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Case report

Training Diaries during Altitude Training Camp in Two Olympic Champions: an Observational Case Study

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Abstract
Traditionally, Live High-Train High (LHTH) interventions were adopted when athletes trained and lived at altitude to try maximising the benefits offered by hypoxic exposure and improving sea level performance. Nevertheless, scientific research has proposed that the possible benefits of hypoxia would be offset by the inability to maintain high training intensity at altitude. However, elite athletes have been rarely recruited as an experimental sample, and training intensity has almost never been monitored during altitude research. This case study is an attempt to provide a practical example of successful LHTH interventions in two Olympic gold medal athletes. Training diaries were collected and total training volumes, volumes at different intensities, and sea level performance recorded before, during and after a 3-week LHTH camp. Both athletes successfully completed the LHTH camp (2090 m) maintaining similar absolute training intensity and training volume at high-intensity (> 91% of race pace) compared to sea level. After the LHTH intervention both athletes obtained enhancements in performance and they won an Olympic gold medal. In our opinion, LHTH interventions can be used as a simple, yet effective, method to maintain absolute, and improve relative training intensity in elite endurance athletes.

Key words: Live high-train high, live high-train low, elite, endurance training, performance.

Introduction

Amongst elite endurance athletes and coaches there is the conviction that hypoxic training can provide unique sea level performance enhancements (Dick, 1992; Millet et al., 2010; Saunders et al., 2009; Wilber, 2007). The classic "Live High-Train High" (LHTH) method has traditionally been employed, and its efficacy has been shown to be maximal when undertaken above 2000 m for at least 3-4 weeks (Lundby et al., 2012). The potential benefit of classic altitude training is that altitude acclimatization provides the stimulus for both central and peripheral adaptations, as well as an additional training load compared to sea level (Bartsch and Saltin, 2008). The main physiological responses to training at altitude are strongly linked to performance (Saunders et al., 2009) and include: i) an increase of total volume of red blood cells or total haemoglobin mass (Hb_{mass}) (Gore et al., 2013), ii) an enhancement of mitochondrial efficiency (Gore et al., 2007) and iii) an improvement of both muscle buffering and ability to tolerate lactic acid production (Gore et al., 2007). In addition to these possible adaptations, it has been reported that performance gains that may be observed with altitude training may also be related to a placebo effect (Bonetti and Hopkins, 2009).

However, the limited and inconclusive supporting research (Friedmann-Bette, 2008; Lundby et al., 2012) has led to the idea that possible beneficial adaptations to hypoxia might be offset by the loss of fitness induced by the detrimental effects of altitude. In fact, when an athlete trains at altitude, the muscles' capacity to receive oxygen exceeds the ability to transport oxygen (Wagner, 2000). Thus, acute exposure to altitude decreases VO_{2max} and performance especially for elite endurance athletes who are subjected to a larger reduction of arterial O_2 saturation during exercise compared to sub-elite athletes (Chapman et al., 1999; Woorons et al., 2007). As a consequence, at any given absolute exercise work rate, a higher percentage of VO_{2max} is required compared to sea level, leading to a higher relative exercise intensity when at altitude (Beidleman et al., 2008). For these reasons, it has been proposed that at moderate altitude some elite athletes are not able to maintain the training velocities required for competitive fitness (Chapman et al., 1998). The consequence of this is a reduction of training intensity at altitude (Wilber, 2001), which might compromise sea level performance (Levine and Stray-Gundersen, 1997). Therefore, LHTH has been reconsidered for its inability to maintain training intensity for all athletes and research focus has moved towards the "Live High-Train Low" (LHTL) method (Levine and Stray-Gundersen, 1997), which allows athletes to combine the physiological benefits of hypoxia (Brugniaux et al., 2006; Wehrlin et al., 2006), while maintaining training intensity.

However, a few studies have reported that elite endurance athletes have improved performance after LHTH (Daniels and Oldridge, 1970); Bailey et al., 1998). In addition, a meta-analysis (Bonetti and Hopkins, 2009) examining the effects of various modalities of altitude training on sea level performance, as well as anecdotal reports from institutions that regularly use LHTH with elite endurance athletes (Saunders et al., 2009), provide support for classic altitude training.

