IMPROVING ENDURANCE PERFORMANCE WITH 'LIVE HIGH - TRAIN LOW' ALTITUDE TRAINING

RELEVANCE AND LIMITS

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Historically, altitude training has been defined as the practice adopted by athletes who train for several weeks in an oxygen-deprived environment (altitude training camp) in order to improve their endurance performance. By extension, altitude training refers to the use of natural or simulated altitude conditions during the course of the training process, at rest and/or during exercise. Whatever the altitude training strategy, athletes exposed to altitude are facing low-oxygen pressure (hypoxia), resulting in a lower blood and tissue oxygenation (hypoxemia).

Altitude training became popular at the time of the 1968 Olympic Games in Mexico (located at 2,400 m), where endurance athletes not only failed to set new records (as opposed to sprinters) but also decreased their performance (e.g. 3000 m steeplechase, 10,000 m and marathon disciplines). The main reason for this was obviously altitude hypoxia, a condition known to decrease aerobic performance in humans. This failure prompted athletes and coaches to implement altitude training camps with the objective to acclimatise to competition at altitude. It soon became apparent, however, that altitude training also could improve endurance performance upon return to sea level. The rationale was that on the one hand, total red blood cell volume is a key factor for endurance performance, as highlighted by experiments incorporating blood manipulations. The larger number of red blood cells an athlete has, the faster he will probably be able to run a marathon. On the other hand, altitude exposure triggers the secretion of the renal hormone erythropoietin (EPO), which in turn stimulates red blood cell synthesis i.e. provided that the 'altitude dose' is sufficient. So, the original concept was that combining training and altitude would boost total red blood cell volume and therefore endurance performance. The fact is that over the years, this attractive hypothesis has led numerous sport federations to build a substantial number of hypoxic facilities worldwide.

After several decades and the involvement of a large number of elite athletes who sometimes set new world records after returning from altitude, the key question arises: **does it really work?** Unfortunately, to date the majority of well-controlled scientific studies fail to demonstrate a systematic positive effect of altitude training on endurance performance in athletes.

Nonetheless, a common observation is that some athletes do benefit from this method, while others do not (reports of a reduction in exercise capacity also exist). So, the next question is: **why does altitude training fail to induce a consistent positive effect on performance?**

Firstly, scientific literature indicates that the individual variation in the adaptive responses to altitude is very large in humans, and the determinants of altitude tolerance exposure are poorly understood.

Secondly, at a practical level, exercising in hypoxia poses a major problem, which is the management of training intensities. Because maximal exercise capacity is reduced under hypoxic conditions, training at altitude at the same absolute intensity as at sea level represents a larger stimulus that could eventually lead to overtraining. Conversely, conserving the same relative intensity at sea level (i.e. decreasing running speed) has the potential to alter running skills or even induce detraining. Therefore, in such a challenging environment, it is very difficult for the coaches to design the optimal training regimen adapted to each athlete. As a consequence, the likelihood of obtaining the expected positive effect on performance for all athletes is low. That said, numerous anecdotal reports showing that elite endurance athletes have produced word-class records after a prolonged sojourn at altitude certainly explain why classical altitude training (i.e. living and training at natural altitude for several weeks) remains a popular method.

NEW METHODS

The various problems encountered with classical altitude training have prompted scientists and coaches to investigate alternative methods, whereby the athletes are discontinuously exposed to hypoxia at rest and/or during exercise sessions. The first of these methods is 'live high - train low' and consists of sleeping at altitude to gain the haematologic adaptations (increased erythrocyte volume) but training near sea level to maximise performance (preservation of sea level training intensity and oxygen flux). Another method is the 'live low - train high' method including intermittent hypoxic exposure during training sessions. However, given the relatively short duration of hypoxic exposure, muscular adaptations (and not necessarily an improved oxygen carrying capacity) are thought to enhance exercise performance after 'live low-train high'. The present article focuses on performance improvements and haematologic adaptations induced by the 'live high - train low' altitude training intervention.

'LIVE HIGH - TRAIN LOW' ALTITUDE TRAINING

Often considered as a variation of classic altitude training, the principle of 'live high - train low' is the following: living/sleeping at altitude for several weeks enables total red blood cell volume to increase (similarly to classic altitude training), while training at or near sea level allows the athletes to maintain their training intensities within normal levels (contrary to classic altitude training, where absolute training intensities are generally reduced). By doing so, training-related problems are overcome and one may therefore expect more consistent adaptations than with classical altitude training. The approach was allegedly first tested on an empirical basis by some athletes in the Italian Alps in the 1980s, but was first shown to be beneficial for enhancing aerobic performance by American scientists in the late 1990s[1]. Since then, several other studies have confirmed that 'live high - train low' might confer some physiological advantages, such as an increase in total red blood cell volume and ultimately, an improvement in maximal oxygen transport. Of note, there is no definitive consensus about the mechanism(s) underlying the increase in performance. Some authors suggest, on a rather robust evidence base, that haematological adaptation is the main factor. Others have rather proposed that skeletal muscle function (but not red blood cell number) is improved after 'live high - train low', so that muscle efficiency and therefore endurance performance are maximised[2].

