Hypoxic Training Is Beneficial in Elite Athletes

Grégoire P Millet, Franck Brocherie

Medicine & Science in Sports & Exercise

Hypoxic training is beneficial in elite athletes

--Manuscript Draft--

Manuscript Number:	
Full Title:	Hypoxic training is beneficial in elite athletes
Short Title:	Hypoxic training for elite athletes
Article Type:	Original Investigation
Keywords:	Altitude Hypoxia Performance
Corresponding Author:	Gregoire P Millet, PhD UNIL Lausanne, SWITZERLAND
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	UNIL
Corresponding Author's Secondary Institution:	
First Author:	Gregoire P Millet, PhD
First Author Secondary Information:	
Order of Authors:	Gregoire P Millet, PhD
	Franck Brocherie
Order of Authors Secondary Information:	
Abstract:	N/A
Funding Information:	

Click here to access/download

Submission Form/Page Charge Agreement

submissionform.docx

Hypoxic training is beneficial in elite athletes

Grégoire P. Millet [1], Franck Brocherie [2]

1 Institute of Sports Sciences (ISSUL), Faculty of Biology and Medicine, University of Lausanne, Lausanne, Switzerland.

2 Laboratory Sport, Expertise and Performance (EA 7370), Research Department, French Institute of Sport (INSEP), Paris, France.

Contrasting perspective.

There is no doubt that many hypoxic conditions or prolonged exposures to altitude result in "*biological costs of hypoxic adaptations that outweigh their benefits*" (1), particularly in endurance athletes exposed to a) exercise-induced arterial hypoxemia leading to a larger decrease in VO_{2max} and aerobic endurance; b) increased sympathetic activity and decreased baroreflex sensitivity; and c) increased pulmonary arterial pressure. There is also no doubt that sleeping in moderate altitude (2000-3000 m) as performed by the athletes using either live high-train high (LHTH) or live high-train low (LHTL) methods leads to periodic breathing, intermittent hypoxia (IH) and increase in desaturation periods; e.g. 3% oxygen desaturation index, but to a larger extent in hypobaric hypoxia (HH, real altitude) than in normobaric hypoxia (NH, simulated altitude), as shown at 2250 m (2).

The three main questions debated in the present contrasting perspective are however different: 1. Are there any evidences showing if the "*counteracting maladaptation*" (reported above) outweigh the benefits of the different hypoxic methods at short- or long-term in elite athletes? ; 2. Are there any robust data supporting that hypoxic training is beneficial in elite athletes? ; 3. Contradictory, are there robust data showing that hypoxic training is not beneficial in elite athletes?

1. Evidence of "*Counteracting maladaptation*" outweighing the benefits of altitude training?

Answering the first question is easy: as stated by Dempsey and Morgan (1), the "*available evidence that predicts that the maladaptive responses (to hypoxic training/exposure or cyclical IH) would oppose or even erode the key adaptive performance-enhancing mechanisms elicited by physical training…are not verified yet*". These concerns are therefore of interest but remain purely theoretical and speculative. Moreover, the severity of altitude recommended for both LHTL and LHTH methods (i.e. 2200-2500 m) (3, 4) is too low for inducing high-altitude illnesses (acute mountain sickness, high altitude pulmonary or cerebral oedemas) (5). Finally, there is a growing literature showing that adequate monitoring of the responses/behaviour of the athletes may limit some hypoxic-induced detrimental effects; illness, dehydration or sympathetic-induced "fatigue" (3). For example, heart rate variability guided training is effective for limiting perceived fatigue during LHTL (6).

A vast majority of elite endurance athletes and support staff utilized altitude training and considered hypoxia as "*very important*" (7). Would you trust your MD not asking you how you feel after a treatment? Or worse, maintaining that the medication was harmful or ineffective if you feel better?

2. Studies supporting that hypoxic training is beneficial in elite athletes?

From the original review by Wilber (8) that defined three models [LHTH; LHTL and live low-train high (LLTH), used in the resting state (intermittent hypoxic exposure, IHE) or during training sessions (intermittent hypoxic training, IHT)], the panorama of the hypoxic training methods utilized in sport has been largely updated in two directions: first, the possibility to combine different methods; e.g. LHTL + IHT; second the development of new methods at high-intensity, potentially useful for intermittent (team-, racket- or combat sports) athletes (9, 10).