Based on the previous observations, this study aimed to present a successful LHTH intervention with two Olympic gold-medal endurance athletes, in an attempt to demonstrate that it is possible for world-class elite athletes with a foundation of several years of training at a high level, to maximise the hypoxic dose by living and training at altitude without a decrease in absolute training intensity compared to sea level.

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Table 1. Anthropometric, physiological and performance/training characteristics of the two participants before LHTH

		Participant 1	Participant 2
Anthropometric and physiological characteristics	Age (years)	28	33
	Height (m)	1.75	1.76
	Body mass (kg)	59	58
	Body mass index ($kg \cdot m^{-2}$)	19.3	18.7
	Fat mass (%)	6.5	4.5
	VO_{2max} ($mL \cdot kg^{-1} \cdot min^{-1}$)	75.0	82.3
	Velocity at VO_{2max} ($km \cdot h^{-1}$)	16.0	22.8
	Hypoxic training camp experience * (n)	28	35
Performance characteristics	Discipline	20-km Race Walking	Marathon
	World ranking	Top 15	Top 20
	Difference between best performance and world's number 1 performance for the year (%)	-2.8 %	- 1.9 %
	Race pace ($min \cdot km^{-1}$)	4 min 00 s	3 min 02 s
	Race pace (% vVO_{2max})	93.7	86.7
Training characteristics	Intensity zone 1, 70-80 % of race pace ($min \cdot km^{-1}$)	5 min 43 s – 5 min 00 s	4 min 20 s – 3 min 47 s
	Intensity zone 1 (% vVO_{2max})	65.6 – 75.0	60.7 – 69.4
	Intensity zone 2, 81-90 % of race pace ($min \cdot km^{-1}$)	4 min 56 s – 4 min 26 s	3 min 44 s – 3 min 22 s
	Intensity zone 2 (% vVO_{2max})	75.9 – 84.3	70.2 – 78.1
	Intensity zone 3, >91 % of race pace ($min \cdot km^{-1}$)	<4 min 23 s	<3 min 20 s
	Intensity zone 3 (% vVO_{2max})	>85.3	>78.9

* all training camps considered last between 21 and 28 days. vVO_{2max} = velocity at VO_{2max}

Methods

Participants and data collection method

One elite race walker (participant 1) and one elite marathon runner (participant 2) were considered for the analysis. The anthropometric, physiological, and performance characteristics of the participants are presented in Table 1.

This observational study includes a retrospective analysis of data collected by the Italian Olympic Committee (CONI).

Physical and physiological characteristics were assessed at the Institute of Sport Medicine and Science, CONI (Rome, Italy), one week before the entire training period considered.

The original training data was obtained directly from training diaries of the two athletes. Finally, performance results were obtained from the International Association of Athletic Federations (IAAF). Both participants were subjected to unannounced doping controls (urine and blood) before (twice), during (once) and after (once in Italy and three times during Olympics) altitude training by national and international Anti-Doping organizations. All tests reported negative results.

Subjects were contacted and informed about the aim of the study and they gave their written consent for the use of the data. All procedures were in accordance with the Declaration of Helsinki.

Training data

Nine consecutive weeks of training diaries were collected before the Games of the XXVIII Olympiad held in Athens (2004) and subdivided in three periods: a) 3 weeks of sea level training before-LHTH (Milan, ITA, 122m; and Rubiera, ITA, 53m, for participant 1 and 2 respectively); b) 3 weeks of LHTH (Sestriere, ITA, 2090m); and c) 3 weeks of sea level training after-LHTH (as per before-LHTL). The training pace ($min \cdot km^{-1}$), training volume (km) and additional information such as injury or illness events were recorded for each training session. Training intensity zones were calculated as a percentage of race pace chosen by coaches (Table 1). Data has also been reported as percentage of velocity at VO_{2max} ($km \cdot h^{-1}$) in order to allow a more meaningful comparison of training intensity between different endurance disciplines (Table 1).

Then training environment at altitude was well known by coaches and athletes. A flat course, previously marked every 500 m, was chosen to perform most of the training sessions.

