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Effects of Pre-acclimatization Applying the "Climb High and Sleep Low" Maxim: An Example of Rapid but Safe Ascent to Extreme Altitude

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Abstract

Pre-acclimatization at a convenient high-altitude location may represent an appropriate method before climbing a more hostile target mountain. The aim of the present field report was to demonstrate the effectiveness of such pre-acclimatizing applying the "climb high sleep low" maxim for a subsequent rapid ascent to almost 7000 m. After some pre-acclimatization in the Alps the authors flew to Chile for further pre-acclimatization in the Aymara village of Putre (3650 m). From there they undertook sojourns up to altitudes of 5700 m within 3 days. Subsequently they went back to Arica (sea level) and climbed Ojos del Salado (6893 m) within 5 days without any health problems. Measurements of heart rate and arterial oxygen saturation and of cerebral oxygenation by near infrared spectroscopy at rest and during exercise indicated adequate acclimatization status. This field report demonstrates highly effective pre-acclimatization by the "climb high and sleep low" strategy supporting anecdotal reports. The up and down strategy may likely have induced hypoxia (pre)conditioning and subsequently allowed rapid ascent to extreme altitudes without any complications. The duration of the carry-over effect after pre-acclimatization has to be evaluated and proposed physiological mechanisms have to be proved by controlled studies in larger samples.

Keywords: pre-acclimatization, climb high and sleep low, high altitude, rapid ascent, mountain sickness

Introduction

Optimal strategies to pre-acclimatize an individual for ascent to high or even extreme altitudes are still unidentified (Shah, Hussain, Cooke, O'Hara, & Mellor, 2015). Pre-acclimatization at a convenient high-altitude location may represent an appropriate method before climbing a more hostile target mountain. At the beginning of 2016 the authors attempted to climb almost 7000 m to the Ojos del Salado (Chile, 6893 m) within 5 days. They expected to achieve this without any health problems and without breaking the rule "not to go too high too fast" (Hackett & Roach, 2001) by specific and careful pre-acclimatization and the application of an appropriate ascent profile. Pre-acclimatization was accomplished by the "climb high and sleep low" maxim. The efficacy of this maxim has been reported anecdotally (Curtis, 1999) and has been experienced by the authors in prior high-altitude sojourns. The aim of the present "notes from the field" was to demonstrate the effectiveness of the application of this maxim when pre-acclimatizing for a subsequent rapid ascent to almost 7000 m.

Methods

The authors (MB and RK) are living in Innsbruck (Tirol, Austria, 600 m) and both are well-trained (VO_2max about 50–55 ml/min/kg) and are regularly practicing mountaineering activities. After some pre-acclimatization in the mountains around Innsbruck and in normobaric hypoxia they flew to Santiago de Chile (South America) and from there to Arica (sea level) and finally they went by car to Putre (3650 m) for further pre-acclimatization. After a 3-day stay in Putre with several ascents to higher altitude they returned to Arica and went on by bus to Copiapó (383 m) from where they started to climb Ojos del Salado within 5 days together with two local guides. The authors are medical doctors and were well equipped with emergency medicines, had regularly checked acclimatization status, and of course were always ready to stop or return in the case of high-altitude problems in any of the accompanying subjects.

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Pre-acclimatization

From Innsbruck, altitudes over 2000 m can be reached within about an hour's drive or even faster by cable car. Thus, three sojourns to an altitude up to 2700 m were performed at the end of a working day or the weekend during the month before departure to Chile (December 8, 12, 17). In addition, 2 nights (December 26, 30) were spent in normobaric hypoxia (Department of Sport Science, University of Innsbruck) at a simulated altitude between 3500 and 4000 m. All these exposures were well tolerated without any signs of acute mountain sickness (AMS). Three days after the last exposure to normobaric hypoxia the authors arrived within 2 days at Putre by plane and car. A 3-day stay in Putre with ascents to 5700 m (Figure 1) constituted the second part of pre-acclimatization before climbing to Ojos del Salado. Putre is a small Aymara village situated in the fantastic Lauca national park (Atacama Desert). It represents a unique opportunity to acclimatize individually by sleeping at an appropriate altitude and to go up and down between 3650 and 5700 m by car and/or hiking depending on individual fitness, physiological responses, and wellbeing.