Beyond the concept's attractiveness or any scientific evidence, it is important to acknowledge that simplicity is certainly another reason behind the success of this approach. Breathing hypoxic air during sleep is easy to implement everywhere on Earth and is by far much less expensive or complicated than organising a long training camp in the mountains, even if the use of natural altitude (hypobaric hypoxia)

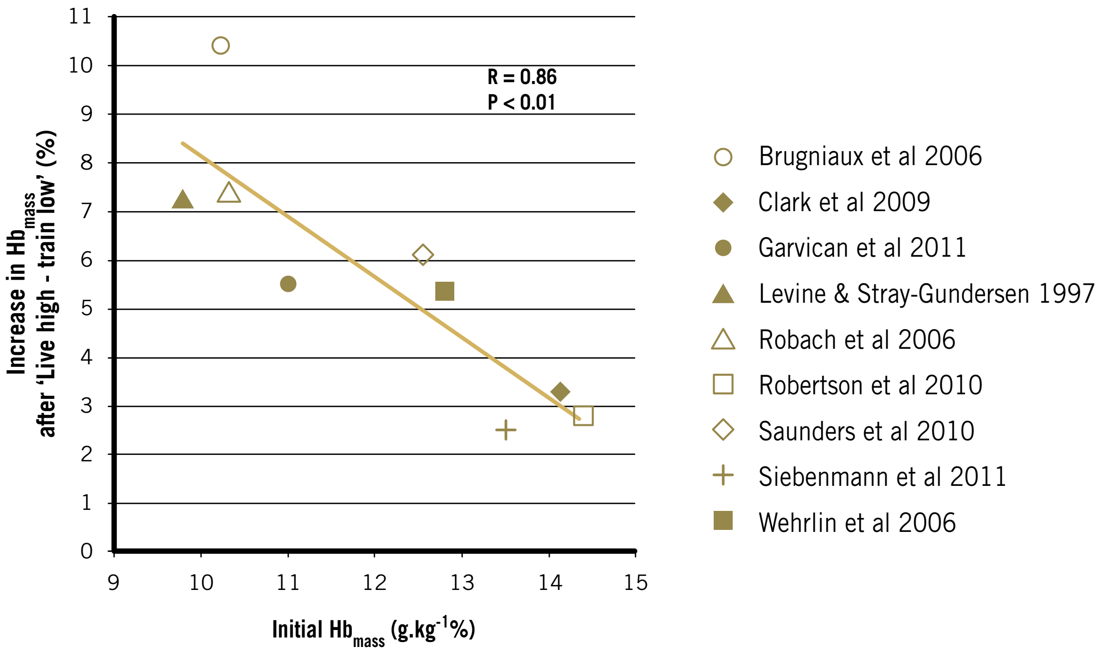

Figure 1: Significant inverse relationship existing between the initial level of total haemoglobin mass (Hb_{mass}, body-weight adjusted) measured prior to 'live high - train low' altitude training and the relative increase in Hb_{mass} induced by 'live high - train low'. The relationship is based on nine previously published studies on 'live high - train low'[6].

was proved efficient[1]. Indeed, building hypoxic rooms or even sleeping in hypoxic tents is technologically affordable, since atmospheric pressure is not modified; only the fraction of oxygen has to be reduced (with oxygen extraction or nitrogen enriching) in order to simulate altitude.

After 20 years of research on 'live high - train low', the general consensus is that this method may help some, but not all, athletes in improving their performance. In this context, natural altitude seems to be more efficient than artificial hypoxia, while sub-elite athletes might benefit more from 'live high - train low' than elite athletes[3]. The observed improvements are nonetheless modest since endurance performance is generally improved by 1 to 2%. It is, however, acknowledged that such a change in performance is considered worthwhile by elite athletes. In any case, the advantages conferred by this legal method are much less than those induced by illegal and potentially harmful blood manipulations such as autologous blood transfusion or prolonged recombinant EPO treatment. Of note, even though the legality of artificial hypoxia is today accepted, the ethical aspects are nonetheless controversial, as illustrated by the recent World Anti-Doping Agency's consideration of placing "artificially-induced hypoxic conditions" on the Prohibited List of Substances/Methods[4].