To ensure that the athletes maintained the desired training pace, coaches followed them using a bike equipped with a GPS device.

Performance measurements

To evaluate performance, the results obtained during official competitions before and after LHTH were collected for both participants. The race-to-race variability for each participant on short- and Olympic- distance events (10-km; and marathon or 20-km race walking, respectively) was calculated using three international competitions, over the three seasons immediately preceding the Olympic year. Reliability was calculated as typical error expressed as percentage coefficient of variation (CV) for both participants (Hopkins, 2000). The CV of short-distance events was 1.0% and 0.7% for participant 1 and 2 respectively. As for Olympic-distance events, CV was 0.4% and 0.3% for participant 1 and 2 respectively. The performance changes after LHTH were then compared to the individual's CV to allow a more meaningful interpretation of the results.

Results

Training data

Total training volume, and percentage of training spent at different intensities are presented in Table 2. More detailed examples of training sessions in each period are shown in Table 3.

Training volume and intensity during LHTH

Distribution of training volume and intensity during the LHTH period is shown in Figure 1 (upper panel). Variation of training volume and intensity during the first week of LHTH is shown in Figure 1 (lower panel).

Injury and illness

Athletes did not suffer illness or injury during the entire period considered.

Performance results

Racing schedule and performance results before- and after-LHTH are shown in Figure 2.

Discussion

This observational study aimed to present the practical experience of two elite endurance athletes who success fully completed a LHTH intervention which was associated with an improvement in sea level performance.

The data here presented shows that elite athletes with extensive altitude training experience and several years of training at high level can maintain the same absolute intensity during LHTH compared to sea level. This could possibly translate to a higher relative intensity during the training at altitude, although this could not be assessed due to the inability to measure oxygen uptake and saturation during this phase of training. Consequently, LHTH may be considered as an effective method to increase relative training intensity while maintaining the same running/walking pace, with possible beneficial effects on sea level performance. There is evidence that high-intensity training is effective to maximize physiological adaptations/performance in elite athletes (Mujika, 2010). The relationship between the mean training intensity/frequency and the changes in performance during one season was assessed on elite swimmers (Mujika et al., 1995). The performance improvements were correlated with the mean training intensity of the preceding season (r = 0.69), but not with training volume or frequency. Similarly, it has been shown that performance can be improved by increasing/maintaining training intensity while reducing the volume during the tapering phase of training

Table 2. Total training volume and percentage of training spent at different intensities during the three training periods.

	before-LHTH				LHTH				after-LHTH			
	Total volume (km)	Zone 1 (%)	Zone 2 (%)	Zone 3 (%)	Total volume (km)	Zone 1 (%)	Zone 2 (%)	Zone 3 (%)	Total volume (km)	Zone 1 (%)	Zone 2 (%)	Zone 3 (%)
Participant 1	391	14.2	55.0	30.8	435	19.5	51.7	28.7	280	30.4	33.9	35.7
Participant 2	600	75.6	14.5	9.9	652	74.7	7.4	17.9	554	47.5	33.8	18.7

Zone 1 = 70-80% of race pace; Zone 2 = 81-90% of race pace; Zone 3 = >91% of race pace

Table 3. Examples of the most important training sessions in each training period

