. At all resident elevations, the hikes were conducted using a global positioning system (GPS) (Garmin, Inc., Olathe, KS) to help maintain a brisk 3.5 to 4.0 mph pace over a predetermined distance over uneven terrain while carrying water, food, and a daypack (approximately 5 to 7 METS). This level of exertion was equivalent to 45% to 60% of altitude specific $\dot{V}O_{2peak}$ (1) which results in a 4% to 9% lower arterial oxygen saturation (SpO_2) values compared to rest (4,9,10). Thus, the hikers experienced for about 3 to 4 h·d^{-1} a “physiological” altitude that was 500 to 700 m higher at each staging elevation than that of the sedentary group.

Volunteers were allowed to eat *ad libitum* throughout their participation in the study. During phase 1, while at SL, volunteers ate typical meals at home. During phase 2, altitude residence and phase 3, target altitude testing, volunteers ate meal ready to eat or first strike rations supplemented with common foods, such as vegetables, fruits, cereals, milk, and juices.

Research Procedures

Resting arterial oxygen saturation. Resting arterial oxygen saturation was measured while seated quietly at rest for at least 3 min via noninvasive finger pulse oximetry (Nonin, Plymouth, MN). SpO_2 was measured for all groups at SL; during the fourth hour (day 1) and 46th hour (day 2) at each resident altitude and during the fourth hour on day 3 at the target altitude of 4300 m.

Peak oxygen uptake ($\dot{V}O_{2peak}$). During the SL baseline phase, an incremental, progressive exercise bout to volitional exhaustion on a treadmill was used to assess $\dot{V}O_{2peak}$ and to determine an individualized work rate that would be used during each SS exercise bout completed before each TT performance assessment. Measurements of O_2 uptake were obtained using a metabolic cart (True Max 2400; ParvoMedics, Sandy, UT). Volunteers first walked for a total of 10 min (five 2-min stages) starting at 3 mph/0% grade and ending at 4 mph/7% grade. Volunteers then began to run as the treadmill speed and grade were changed to 6 mph and 0%, respectively. Every 2-min stage thereafter, the speed and/or grade was increased slightly (1 MET increments) until O_2 uptake failed to increase or the volunteer could no longer continue.

SS exercise. Cardiorespiratory and perceived exertion responses during SS exercise were assessed while volunteers walked for 20 min on a treadmill at an identical work rate (equal to 45% ± 3% of their SL $\dot{V}O_{2peak}$) while at SL and while at the target altitude of 4300 m (day 3). Volunteers warmed up for 5 min at a speed and grade of 3 mph and 0% grade, respectively, before both were increased to individually predetermined work rate levels. During the last 10 min of each SS exercise bout, $\dot{V}O_2$ and ventilatory data via metabolic cart (True Max 2400; ParvoMedics) were collected continuously. Also continuously recorded was arterial oxygen saturation (SpO_2) using noninvasive finger pulse oximetry (Nonin, Plymouth, MN), HR (Polar HR watch, Hempstead, NY), and at 5-min intervals, RPE using the 6 to 20 Borg scale.

TT performance. At SL and while at the target altitude of 4300 m on day 3, volunteers performed a 5-mile TT at a self-selected pace. Each TT was performed after a 5-min break from the SS exercise bout. This performance test was chosen due to its high-test-retest reproducibility and low coefficient of variance (4,12). During the test, the grade was fixed at 3% for all volunteers, and each volunteer was allowed to alter the treadmill speed at any time by any desired increment. The only instruction was to complete the 5 miles as quickly as possible. During the TT, volunteers were provided real-time feedback (via computer screen graphics) of the completed and remaining distances but were not informed of their selected speeds, or TT duration. HR, SpO_2, and RPE were collected at 5-min intervals.

Because of logistic and scheduling restrictions, we did not assess endurance exercise outcomes without 2 d of altitude residence before target altitude exposure. Thus, to determine if acclimatizing for 2 d while living at either 2500, 3000, 3500, or 4300 m actually improved TT performance beyond what would be determined with direct target altitude exposure (≤4 h), we used a recently validated prediction model from our laboratory (11) that was developed using volunteers having similar physical and fitness characteristics to those in the present study. These estimated direct exposure TT performance values were then compared with the respective TT performance durations actually determined in the present study.

Acute mountain sickness. Acute mountain sickness assessments were performed frequently at each resident elevation using the same subjects as in the present study, and those results are presented in detail elsewhere (13). Briefly, AMS assessments (taken at 4, 8, 12, 22, 28, 32, 36 and 46 h of residence) consisted of a 3-min, self-reported questionnaire that was administered while the subjects were seated at rest. A weighted score ranging from 0 (no AMS) to 5 (incapacitating AMS) was then calculated. If the weighted score was ≥0.7 for a volunteer at any time point during staging, then AMS was considered present.