Recently, the view that 'live high - train low' improves performance has been challenged by a study conducted on highly-trained cyclists, for the first time in a double blind manner, showing no change in endurance performance[5]. In these athletes, neither total red blood cell volume nor skeletal muscle function improved after 'live high - train low' intervention. Such findings clearly raise the question of the actual ergogenic effects of 'live high - train low' in elite endurance athlete populations i.e. those already possessing very high levels of total red blood cell volume and maximal oxygen uptake, therefore having very little room for further improvement. A recent analysis showing an inverse linear relationship between the initial levels of total haemoglobin mass (a parameter equivalent to total red blood cell volume) and the response of total haemoglobin mass induced by 'live high - train low' (Figure 1), suggests that the more red blood cells an athlete has before entering a 'live high - train low' camp, the lower his likelihood of obtaining a substantial effect and vice versa[6]. Basically, the elite athletes possessing the highest levels of total haemoglobin mass are the cross-country skiers, the distance runners and the cyclists. Elite swimmers, although they are also engaged in highly aerobic activities, usually have total haemoglobin mass levels lower than those measured in terrestrial endurance sports. Elite team sports athletes whose performance level relies on both their aerobic and anaerobic capacities, but are also highly dependent on technical and tactical skills usually possess a total haemoglobin mass of 11 $g.kg^{-1}$ within or slightly above the normal range (10 to 11 $g.kg^{-1}$). For those athletes it is reasonable to expect that 'live high - train low' may substantially increase their red blood cell synthesis, therefore reinforcing their aerobic potential. Whether this translates into an elevated exercise performance is questionable, as one would assume the organisms of elite athletes already to be fully optimised, i.e. if a high haemoglobin mass and aerobic capacity would be a requirement in order to become Olympic champion these values would be higher in the best athletes, but this is not the case.

A FEW RECOMMENDATIONS ON 'LIVE HIGH - TRAIN LOW' ALTITUDE TRAINING

Although the efficacy of 'live high - train low' in elite endurance athletes has been challenged recently[7], beneficial effects on aerobic performance may nonetheless exist in other athletes, such as team sports players. Accordingly, some practical recommendations can be formulated.

Dose of hypoxia

Current recommendations indicate that daily exposure to hypoxia should be as long as possible, while the total duration of the 'live high - train low' camp should be 3 to 4 weeks. Altitude should not exceed 2,500 to 3,000 m. Pending confirmatory research, it is believed that higher altitudes, which could theoretically induce a stronger synthesis of red blood cells, are thought to impair the athletes' recovery process. Nevertheless, it is not excluded that adequate progressive acclimatisation may preserve sleep quality at altitude >3,000 m.

Training

There are no evidence-based guidelines regarding the best training regimen for an optimal 'live high train low' paradigm. Nevertheless, a precautionary principle would indicate that training load should be lightened over the first 2 to 3 days to avoid overtraining, although no evidence supports this statement.

Illness

Inflammation or viral infection is associated with a blunted haematological response during 'live high - train low'. Even if a causal link has not been established, it seems important to carefully monitor health status during the camp, especially when two or more athletes share the same room.

Supplementation

Since iron is required for red blood cell synthesis, athletes are often supplemented with iron prior to and during a camp. While the role of iron on erythropoiesis is not debatable, systematic supplementation in iron-replete individuals may induce oxidative stress in some cases. Case-by-case iron supplementation should be preferred, by targeting the athletes with depleted iron stores prior to the altitude training camp. Of note, absolute iron deficiency is characterised by ferritin levels <30 µg/L, and functional iron deficiency is defined by ferritin cut-off value of 30 to 99 µg/L or even 100 to 299 µg/L if associated with a transferrin saturation of <20%.

Natural or simulated altitude?

Hypobaric hypoxia (natural altitude) is suggested to be more efficient than normobaric hypoxia (simulated altitude) for 'live high - train low'. One reason is that hypobaric hypoxia is thought to induce more pronounced adaptive responses than normobaric hypoxia, such as ventilation, fluid balance or nitric oxide metabolism. This hypothesis is, however, debated and to date, no experimental evidence exists to suggest that natural altitude is the best option. Nonetheless, the acute rise in plasma EPO is similar with normobaric and hypobaric hypoxic exposure.

Competition at altitude

Even if evidence is lacking, it would seem prudent to recommend implementing 'live high - train low' or even classical altitude training for preparing for a competition at moderate altitude. Indeed, endurance performance is acutely reduced at moderate altitude but acclimatisation has the potential to restore, at least in part, the athlete's capacity for prolonged exercise. To this regard, a period of 1 to 2 weeks at moderate altitude seems appropriate to maximise acclimatisation. However, it should be reminded that even after prolonged acclimatisation (3 weeks or more), full restoration of performance at altitude is virtually impossible.

IN SUMMARY

Among the various existing methods using hypoxia during the training process, 'live high - train low' altitude training appears the most relevant approach to improve endurance performance in athletes. However, it should be emphasised that the improvements remain modest and that the method may have limited or no impact at all when applied to elite endurance athlete populations. The large individual variability in the response to hypoxia might explain, at least in part, why some athletes do benefit from 'live high - train low' and others do not. Unfortunately, the predictive factors of altitude tolerance remain unknown. Finally, the cost effectiveness of 'live high - train low' has to be considered. On one hand, sleeping/living in altitude facilities or hypoxic rooms during 3 to 4 weeks represents a significant effort for the athletes (indeed the logistic strain that may be experienced by athletes being subjected to 'live high - train low' is often neglected. Also, if using hypoxic room exposure it should be acknowledged that athletes may not find it very attractive to spend up to 16 hours per day in strict confinement). On the other hand, the outcome, although potentially worthwhile, may be modest. Consequently, to be relevant, this method requires a strong adherence of the athletes.

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