	Before-LHTH			LHTH			After-LHTH		
P1	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 1**	**Zone 2**	**Zone 3**
Week 1	20 km 5’00”·km^{-1}	15 km 4’40”·km^{-1}	12x1000m 4’00”·km^{-1} rec 2’	10 km 5’00”·km^{-1}	15 km 4’45”·km^{-1}	15 km uphill 4’50”- 4’10”·km^{-1}	15 km 5’00”·km^{-1}	10 km 4’30”·km^{-1}	7x2000m 3’50”·km^{-1} rec 2’
Week 2	20 km 5’00”·km^{-1}	25 km 4’45”·km^{-1}	7x2000 m 4’00”·km^{-1} rec 3’	20 km 5’00”·km^{-1}	20 km 4’45”·km^{-1}	5x1000m 4’00”·km^{-1} rec 3’ + 1x5000m 4’05”·km^{-1}	10 km 5’00”·km^{-1}	25 km 4’40”·km^{-1}	10 km 38’24”.00 (NR)
Week 3	10 km 5’00”·km^{-1}	15 km 4’45”- 4’30”·km^{-1}	10x1000m 3’55”·km^{-1} rec 2’	15 km 5’00”·km^{-1}	2x7.5 km 4’30”·km^{-1} rec 3’	2x10x500m 3’50”·km^{-1} rec 1’ and 4’	10 km 5’00”·km^{-1}	15 km 4’25”·km^{-1}	10x500m 3’30”·km^{-1} rec 1’ + 5x1000m 3’40”·km^{-1} rec 2’
P2	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 1**	**Zone 2**	**Zone 3**
Week 1	20 km 3’59”·km^{-1}	12 km 3’31”·km^{-1}	10x400 m 2’40” ·km^{-1} rec 200 m 3’30” ·km^{-1}	15 km 3’59”·km^{-1}	17 km 3’31”·km^{-1}	5x4000m 3’03”·km^{-1} rec 3’	13 km 3’50”·km^{-1}	11 km 3’38”·km^{-1}	10 km 27’53”.00
Week 2	20 km 3’50”·km^{-1}	10 km 3’20·km^{-1}	5x4000m 3’02”·km^{-1} rec 3’	20 km 3’56”·km^{-1}	16 km 3’45”·km^{-1}	5x3000m 3’06”·km^{-1} rec 3’	25 km 3’50”·km^{-1}	11 km 3’38”·km^{-1}	4x5000m 3’04”·km^{-1} rec 1000m 4’00”·km^{-1}
Week 3	15 km 3’59”·km^{-1}	17 km 3’34”·km^{-1}	10x1000m 2’50·km^{-1} rec 400m 3’40”·km^{-1}	20 km 3’56”·km^{-1}	10 km 3’34”·km^{-1}	14 km 3’05”·km^{-1}	17 km 3’50”·km^{-1}	12 km 3’34”·km^{-1}	5x2000 3’03”·km^{-1}- 2’52”·km^{-1} rec 1’

Zone 1 = 70-80% of race pace; Zone 2 = 81-90% of race pace; Zone 3 = >91% of race pace ; P1 = participant 1, P2= participant 2; rec=recovery; NR=national record