Ascent to Ojos del Salado (6893 m)

In Copiapó (383 m) two pre-booked guides were prepared with an off-road vehicle packed with tents, provisions, and water for climbing up the Ojos during the subsequent 5 days. Thus, we had the opportunity to compare physiological responses between the two authors and the two guides (who provided informed consent). The excellent guides were natives used to climbing to altitudes above 6000 m but had not been at those altitudes during the preceding 2–3 weeks. Thus, the rapid ascent was a challenge for them as demonstrated by the physiological responses to altitude at rest and during exercise. After one overnight stay at 4800 m the Atacama hut (5250 m) was reached on the second day. On the third day equipment and provisions were carried to the Tejos hut at 5800 m with

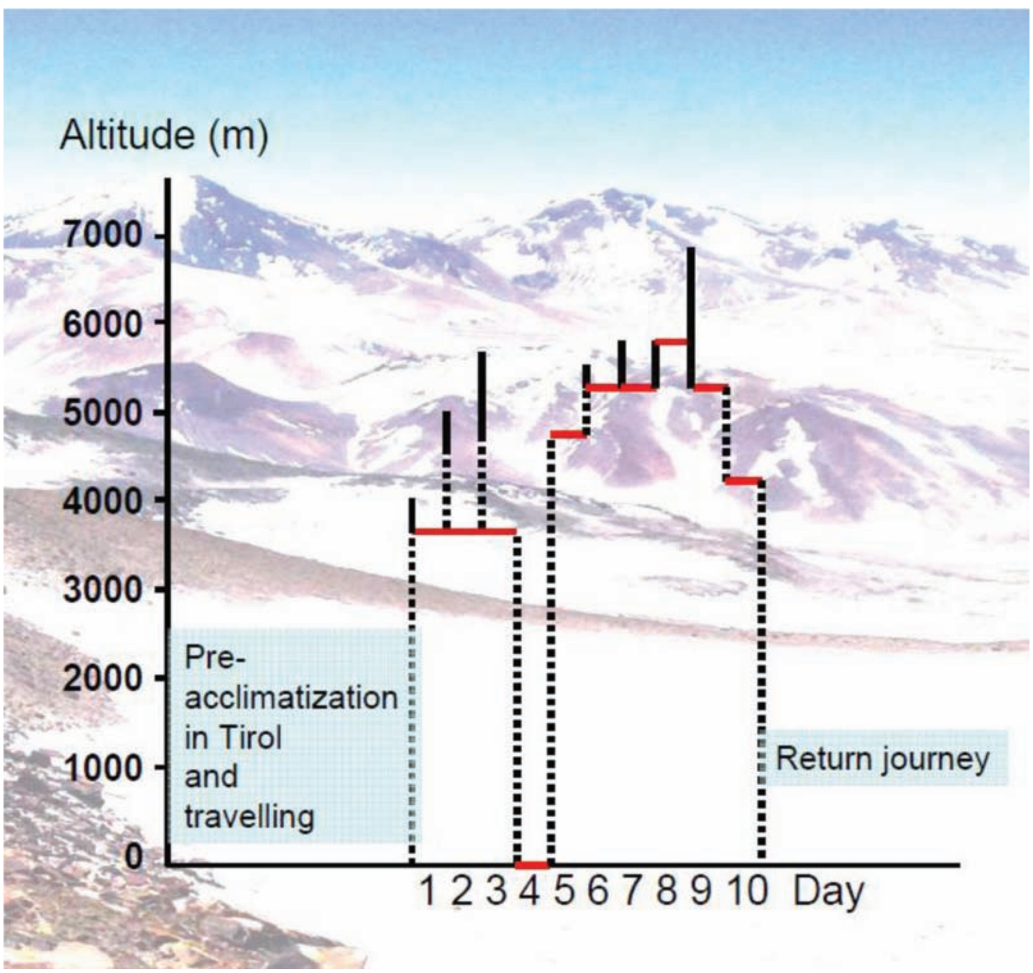

Figure 1. Acclimatization and ascent profile of the entire high-altitude sojourn. Dotted vertical lines indicate going by car, solid vertical lines indicate hiking, and horizontal lines indicate sleeping altitude.

Figure 2. Ascent to Tejos hut at 5800 m.

subsequent return to the Atacama hut (Figure 2). On the fourth day we again went up to the Tejos hut and climbed Ojos on the fifth day and returned to the Atacama hut on the same day. Weather conditions were always perfect and night temperatures dropped down to minus 25℃. Tents and huts were used for lodging and outstanding meals and beverages were served by the guides. Small doses of acetazolamide (2 × 125 mg) were taken on day 1 in Putre, when leaving Copiapó, and the night before climbing Ojos.

