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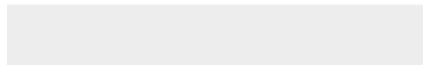
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Hypoxic training is beneficial in elite athletes

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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 underlying 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 erythropoietic 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.

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