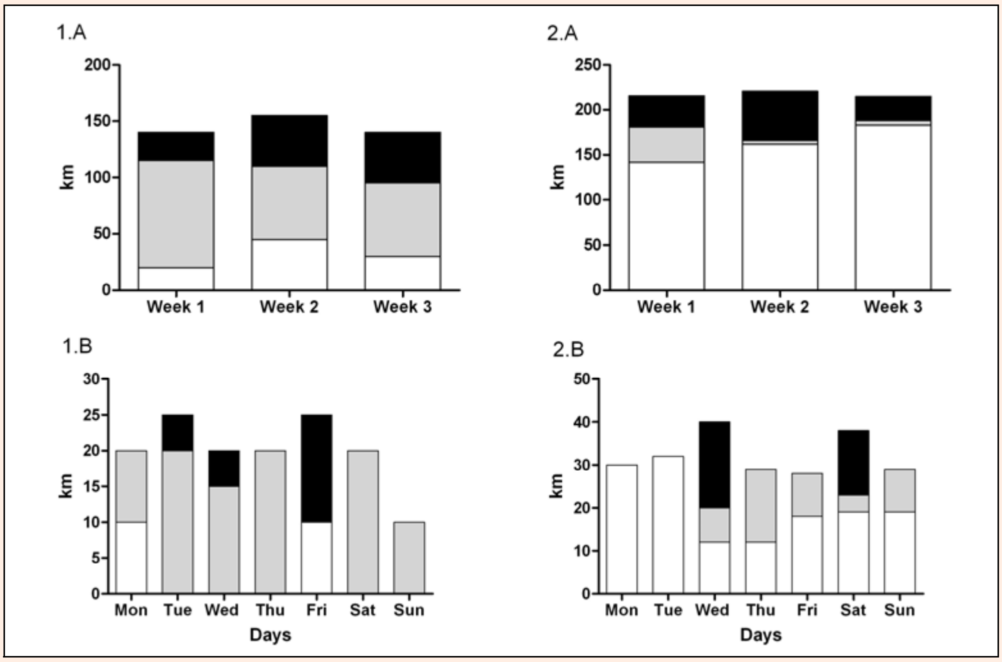

Figure 1. Upper panel; distribution of training volume and intensity during the LHTH period for participant 1 (1.A) and 2 (2.A). Lower panel; variation of training volume and intensity during the first week of LHTH for participant 1 (1.B) and 2 (2.B). *White bars*, intensity zone 1; *grey bars*, intensity zone 2; *black bars*, intensity zone 3.

(Bosquet et al., 2007). Our results support these observations, with the two athletes maintaining similar training intensities and similar training volume at the high-intensity zone during the three periods. A common pattern in the distribution of training volume can be observed; total training volume was increased during LHTH compared to before-LHTH (11.2 and 8.7 % for participant 1 and 2, respectively), while decreasing by ~35 and 17 % after-LHTH in participant 1 and 2, respectively (Table 2). In particular, training volume at high-intensity (> 91% of RP) was similar (28.7% vs 30.8%) for participant 1 and increased (17.9% vs 9.9%) for participant 2 during-LHTH compared to baseline (Table 2). This modulation of training volume was carefully planned with the aim of achieving the best performance during Olympic Games, thus the variation of volume during the three periods should be viewed in this context. However, the most interesting aspect is that both athletes were able to maintain training quality at altitude, expressed as absolute intensity (training pace) compared to sea level.

Table 3 shows some significant examples of training sessions in each period. Both athletes performed training sessions in “Zone 1” and “Zone 2” at very similar training pace both at altitude and sea level. As for the most qualitative work, both maintained similar absolute intensity. The main difference to be noted between LHTH and sea level training is the methodological approach in order to achieve the intensity required in “Zone 3”.

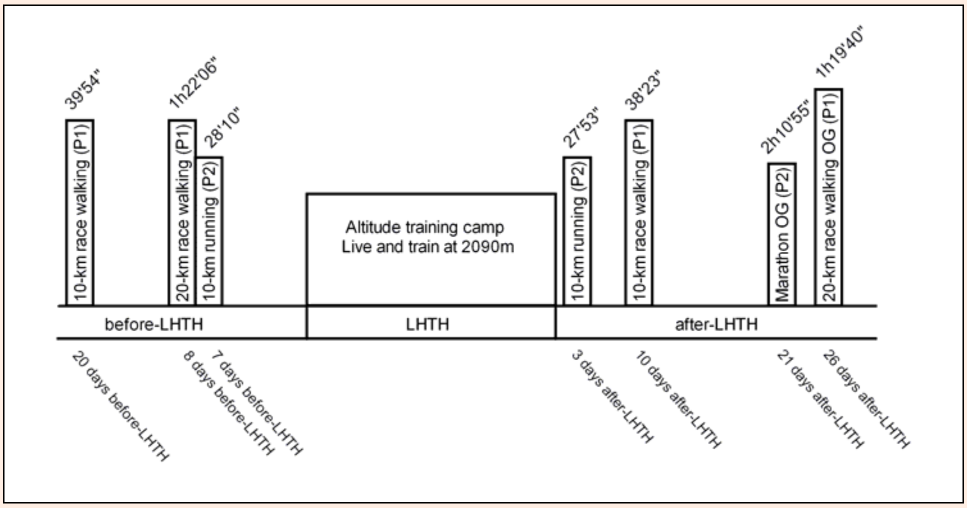

Figure 2. Racing schedule and performance results before- and after-LHTH. P1, participant 1; P2, participant 2; LHTH, living high train low; OG, Olympic Games