Assessment of Physiological Responses and Acclimatization Status

Measurements of heart rate and arterial oxygen saturation (SpO_2) by finger pulsoximetry (Onyx II 9550, Nonin, USA), and of cerebral oxygenation by near infrared spectroscopy (NIRS; PortaLite, Artinis Medical Systems, The Netherlands) were taken at rest and during standardized exercise 3 to 5 hours after arrival at the new altitudes of 3650 m, 5250 m, and 5800 m. In addition, heart rate and SpO_2 measurements were performed several times on all days at rest and during hiking, and sometimes also during the night. To collect NIRS data, one NIRS emitter and detector pair was placed over the left frontal lobe fixed with the use of a black plastic spacer and a tensioning black headband. Standardized exercise testing was performed by stepping up and down 20 to 25 times per minute for 2 minutes on a 50 cm high step. Symptoms of acute mountain sickness were recorded every evening and morning by the use of the Lake Louise Scoring system (Roach, Bartsch, Hackett, & Oelz, 1993). A rough self-assessment of sleep quality was based on daily subjective ratings of sleep quality, the number of awakenings during the night, feeling rested or tired in the morning and/or during the day. In addition, daily self-assessment of appetite, general wellbeing, and climbing performance was carried out.

Results and Discussion

In contrast to prior rapid ascents without sufficient pre-acclimatization, pre-acclimatization at home (Innsbruck, Tirol, Austria) and in Putre (Chile) with repeated and increasingly higher ascents above the sleeping altitude were likely the reason why the authors did not experience any AMS symptoms (LLS was never higher than 1) throughout the rapid ascent to almost 7000 m. General rules for safe acclimatization at altitudes above 2500 m include (1) increasing sleeping altitude not more than 300 to 500 m per day and (2) having a rest day for every 1000 m altitude gain or every 2 to 3 days but also prior to and/or following a greater ascent rate than usually recommended. This would mean at least 13–15 days from Copiapó to the summit which is also generally recommended by commercial expedition offerings. When considered superficially the authors had only 5 days instead of 13–15 days for this trip which would be much too fast and probably also hazardous. However, when including the pre-acclimatization period (3 days at moderate altitude in the Alps, 2 nights in a hypoxia chamber, 1 day and night flight, 3 days in Putre), the authors had a total of 14 “altitude” days before reaching the summit and fulfilled common acclimatization rules. However, it is important to note that pre-acclimatization was performed in a safe and convenient way situated apart from the target mountain (Ojos). Good acclimatization was indicated by high levels of wellbeing, appetite, sleeping quality, SpO_2 values during night and day, and climbing performance. Climbing performance per hour at 70–80% of the individual maximum heart rate was 350 vertical meters at an altitude of about 4500 m, 290 m at 5500 m, and still 240 m at 6500 m.

An important aspect favorably influencing the acclimatization process is likely represented by the type of acclimatization, i.e. climb high and sleep low. Due to the short period between pre-acclimatization and the ascent on the Ojos, acclimatization effects were fully maintained. Besides being free of AMS symptoms, heart rate, SpO_2 values, and data on cerebral oxygenation at rest and during standardized exercise confirm successful acclimatization (Table 1; Figures 3 and 4). Both authors showed very similar physiological responses throughout the trip. Thus, resting, exercising, and sleeping values at various altitudes are only shown for one author (Table 1). It is important to note that exercise and sleep provoked similar effects on SpO_2 values probably representing similar hypoxic stimuli for acclimatization. Typically, SpO_2 increased in the second night at the same altitude likely indicating progress of acclimatization. However, prolonged and intense exercise may even have delayed acclimatization as demonstrated by the values of night 3 at 3650 m (Table 1) which was also associated with subjective feeling of lower sleep quality. Optimal recovery occurred during the following day when traveling down to sea level. In contrast to the less

Table 1
Daily resting, exercising (hiking), and sleeping values of arterial oxygen saturation (SpO_2) and heart rate of one author taken at various altitudes. Days 1–3: pre-acclimatization in Putre; day 4: travel to Copiapó; days 5–9: ascent to Ojos.