There are many articles (11) supporting the positive hematological effects of LHTH or LHTL as long the hypoxic dose is high enough. The increase in total hemoglobin mass (Hb_{mass}) is estimated at a mean rate of 1.0-1.1% per 100 h of exposure in both NH and HH conditions (12, 13) . In a critical review (4), some relevant weaknesses or methodological limitations have been emphasized as the needs of better controlling the placebo effects with elite athletes; but the main conclusion was "*LHTH and LHTL may increase exercise performance in some but certainly not in all athletes*" and did not throw the baby out with the bathwater. Several confounding factors that may limit the Hb_{mass} increase, as the health (illness/injuries) status of the athlete (14), insufficient iron store/supplementation (15), insufficient hydration for compensating the increased respiratory water loss (hyperventilation) and diuresis (16), insufficient energy (particularly carbohydrate) availability (16) are now clarified and thus better monitored on the field by the servicing physiologists who support athletes during altitude training camps.

Importantly, hypoxic training is not limited to LHTH and LHTL anymore and the recent implementation of innovative methods such as repeated-sprint training in hypoxia (RSH) is an important step forward (17, 18). Despite its novelty, RSH is of high interest in exercise physiology: with 25 experimental studies published in the 5-years period (19) following the pioneer RSH article in 2013 (18), RSH is shown to be effective for improving repeated-sprint ability in intermittent [team- (rugby, football, field hockey); racket (tennis) as well as endurance (cycling, cross-country ski) sports (for an updated review: (19)). Moreover, from a mechanistic point of view, RSH questions the non-hematological responses to hypoxia: The underlying mechanisms are specific to RSH and not observed neither with passive exposure to hypoxia nor in the other hypoxic methods utilizing lower training intensities. The transcriptional and vascular responses lead to improved behavior of fast-twitch fibers, notably via compensatory vasodilatation and faster rate of phosphocreatine resynthesis (18, 20). To our knowledge, there is no maladaptation to RSH (e.g. impaired immune function) identified yet.

3. Studies supporting that hypoxic training is not beneficial in elite athletes?

An interesting point of view that "*altitude training does not convincingly increase exercise performance and should not be recommended to elite (endurance) athletes*" (21) is not based on the "*counteracting maladaptation*" discussed above (point 1) but on the assumption that athletes with a high initial Hb_{mass} value are close to a "ceiling" level and would therefore not increase Hb_{mass} and maximal oxygen consumption (22). We had already the opportunity to state that some of the previous studies supporting this non-effectiveness of LHTL may come from inaccurate data coming from "*noisy*" (poor "signal-to-noise ratio") data with a relatively high typical error of Hb_{mass} measurement (23). Furthermore, additional findings (24) confirmed that even athletes with high initial Hb_{mass} value did benefit from a substantial increase (3-4%) as long the hypoxic dose was high enough (200-230 h at 2250 m). Recently, an additional study (25) on elite cross-country skiers performing LHTL with 26 nights at 2207 m (terrestrial altitude) did not show any additional effect on running economy, performance, oxidative muscle capacities or lung diffusive capacity, when compared to a LLTL group that trained up to 1500 m and slept at 1035 m. Unfortunately, there was no sea-level control group. Overall, it remains unclear if these authors are discussing the non-effectiveness of all hypoxic/altitude methods or if they restrict their concerns only to LHTL. If so, we concede that we could find an agreement since the superiority of LHTL over LHTH remains questionable, unclear and probably overestimated.

Regarding the effectiveness of RSH, only two studies of 25 did not report some positive outcomes (19). Although further work is requested on the underyling mechanisms and the optimal parameters specific to each sport, there is little doubt that this innovative method brings improvement in repeated-sprint ability (19), as now admitted by Prof. Lundby (http://www.worldrowing.com/photos-videos/videos/2018-world-rowing-coaches-conference-thursday 4:09:13 to 4:11:10).

In conclusion, there are some maladaptative mechanisms related to altitude exposure but most are not relevant to the conditions (altitude severity, duration of exposure, …) and methods recommended and used by elite athletes. The altitude-induced erythropoeitic effects and improvement in oxygen transport capacity are observed in most athletes as long as the hypoxic dose is important enough. There are new effective hypoxic methods in intermittent sports. The robustness of most contradicting studies that reported a non-effectiveness of altitude training (LHTL only?) methods is questionable.