Participant 1 generally performed a similar volume of high-intensity interval training during LHTH, however intervals were shorter while recovery time was similar. Participant 1 undertook additional uphill training during LHTH in order to further increase intensity. A different approach for the high-intensity training can be noted for participant 2. In this case the training volume in “Zone 3” was increased compared to before-LHTH. This was achieved through long intervals rather than the short intervals mainly performed at sea level. However recovery periods during long intervals training were similar compared to before-LHTH. The further increment in absolute intensity for both athletes, with a reduction of total training volume after-LHTH, should be considered as intentional in the context of training periodization and discipline given the proximity of the major competition (Olympic Games). Moreover, different technical coaching publications summarized in a recent review (Chapman et al., 2014) suggest to undertake ~2-3 weeks of sea level training after returning from altitude training, before a major competition. Chapman et al (2014) concluded that this period may in fact be beneficial if the athlete can gain an additional positive training response (e.g. train at higher intensities) due to adaptations from altitude acclimatization.

An interesting result of this study originates from the analysis of training characteristics during the first week of LHTH (i.e., acclimatization phase). This crucial phase usually lasts 7–10 days depending on the total camp duration and the athlete’s experience (Millet et al., 2010). The traditional approach to acclimatization phases was to avoid high-intensity exercise during these periods. However, our data shows that elite athletes with extensive altitude experience were able to undertake intense training in the very first days of LHTH exposure (Figure 1, lower panel). In any case, total volume at higher intensities in week 1 was lower compared to week 2 and (only for participant 1) to week 3 in altitude, in order to avoid placing the immune system under excessive stress from both hypoxia and hard training (Saunders et al., 2009). It is legitimate to point out that training “hard” in altitude has been related with an increased chance of incurring illness or overtraining (Gore et al., 1998) compromising beneficial training adaptations. In this case both participants successfully concluded all training sessions in altitude without injury or illness during or after LHTH.

It is also important to associate the LHTH training characteristics with performance results measured before and after hypoxic exposure (Figure 2). The best time to return from altitude training prior to competition remains unclear, especially from a physiological perspective (Chapman et al., 2014). The recommendation regarding when to compete after altitude training may be dependent on the individual responses to altitude training and acclimatization, de-acclimatization, as well as the training responses that occurs within the first days post-altitude (Chapman et al, 2014).

Top coaches and sport scientists have observed an early phase (2-7 days) and a delayed phase (day 10 to day 25) where best performances may occur (Chapman et al., 2014; Millet et al., 2010).

In this case, both participant 1 and 2 improved their 10-km performance 10 and 3 days after LHTH by 3.8% and 1.0%, respectively. Moreover, 21 and 26 days after the conclusion of the LHTH camp, the two athletes won the Olympic gold medal in their respective events. Participant 1 succeeded in his competition with a 2.9% improvement on the same distance compared to before-LHTH. Unfortunately, for participant 2, it was not possible to make a comparison with previous results on the same distance, mainly due to the significant overall climb that characterized the Athens 2004 Olympic course. The elevation differential (drop) between start and finish was more than 1 $m \cdot km^{-1}$, therefore the course failed the IAAF “record-eligible criteria”. However, the performance still remains the best result recorded on that course.

In both cases, enhancements in performance in the short-distance event after-LHTH are greater than the individual race-to-race variability. It is acknowledged that enhancements in performance greater than the CV suggest meaningful effects since the smallest worthwhile change in performance (representing a worthwhile increase in the chance of winning an event) was shown to be 0.3 of the CV for individual top-level athletes (Hopkins et al., 1999). The improvement in Olympic-event distance after-LHTH (measurable only for participant 1) was also larger than the smallest worthwhile change. Finally, the difference between participant 1 and the silver medallist was only of 0.1%. Similarly, participant 2 won the Olympic marathon with a difference of 0.4% on the silver medallist. This highlights the importance of identifying the correct interventions that can allow elite athletes to obtain performance enhancements even smaller than 1% (Hopkins and Hewson, 2001).

Lastly, this observational study adds practical insight to the limited body of knowledge regarding LHTH interventions in elite endurance athletes. To the best of our knowledge few studies focusing on performance after LHTH have employed authentic elite endurance athletes (VO_{2max} values ≥70 $mL \cdot kg^{-1} \cdot min^{-1}$ (Joyner and Coyle, 2008) and/or world-class performance results) as their experimental population (Adams et al., 1975; Bailey et al., 1998; Daniels and Oldridge, 1970; Gore et al., 1998; Gough et al., 2012; Ingjer and Myhre, 1992; Saunders et al., 2004; Svedenhag and Saltin, 1991).