Day/night	Altitude (m)	SpO_2 (%)			Heart rate (bpm)		
		Rest	Exercise	Sleep	Rest	Exercise	Sleep
1	3650	88	84		70	122	
1	4000	85	79		73	127	
1	3650			84			74
2	3650	90	86		66	166	
2	4800	84	78		74	130	
2	3650			88			64
3	3650	91	88		63	115	
3	5600	83	75		75	135	
3	3650			83			75
4	0	97	96	97	56	105	51
5	4800	89	83		69	117	
5	4800			84			69
6	5250	86	77		72	120	
6	5500	83	75		75	126	
6	5250			76			73
7	5250	88	80		69	119	
7	5500	85	77		73	125	
7	5250			79			71
8	5800	78	70		77	124	
8	5800			72			76
9	6200	77	69		79	127	
9	6700	74	66		83	131	

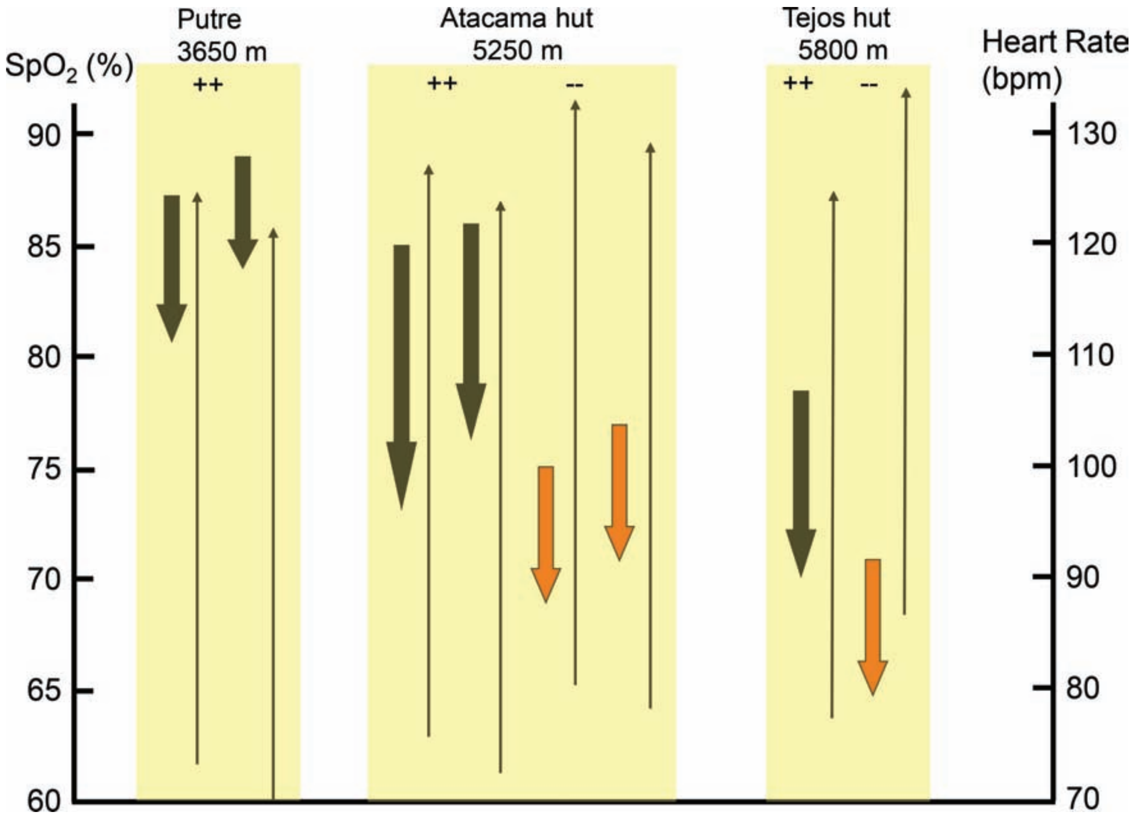

Figure 3. Changing values of oxygen saturation (thick arrows) and heart rate (thin arrows) from rest to exercise (2 min stepping up and down a 50 cm step) at various altitudes. ++, acclimatized authors; –, less acclimatized guides (in the right panel values of only one acclimatized and one less acclimatized person are depicted).

acclimatized guides who had resting SpO_2 values of about 75% which dropped below 70% during exercise, the resting SpO_2 of the authors was about 85% which dropped to about 75% during exercise at 5250 m (Figure 3). Accordingly, also heart rates at rest and during exercise were somewhat higher when acclimatization was lacking. Physiological responses and the progress of acclimatization may also have been influenced by the use of small doses of acetazolamide on day 1 in Putre, when leaving Copiapó, and the night before climbing Ojos. Acetazolamide is a well-known potent carbonic anhydrase inhibitor that causes diuresis and renal bicarbonate loss, increases minute ventilation and oxygenation, and improves sleep quality thereby hastening acclimatization (Swenson, 1998). This may probably also be the reason why the less acclimatized subjects who took acetazolamide only the night before climbing Ojos did not suffer from more severe AMS.