Just after the 46-h AMS assessment at 2500, 3000, or 3500 m, each group departed their campsites and was transported by automobile to the Pikes Peak laboratory where target altitude testing was soon initiated. The 4300-m group began testing midmorning on their third day of continued exposure to 4300 m.

Statistical Analyses

A one-way ANOVA was used to determine differences in age, height, weight and $\dot{V}O_{2peak}$ among the altitude resident groups. A two-way mixed-model ANOVA (group by time) was used to determine potential differences at SL and the target altitude of 4300 m between the A and S groups. A two-way mixed-model ANOVA was then used to determine differences at SL and the target altitude between the four altitude resident groups and to determine within group differences at the fourth, 46th hours of and the fourth hour at the target altitude.

A previously published exercise model (11) was used to estimate nonacclimatized individual TT performances within a few hours of direct exposure to 4300 m. These results were compared with actual TT performances at the target altitude in the present study after 2 d of altitude residence to determine if TT performance was improved. A two-way mixed-model ANOVA was used to determine TT differences from day 1 (predicted) to day 3 (actual) at 4300 m among the four altitude resident groups. Given unequal sample sizes, a weighted mean was used as opposed to the grand mean for these analyses. Tukey's HSD procedure was used to identify differences among means following significant main and/or interaction effects. As the primary outcome variable of interest was the time to complete the 5-mile TT, the chosen effect size was calculated to be 0.71 based on the TT performance reported by Fulco et al. (9). With an alpha of 0.05 and beta of 0.20, the sample size required to detect a meaningful effect of acclimatization on TT performance was 12 to 14 volunteers for each resident group using a one-way ANOVA. All values were expressed as means ± SD. All analyses were conducted using Dell Statistica version 13 (2016).

RESULTS

Subject Characteristics

The physical characteristics of the volunteers were determined at SL and are presented in Table 1. All volunteers ranged in the good to superior fitness category as outlined in the *ACSM's Guidelines for Exercise Testing and Prescription* (14). There were no differences ($P > 0.05$) in age, height, weight, or $\dot{V}O_{2peak}$ among the four groups.

Physical Activity

During the 8-h period from 8:00 AM to 4:00 P.M., the A groups expended approximately 500 kcal more than the S group for each of the 2 d of residence. The average 8 h·kcal^{-1} energy expenditure each day was 1611 ± 202 kcal versus 1119 ± 376 kcal ($P < 0.05$) at 2500, 3000, 3500, and 4300 m, for the A and S groups, respectively. Despite differences in daily energy expenditure, there were no statistical differences ($P > 0.05$) between the A and S subgroups within each resident group for any of the resting, or SS exercise and TT measurements made at the target altitude (Table 2). As such, the S and A subgroups were combined for subsequent analyses.

Resting SpO_2. SpO_2 values were not different ($P < 0.05$) among any of the groups at SL. After 4 h of residence at each altitude, resting SpO_2 declined ($P < 0.05$) from SL values. SpO_2 values at 4 h were different ($P < 0.05$) among each of the groups (2500 m > 3500 m and 4300 m; 3000 m > 4300 m) and these values were consistent after 46 h of residence. After 4 h at the target altitude of 4300 m (day 3), SpO_2 of the 2500-, 3000-, and 3500-m groups further declined ($P < 0.05$), whereas values for the 4300-m group did not change. There were no differences ($P > 0.05$) among groups in SpO_2 at the fourth hour at the target altitude (Fig. 1).

SS exercise responses. During SS exercise at SL and at the target altitude (day 3), there were no differences ($P > 0.05$) among groups in absolute or relative $\dot{V}O_2$ (mL·min^{-1} or mL·min^{-1}·kg^{-1}), VE (L·min^{-1}), HR (bpm), RPE, or SpO_2 (%). From SL to the target altitude, $\dot{V}O_2$ did not change, whereas VE and HR increased ($P < 0.01$) and SpO_2 decreased ($P < 0.01$) for all groups; however, there were no differences in response among groups. The RPE response to SS exercise was statistically similar for all groups from SL to the target altitude (i.e., within 1 to 2 units).

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TABLE 2. Resting and SS exercise cardio-respiratory, perceptual and TT performance measures for sedentary and active groups at SL and 4300 m.

