The following is the abstract of the article discussed in the subsequent letter:

**Green, H. J., B. Roy, S. Grant, R. Hughson, M. Burnett, C. Otto, A. Pipe, D. McKenzie, and M. Johnson.** Increases in submaximal cycling efficiency mediated by altitude acclimatization. *J Appl Physiol* 89: 1189–1197, 2000.—To investigate the hypothesis that respiratory gas exchange and, in particular, the O2 consumption (VO2) response to exercise is altered after a 21-day expedition to 6194 m, five male climbers (age 28.2 ± 2 yr; weight 76.9 ± 4.3 kg; means ± SE) performed a progressive and prolonged two-step cycle test both before and 3–4 days after return to sea level. During both exercise tests, a depression (P < 0.05) in VO2 (l/min) and an increase (P < 0.05) in minute ventilation (VE; l/min) and respiratory exchange ratio were observed after the expedition. These changes occurred in the absence of changes in CO2 production (l/min). During steady-state submaximal exercise, net efficiency, calculated from the rates of the mechanical power output to the energy expended (VO2) above that measured at rest, increased (P < 0.05) from 25.9 ± 1.6 to 31.3 ± 1.3% at the lighter power output and from 24.4 ± 1.3 to 29.5 ± 1.5% at the heavy power output. These changes were accompanied by a 4.5% reduction (P < 0.05) in peak VO2 (3.99 ± 0.17 vs. 3.81 ± 0.18 l/min). After the expedition, an increase (P < 0.05) in hemoglobin concentration (15.0 ± 0.49 vs. 15.8 ± 0.41 g/100 ml) was found. It is concluded that, because resting VO2 was unchanged, net efficiency is enhanced during submaximal exercise after a mountaineering expedition when the exercise is performed soon after return to sea level conditions.

**Efficiency After Altitude Acclimatization**

*To the Editor:* Green et al. (2) have described “increases in submaximal cycling efficiency mediated by altitude acclimatization” in 5 men 3 days after return from Mount Denali (6194 m of altitude) in their article. There are many speculations about the cause, but one important factor is not even mentioned: pedal frequency markedly influences efficiency, especially at low work rates (e.g., Ref. 1). If the experiments have not been carefully controlled for this parameter (nothing is said about this in the paper), they cannot be used for efficiency calculations.

Hochachka et al. (3), who obtained results similar to those of Green et al. (2) in altitude natives compared with lowlanders, controlled pedal frequency (60 rpm, Monark ergometer). But their net efficiency values for lowlanders are unusually low at moderate work rates (minimum 10%, ~16% at 60 W); we, for instance, have measured 25% at 50 and 100 W (1). In addition, the Monark ergometer is not well suited for small work rates because the friction in the chain (~10 W) is not considered in the calibration but needs metabolic power as well as the unloaded movement of the legs.

Therefore, at the moment, the evidence for an increase of efficiency after altitude acclimatization is not convincing.

I might comment on two other aspects of the paper of Green et al. (2). First, lactate concentration in blood was reduced after the expedition. This is partly an effect of the hematocrit increase (from 43.7 to 47.4%), because the red cells contain 50% less lactate than plasma; therefore, it is not necessarily an indication of the lactate paradox. Second, the authors have calculated a decrease in plasma volume from hemoglobin concentration and hematocrit values. Are they sure that after 13 wk at high altitude the red cell volume has been unchanged? Otherwise, the figures are not correct.

**REFERENCES**


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**REPLY**

*To the Editor:* We thank Dr. Böning for his comments regarding our observation of an increase in cycling efficiency after a mountaineering expedition to Mount Denali (1). Dr. Böning questions whether or not we have controlled for pedal frequency, which, as he correctly emphasizes, could affect our net efficiency calculations, particularly at low power outputs. Although not mentioned specifically in the article, we can assure Dr. Böning that the electrically braked cycle ergometer (Quinton 870), which was calibrated daily, was pedaled at ~60 rpm. All participants were instructed to maintain this pedal frequency throughout the test protocols, and when deviations from this frequency were observed, instructions were quickly given for correction. Moreover, as emphasized in the article, we have been able to confirm the results in an additional paper, which addressed muscle blood flow and O2 consumption kinetics, using a different gas-exchange system, a
different ergometer, and a different test protocol (4). As in the companion paper, participants were instructed to maintain a constant pedal frequency. We would emphasize that we have been very conscious of the need to maintain rigid test standardization because of the publication by our group, some 15 years ago, of the role of internal work that is required to raise and lower the legs and change their velocities on the physiological response (5).

Although Hochachka et al. (3) have also reported higher values for mechanical efficiency in altitude natives compared with lowlanders, comparisons between the two studies is inappropriate because we did not use a Monark ergometer in our work. Moreover, our study was longitudinal, with measurements performed before and after the expedition. A major concern in the Hochachka et al. (3) study was the large difference in body mass between the two groups. Because the lowlanders were considerably heavier, internal work and, consequently, net mechanical efficiency would be expected to be lower.

Dr. Böning has also commented on the possible importance of the increased hematocrit that we have observed after the expedition on the interpretation of our blood lactate data. We have found a lower blood lactate content during progressive exercise only at the higher power outputs after acclimatization. We have been very careful in the article not to interpret the cause, recognizing that we only measure content with no insight into the role of removal vs. production after acclimatization. Although, the red cells represent a possible sink for the lactate after acclimatization, one must be careful with even this interpretation given the fact that the total account of hemoglobin may not have changed substantially. Our results, although approximate, because of assumptions of the constancy of red cell size when hematocrit and hemoglobin are used in the calculation, suggest that the primary reason for the elevated hematocrit and hemoglobin content is the loss of plasma volume. The valid concerns of Dr. Böning notwithstanding, the failure to find increases in red cell mass after the expedition is generally consistent of what would be expected given the conditions of the expedition.

It must be emphasized that the lower blood lactate levels observed after the expedition provide no insight into the “lactate paradox,” which is typically measured under hypoxic conditions (2) and not at sea level, where our measurements were collected.

REFERENCES


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