NIRS measurements of cerebral oxygenation demonstrated a tissue saturation index of 71% before starting pre-acclimatization in Tyrol, 63% when arriving in Putre, and again 71% on the second day at 5250 m without change between rest and exercise (Figure 4). This value was only 58 to 59% in the not-well-acclimatized subjects after rapid ascent to 5250 m, similar to that of the authors measured in Putre. Whereas HbO_2 and tHb slightly increased during exercise in normoxia and in hypoxia before pre-acclimatization (data not shown), these values decreased in the acclimatized state at 5250 m but increased considerably at that altitude in the less acclimatized subjects (Figure 4). How does one explain such beneficial pre-acclimatization effects? According to anecdotal reports, particularly repeated active ascents to altitudes above the subsequent sleeping altitude seem to prevent AMS development by favoring acclimatization. In fact, such hypoxic challenges could evoke preconditioning effects which for instance have been shown to prevent severe cardiovascular events at altitude (Burtscher, 2014). Preconditioning describes a powerful endogenous mechanism protecting an organ against damage. After single or repeated exposures to a noxious stimulus below the threshold of damage, e.g. hypoxia, the organism develops tolerance to similar or even different stimuli (Murry, Jennings, & Reimer, 1986) likely being also protective against the development of high-altitude illnesses. Although clinical and experimental data on the preventive efficacy of hypoxia preconditioning in humans are mostly lacking, those from animal studies clearly indicate the existence of such effects. For example, an 8-hour exposure to hypoxia (9% FiO_2) prevented the formation of edema in various brain regions in rats after provoking injury by kainic acid on days 1, 3, and 7, but not