Adams et al. (1975) found no improvements in sea level performance after altitude training (2300 m) in elite runners. Athletes trained at a relative intensity corresponding to 75% of VO_{2max} and presumably this training intensity was too low to obtain beneficial adaptations in elite athletes.

Saunders et al. (2004) showed that living at 1500 m and training at ~2000 m was an insufficient stimulus to alter variables associated with running economy. In this study authors gave appropriate information about training volume but training intensity was controlled using a simple scale from 1 to 5 that did not permit to evaluate the effective training intensity sustained.

Gough et al. (2012) reported a decrement in swimming performance after LHTH (~2300 m) despite an increase of 3.8 ± 1.3% (mean ± 90% CL) in Hb_{mass}. In this study training load during altitude training was assessed on relative intensity and there was no comparison with sea level training load. As suggested by the same authors, it cannot be excluded that differences in training load between LHTH and control groups influenced swimming performance.

Gore et al. (1998) found controversial results after LHTH (2690 m) in elite cyclists. The mean performance of the group in a 4000 m individual pursuit did not change after the altitude training but some participants had their overall best performance after altitude training while others had an absolute worst performance post-altitude relative to their baseline score. It must be noticed that cyclists reduced the training volume at high-intensity (>92% HR_{max}) by ~30% during LHTH compared to 1-month before LHTH.

Daniels and Oldridge (1970) found an increase in VO_{2max} after altitude training (2300m) in world-class middle-distance runners (74.4 ± 3.6 $mL \cdot kg^{-1} \cdot min^{-1}$). Authors reported that subjects performed a rigorous training at altitude, equal in intensity to normal sea level. Unfortunately no data about training intensities is available.

Finally, Bailey et al. (1998) reported a decreased mean blood lactate concentration during a submaximal test in runners, and an improved performance at 2 and 4 $mmol \cdot L^{-1}$ after hypoxic training by 9 and 12%, respectively. In this case, it is interesting to notice that the athletes undertaking LHTH exercised with higher relative intensity compared to the sea level control group.

In summary, studies investigating the effects of LHTH on elite endurance athletes are still limited and it is not possible to provide a clear conclusion concerning the effectiveness of LHTH (Lundby et al., 2012). A common flaw of these studies is the reduction of absolute training intensity in order to obtain similar relative training intensity. Even if this approach is correct to compare training at altitude with training at sea level, in our opinion this translates in insufficient stimulus for experienced elite endurance athlete that presumably need “stronger” stimuli to obtain further improvements in performance.

Conclusion

We reported that elite athletes, with extensive altitude training camp experience, can maintain absolute pre-camp training intensity during 3 weeks of LHTH. Possibly due to an increased relative training intensity and no illness or injury, we observed a meaningful improvement in performance after 3-10 days and approximately 3 weeks after LHTH intervention. Overall, this observational case study highlights that LHTH, beyond the physiological adaptations classically attributed to altitude training, may be an effective tool to increase relative training intensity maintaining similar training pace, and possibly enhance performance in “world-class” elite endurance athletes.

It is not possible to know whether the two participants had reached similar results after the same training program performed at sea level and if performance enhancements were related to an increase of haematological parameters, non-haematological adaptations due to altitude exposure, or influenced by placebo effects. However, the aim of this observational study was primarily to show that elite endurance athletes can maintain similar absolute training intensity during LHTH and, in our opinion, this could be the key for successful high-level LHTH camp. Future research is needed in order to clarify the effects of LHTH on sea level performance for elite endurance athletes when absolute training intensity is maintained at altitude.

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Key points

- Elite endurance athletes, with extensive altitude training experience, can maintain similar absolute intensity during LHTH compared to sea level.
- LHTH may be considered as an effective method to increase relative training intensity while maintaining the same running/walking pace, with possible beneficial effects on sea level performance.
- Training intensity could be the key factor for successful high-level LHTH camp.

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