References

1. Dempsey JA, Morgan BJ. Humans In Hypoxia: A Conspiracy Of Maladaptation?! *Physiology*. 2015;30(4):304-16.
2. Saugy JJ, Schmitt L, Fallet S et al. Sleep Disordered Breathing During Live High-Train Low in Normobaric Versus Hypobaric Hypoxia. *High Alt Med Biol*. 2016;17(3):233-8.
3. Constantini K, Wilhite DP, Chapman RF. A Clinician Guide to Altitude Training for Optimal Endurance Exercise Performance at Sea Level. *High Alt Med Biol*. 2017.
4. Lundby C, Millet GP, Calbet JA, Bartsch P, Subudhi AW. Does 'altitude training' increase exercise performance in elite athletes? *Br J Sports Med*. 2012;46(11):792-5.
5. Bartsch P, Swenson ER. Clinical practice: Acute high-altitude illnesses. *The New England journal of medicine*. 2013;368(24):2294-302.
6. Schmitt L, Willis SJ, Fardel A, Coulmy N, Millet GP. Live high-train low guided by daily heart rate variability in elite Nordic-skiers. *Eur J Appl Physiol*. 2018;118(2):419-28.
7. Turner G, Fudge BW, Pringle JSM, Maxwell NS, Richardson AJ. Altitude training in endurance running: perceptions of elite athletes and support staff. *J Sports Sci*. 2019;37(2):163-72.
8. Wilber RL. Application of altitude/hypoxic training by elite athletes. *Med Sci Sports Exerc*. 2007;39(9):1610-24.
9. Millet GP, Faiss R, Brocherie F, Girard O. Hypoxic training and team sports: a challenge to traditional methods? *Br J Sports Med*. 2013;47 Suppl 1:i6-i7.
10. Girard O, Brocherie F, Millet GP. Effects of Altitude/Hypoxia on Single- and Multiple-Sprint Performance: A Comprehensive Review. *Sports Med*. 2017;47(10):1931-49.
11. Levine BD, Stray-Gundersen J. Point: positive effects of intermittent hypoxia (live high:train low) on exercise performance are mediated primarily by augmented red cell volume. *J Appl Physiol*. 2005;99(5):2053-5.

12. Gore CJ, Sharpe K, Garvican-Lewis LA et al. Altitude training and haemoglobin mass from the optimised carbon monoxide rebreathing method determined by a meta-analysis. *Br J Sports Med*. 2013;47 Suppl 1:i31-9.
13. Wehrlin JP, Marti B, Hallen J. Hemoglobin Mass and Aerobic Performance at Moderate Altitude in Elite Athletes. *Adv Exp Med Biol*. 2016;903:357-74.
14. Wachsmuth NB, Volzke C, Prommer N et al. The effects of classic altitude training on hemoglobin mass in swimmers. *Eur J Appl Physiol*. 2013;113(5):1199-211.
15. Garvican-Lewis LA, Govus AD, Peeling P, Abbiss CR, Gore CJ. Iron Supplementation and Altitude: Decision Making Using a Regression Tree. *Journal of sports science & medicine*. 2016;15(1):204-5.
16. Butterfield GE. Nutrient requirements at high altitude. *Clin Sports Med*. 1999;18(3):607-21, viii.
17. Faiss R, Girard O, Millet GP. Advancing hypoxic training in team sports: from intermittent hypoxic training to repeated sprint training in hypoxia. *Br J Sports Med*. 2013;47 Suppl 1:i45-i50.
18. Faiss R, Leger B, Vesin JM et al. Significant molecular and systemic adaptations after repeated sprint training in hypoxia. *PLoS ONE*. 2013;8(2):e56522.
19. Millet GP, Girard O, Beard A, Brocherie F. Repeated Sprint Training in Hypoxia – An innovative method. *Deutsche Zeitschrift für Sportmedizin*. 2019.
20. Brocherie F, Millet GP, D'Hulst G, Van Thienen R, Deldicque L, Girard O. Repeated maximal-intensity hypoxic exercise superimposed to hypoxic residence boosts skeletal muscle transcriptional responses in elite team-sport athletes. *Acta Physiol (Oxf)*. 2018;222(1).
21. Lundby C, Robach P. Does 'altitude training' increase exercise performance in elite athletes? *Exp Physiol*. 2016.
22. Robach P, Lundby C. Is live high-train low altitude training relevant for elite athletes with already high total hemoglobin mass? *Scand J Med Sci Sports*. 2012;22(3):303-5.
23. Millet GP, Chapman RF, Girard O, Brocherie F. Is live high-train low altitude training relevant for elite athletes? Flawed analysis from inaccurate data. *Br J Sports Med*. 2017.
24. Hauser A, Troesch S, Steiner T et al. Do male athletes with already high initial haemoglobin mass benefit from 'live high-train low' altitude training? *Exp Physiol*. 2018;103(1):68-76.
25. Robach P, Hansen J, Pichon A et al. Hypobaric live high-train low does not improve aerobic performance more than live low-train low in cross-country skiers. *Scand J Med Sci Sports*. 2018;28(6):1636-52.