	Sedentary (n = 30)		Active (n = 36)	
	SL	4300 m	SL	4300 m
Resting SpO_2 (%)	98 ± 1	82 ± 5*	98 ± 1	83 ± 5*
SS $\dot{V}O_2$ (%SL $\dot{V}O_{2peak}$)	45 ± 2	46 ± 4	44 ± 2	44 ± 4
SS $\dot{V}O_2$ (mL·min^{-1})	1615 ± 384	1621 ± 358	1648 ± 406	1640 ± 376
SS HR (bpm)	124 ± 10	142 ± 12*	123 ± 11	139 ± 12*
SS RPE (units)	9 ± 2	10 ± 2	9 ± 2	11 ± 2*
SS SpO_2 (%)	97 ± 2	74 ± 5*	97 ± 2	73 ± 4*
TT performance (min)	51 ± 8	73 ± 18*	51 ± 9	73 ± 14*
SL $\dot{V}O_{2peak}$ (mL·min^{-1}·kg^{-1})	48.9 ± 6		49.8 ± 7	

Values are means ± SD.
*$P < 0.05$ from SL.

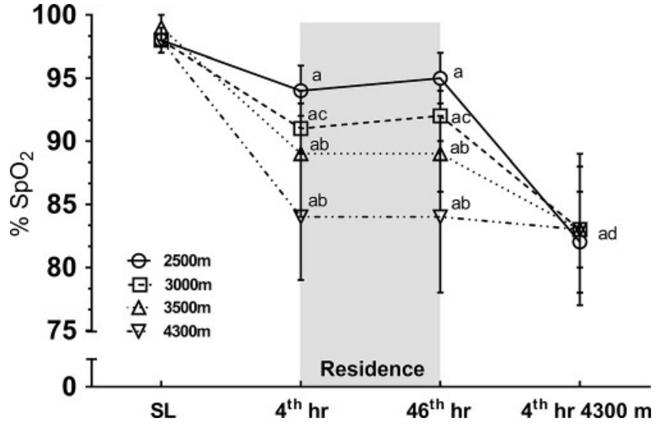

FIGURE 1—Resting SpO_2 values while at SL; during the fourth and 46th hours while residing at 2500, 3000, 3500, and 4300 m; and during the fourth hour at 4300 m. a denotes significant difference (P < 0.05) from SL value; b denotes significant difference (P < 0.05) from 2500 m at fourth and 46th hours; c denotes significant difference (P < 0.05) from 4300 m at fourth and 46th hours; d denotes significant difference (P < 0.05) from 2500 m, 3000 m, and 3500 m at fourth and 46th hours.

TT performance. Time-trial performances were estimated for rapid and direct ascent to 4300 m from SL for all of our subjects (11). These predicted performance times were then compared to their respective actual TT performance times on day 3 (i.e., at the target altitude after 2 d of residence). As illustrated in Figures 2A and B, there were no significant mean TT duration differences from day 1 (predicted) to day 3 (actual) within a group, among groups, or for the entire cohort expressed as either an absolute (min at 4300 m) or relative (% change from SL) value.

Acute Mountain Sickness

AMS occurred primarily in the first 32 h after ascent to the higher resident elevations. That is, in the first 32 h of residence, there were no reports of AMS in the 2500-m group; 2 were reported in the 3000-m group, 6 in the 3500-m group, and 10 in the 4300-m group. By the 46th hour of residence (or 4 to 6 h before the subsequent exercise assessments at the target altitude), there were only a total of three volunteers who reported having AMS, all of which were mild cases (<1.5 AMS weighted score); one in the 3000-m group and two in the 4300-m group. Thus, AMS was not a major factor influencing target altitude exercise outcomes.

DISCUSSION

The overall hypothesis of this study was that residing for 2 d at altitudes of 2500, 3000, 3500, or 4300 m, with and without increased daily physical activity, would provide a sufficient hypoxic stimulus to initiate partial acclimatization that would, in turn, improve TT performance outcomes during subsequent exposure to a target terrestrial altitude of 4300 m. Contrary to our hypotheses, we conclude the following: 1) there were no improvements in resting SpO_2 over the 2 d while residing at any of the four altitudes, nor were there differences between activity groups; 2) there were no differences among the four altitude groups and activity groups at the target altitude of 4300 m for SpO_2 at rest; or for SpO_2, ventilation, HR, and ratings of perceived exertion responses during SS exercise; and 3) 2 d of residence did not result in improved TT performance at 4300 m among the four altitude or physical activity groups.