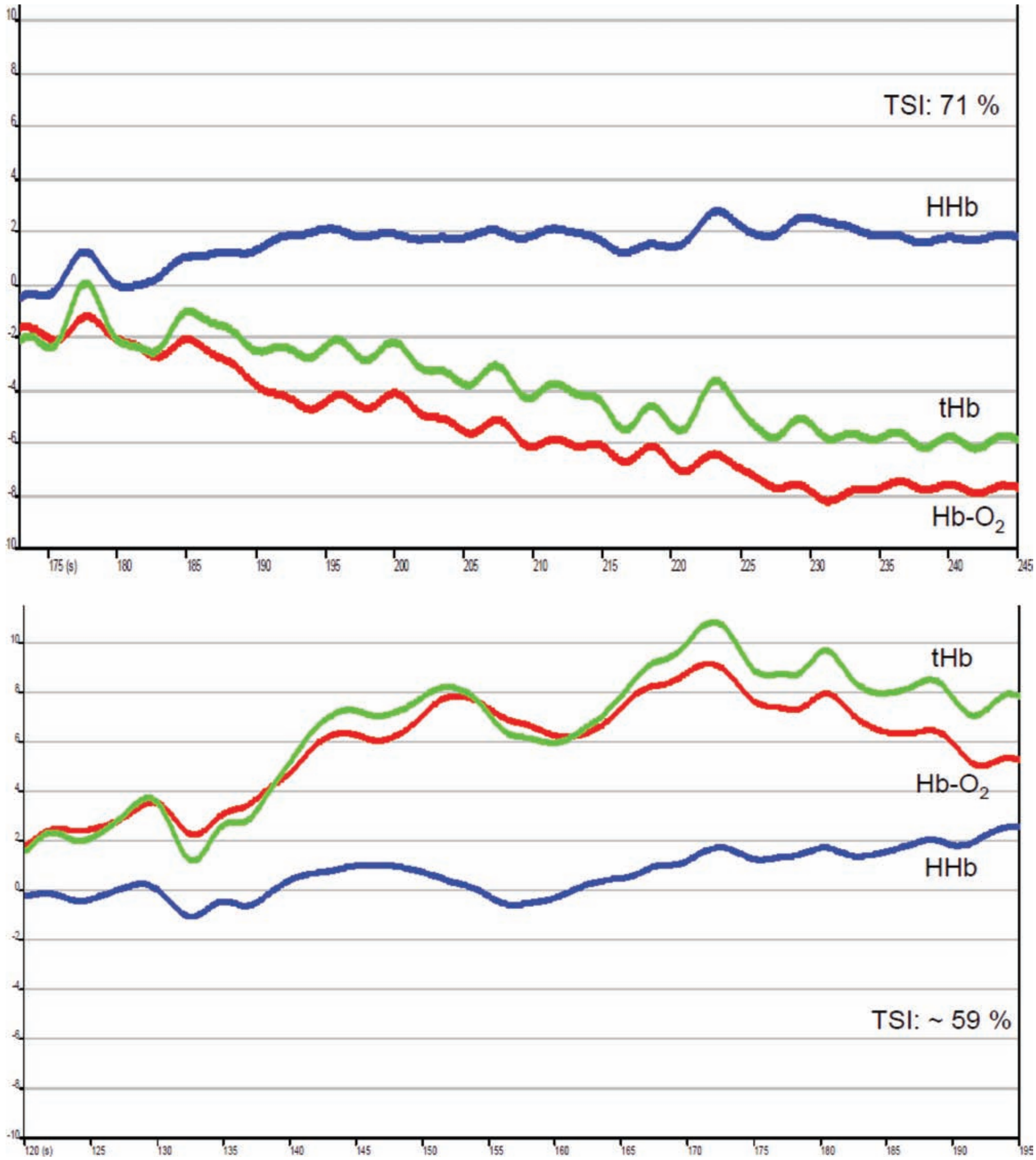

Figure 4. Two characteristic NIRS measurements of cerebral oxygenation during stepping up and down a 50 cm step on the second day at 5250 m. The upper panel shows the NIRS signals (Gaussian average) of an acclimatized person and the lower panel of a less acclimatized person. Hb-O_2: oxygenated hemoglobin; HHb: deoxygenated hemoglobin; tHb: total hemoglobin; TSI: tissue saturation index (remained nearly unchanged during rest and exercise).

14 days post-hypoxia exposure (Emerson, Nelson, Samson, & Pazdernik, 1999). Another study demonstrated that hypobaric hypoxia preconditioning by exposure of rats to 18.3% O_2 for 5 h/day on five consecutive days attenuated the occurrence of pulmonary edema, inflammation, and ischemic and oxidative damage caused by subsequent (at 2 weeks) high-altitude exposure (simulated 6000 m) by up-regulating heat-shock protein 70 (Lin et al., 2011). Thus, we strongly suggest that

well-dosed intermittent exposures to increasing hypoxic stimuli with sufficient recovery periods may at least partly explain our successful ascent by preconditioning effects.

Of course, all these suggestions are based on a limited dataset and therefore remain speculative, and further experimentation is needed to confirm the presented observations. In particular, the NIRS data are very difficult to interpret due to the few measurements available but might indicate increased blood flow and reduced cerebral tissue saturation when acutely exposed to high altitude and reduced cerebral blood volume (flow) with preserved cerebral tissue oxygenation after acclimatization. These conjectures are at least partly in line with study findings from Subudhi et al. (2014) and Sanborn et al. (2014). Subudhi and colleagues demonstrated that cerebral blood flow increased when acutely exposed to high altitude and decreased after 16 days at altitudes between 3800 and 5260 m (Chacaltaya Research Station, Bolivia). Cerebral blood flow was opposed by changes in arterial oxygen content thereby preserving oxygen delivery to the brain. Also Sanborn and colleagues found an intensification of the normal hyperventilation-related cerebral hypocapnic vasoconstrictive response; however, without improving cerebral oxygenation likely due to partial acclimatization after only 7 days at 4559 m. In contrast, our data indicate rather good acclimatization at least with regard to wellbeing, sleeping quality, and SpO_2 values.

In conclusion, these notes from the field demonstrate highly effective pre-acclimatization by the “climb high and sleep low” strategy supporting anecdotal reports. The up and down strategy may likely have induced hypoxia (pre)conditioning and subsequently allowed rapid ascent to extreme altitudes without any complications. Of course, the duration of the carry-over effect after pre-acclimatization has to be evaluated and proposed physiological mechanisms have to be proved by controlled studies in larger samples of mountaineers of different ages and sexes.

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