We attempted to use changes in resting SpO_2 (Fig. 1) as a field-expedient surrogate measure to be a useful monitor of acclimatization. We anticipated that changes in resting SpO_2 would be higher in a stepwise manner due to an increasing hypoxic stimulus as the resident elevations increased. However, this turned out not to be the case since there was no measurable improvement in SpO_2 for any of the elevations used, and there was no difference in resting SpO_2 among groups when exposed to the target altitude of 4300 m. A previous study (9) conducted over 6 d also did not observe a resting SpO_2 improvement during staging at 2200 m but did report that resting SpO_2 increased from before to after staging when measured at 4300 m. Collectively, these results suggest that the use of resting SpO_2 as a proxy for monitoring rate of acclimatization during 2 to 6 d of staging at altitudes of 2200 to 2500 m while staging or for

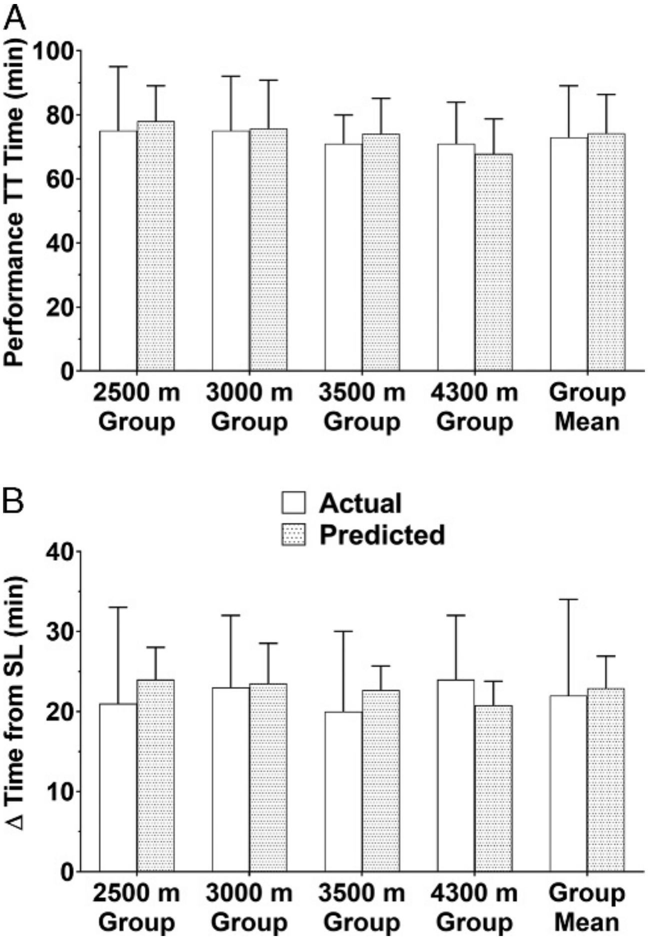

FIGURE 2—A, Actual and predicted TT performance (min) at target terrestrial altitude of 4300 m for each staging group. B, Difference in actual and predicted TT performance (min) from SL to 4300 m for each staging group. There were no differences between Actual and Predicted performance TT times for each altitude group or for the group mean (P > 0.05).

subsequent outcomes at a target altitude of 4300 m is not useful. In contrast, the use of SpO_2 as an acclimatization index during staging may be effective if the duration is longer than four or more consecutive days and the staging elevations are closer to the target elevation (8,15,16).

We also hypothesized that increased physical activity during the 2 d of altitude residence would exacerbate arterial hypoxemia and therefore increase the hypoxic stimulus for acclimatization (4,9,10) and translate into a more improved endurance exercise performance (vs no activity) at the target altitude of 4300 m. Although we did not measure SpO_2 during physical activity at each resident altitude, it was reasonable to assume that there was a sustained significant reduction during the two-a-day hikes at each resident altitude (4,9,10) and that for the participating subjects the "physiological" altitude experienced at each elevation would be higher by the equivalent of 500 to 700 m (7). Given that resting SpO_2, SS exercise responses and TT performances at the target altitude of 4300 m were not different between the high activity and sedentary groups (Table 2), this hypothesis proved to be incorrect. Thus, under the constraints of the present study, we did not observe any improvement in exercise performance that was associated with increased daily physical activity during 2 d of residence at altitudes ranging from 2500 to 4300 m.

We did not assess endurance exercise outcomes on the first day of target altitude exposure using a fifth group of volunteers, that is, a "control" group, who would ascend directly from SL to 4300 m. Not doing so could be considered a limitation of the study because it is not possible to know if endurance exercise performance improves from the first to the third day of residence at 4300 m. Because we did not observe a difference in endurance performance among the four groups at the target altitude of 4300 m, it could be interpreted that for all four groups TT performance did not improve or that for all four groups TT performance improved similarly.

To determine whether endurance performance did or did not improve among the four groups, we compared the results of the present study to those of previously published investigations from our laboratory that used volunteers with similar physical and fitness characteristics, who participated in similar resting and endurance exercise test procedures, and most importantly, who directly and rapidly ascended from SL to a target altitude of 4300 m. Furthermore, we compared the TT performance of volunteers in the present study to a performance prediction algorithm based on the TT results from our previous work (11).

Our previous studies reported that unacclimatized SL resident men and women ascending from SL directly to 4300 m, had an average decline in resting SpO_2 of 16% (from 98% to 82%) (16–19) that was further reduced by another 8% (to ~75%) during SS exercise at 45% of SL $\dot{V}O_{2peak}$ (4,9,10). Also from SL to 4300 m, HR increased by an average of 15 bpm and RPE increased by an average of 2 units during SS exercise (10,20,21). These previously published results agree within a very narrow range with SS exercise values of all the altitude resident groups in the present study (Table 3). The similarity between the SpO_2, HR, and RPE data in our current study and that in previous investigations, suggests that, for the current study, there was no improvement in these variables at the target altitude after 2 d of residence at altitudes of 2500 to 4300 m.

For a second method of determining whether TT performance from SL to the target altitude was improved by 2 d of altitude residence, results from a validated prediction model were compared with the present results (11). For the 66 volunteers in the present study, it was estimated that the TT performance durations among the four groups if assessed within the first 4 h of exposure to a terrestrial altitude of 4300 would range from 67 to 78 min (average, 74 ± 12 min), 23 ± 4 min longer than the TT at SL. These predicted TT performance durations at 4300 m were similar (nearly numerically identical) to the actual results on day 3 for our subjects (range, 71–75 min), with an overall average of 73 ± 16 min, which was 22 ± 12 min longer than the SL TT performance duration (Fig. 2A). Furthermore, the actual TT performance time difference from SL to the target altitude of 4300 m for each of our groups was remarkably similar to the predicted values (Fig. 2B). Collectively, we interpret the similar resting and SS exercise values in the present study and our previous studies, and the nearly identical prediction of TT performance using our prediction model, to be consistent with the conclusion that 2 d of residence at any of the altitudes ranging from 2500 to 4300 m, regardless of activity level, was simply too short a duration to promote a degree of acclimatization resulting in improved TT performance at 4300 m.

The results of the present study clearly indicate that resting and SS exercise acclimatization indices, as well as TT performance results obtained during or after 2 d of residence at various altitudes, did not meaningfully differ from the results of multiple published reports of individuals who directly ascended to the same target altitude of 4300 m. Because there were minimal reports of AMS symptoms (n = 3

TABLE 3. SS exercise responses at SL and 4300 m.

	2500 m		3000 m		3500 m		4300 m	
	SL	4300 m	SL	4300 m	SL	4300 m	SL	4300 m
$\dot{V}O_2$ (mL·min^{-1})	1628 ± 369	1610 ± 382	1657 ± 476	1661 ± 399	1622 ± 288	1662 ± 275	1620 ± 437	1593 ± 406
$\dot{V}O_2$ (%SL $\dot{V}O_{2peak}$)	45 ± 3	45 ± 4	44 ± 3	44 ± 2	46 ± 2	47 ± 3	44 ± 2	44 ± 4
VE (L·min^{-1})	38 ± 7	53 ± 12*	39 ± 10	57 ± 13*	39 ± 9	61 ± 13*	38 ± 9	56 ± 15*
HR (bpm)	123 ± 11	139 ± 13*	124 ± 13	139 ± 13*	122 ± 5	143 ± 9*	124 ± 10	140 ± 14*
RPE (units)	9 ± 2	10 ± 2	9 ± 2	11 ± 2	10 ± 3	11 ± 2	9 ± 2	10 ± 2
SpO_2 (%)	97 ± 2	74 ± 4*	97 ± 2	73 ± 5*	97 ± 2	73 ± 6*	98 ± 1	74 ± 3*

Values are means ± SD.
*P < 0.05 from SL to 4300 m.

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reporting "mild") before target altitude assessments at 4300 m, we are confident that AMS did not confound exercise performance. Collectively, the results of the present study indicate that a duration of 2 d, at resident altitudes of 2500 to 4300 m was not an effective acclimatization strategy to improve endurance exercise performance outcomes during subsequent assessments at a target altitude of 4300 m. Given our previous findings that 6 d of staging at 2200 m improved TT performance at 4300 m (9) and the results in the current study, future work should determine if there is a threshold duration between 2 and 6 d of residence that could prove an effective acclimatization strategy to improve endurance exercise performance at chosen target altitudes.

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No conflicts of interest for all authors. The results of the present study do not constitute endorsement by the American College of Sports Medicine. The authors affirm that the results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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