Hot Topic Review

Does 'altitude training' increase exercise performance in elite athletes?

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New Findings

- **What is the topic of this review?**
  The aim is to evaluate the effectiveness of various altitude training strategies as investigated within the last few years.
- **What advances does it highlight?**
  Based on the available literature, the foundation to recommend altitude training to athletes is weak.

Athletes may use one of the various altitude training strategies to improve exercise performance. The scientific support for such strategies is, however, not as sound as one would perhaps imagine. The question addressed in this review is whether altitude training should be recommended to elite athletes or not.

(Received 21 March 2016; accepted after revision 10 May 2016; first published online 13 May 2016)
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Introduction

Altitude training in any of its many forms is endorsed by top athletes worldwide. Many of the very best cyclists from Union Cycliste Internationale (UCI) World Teams venture to the volcanic landscape surrounding Teide on Tenerife (Spain) as part of their seasonal preparations. Likewise, ambitious cross-country skiers and teams may spend 1–2 weeks on the glaciers above Val Senales (Italy) in October to prepare for the coming season. In contrast to this, a review questioning the scientific evidence for altitude training was published in 2012 as part of an International Olympic Committee (IOC) consortium (Lundby *et al.* 2012). The present Hot Topic Review is based on a presentation by C.L. at the *Biomedical Basis of Elite Performance 2016* congress organized by The Physiological Society and focuses on studies published after that review. Furthermore, the present Hot Topic Review focuses on repeated sprint training in hypoxia because this altitude training modality has received particular attention among scientists since 2012.

Live high–train low

The live high–train low (LHTL) approach is based on the 1997 Levine & Stray-Gundersen study (Levine & Stray-Gundersen, 1997) in which they demonstrated greater improvements in endurance performance in the LHTL compared with the matched control group. The fact that subsequent studies using normobaric hypoxia repeatedly failed to show such positive outcome, in particular in highly trained individuals (Robertson *et al.* 2010; Siebenmann *et al.* 2012), raised question about the overall efficacy of LHTL (Lundby *et al.* 2012) but at the same time reinforced the idea that LHTL using natural altitude remained the best approach for elite athletes (Bonetti & Hopkins, 2009). Unfortunately, most subsequent LHTL studies using natural altitude did not include a matched sea-level control group (Stray-Gundersen *et al.* 2001; Wehrlin *et al.* 2006; Chapman *et al.* 2014; Saugy *et al.* 2014) and therefore cannot be used to confirm or discard the rationale for LHTL. In contrast, one recent controlled study suggested

 DOI: 10.1113/EP085579

Experimental Physiology

a beneficial effect on performance (Hauser *et al.* 2016). It has, however, been pointed out that the observed changes in that study might have been influenced by a training camp effect rather than by hypoxia *per se* (Siebenmann, 2016). Such problems should be considered in studies using distant locations for the two groups (control and natural LHTL), because training and living conditions may vary substantially from one group to the other. Even in the carefully controlled study of Levine & Stray-Gundersen (Levine & Stray-Gundersen, 1997) (in which experimental groups resided and trained >1000 km apart), this issue should not be omitted. In summary, LHTL at natural altitude deserves further controlled research to determine the potential advantage of this training strategy.

Sprint interval training in hypoxia

Sprint interval training in hypoxia is a new variation of live low–train high, which has received much attention over the last few years. In contrast to the ongoing discussion on whether LHTL may or may not elicit a slight performance advantage, the discussions regarding sprint interval training in hypoxia are far more dramatic, as researchers argue for a from 'zero' effect to performances gains of up to 55%. How can this be? First of all, it has to be said that most studies apply a large panel of exercise performance related tests, some of which, although related to performance, are certainly not as valid as direct measures hereof. Also, by applying a large test battery, often of modest quality, the risk of finding a random change that may not be true is increased. Thus, in some studies two almost identical measures of performance may give different results, and in the following summary of studies only direct measures of performance are considered. The studies are discussed in chronological order of publication.

The underlying rationale for 'classic' live low–train high (LLTH) is that this type of training will induce greater skeletal muscle adaptions than similar training conducted in normoxia (Hoppeler *et al.* 2008; Lundby & Jacobs, 2016), and this has also been verified experimentally on several occasions by Hans Hoppeler's research group (Hoppeler *et al.* 2008). Despite these greater peripheral adaptations, LLTH does not facilitate sea-level maximal oxygen uptake ($\dot{V}_{O_2\,max}$) or time trial performance any more than sea-level training, which is also why LLTH was one of the first altitude training modalities deemed uncertain (Hoppeler *et al.* 2008) or even irrelevant (Lundby *et al.* 2012) for elite athletes unless preparing for competition at altitude, where LLTH has been shown to be effective in augmenting performance somewhat (Robach *et al.* 2014; Ventura *et al.* 2003). Curiously, this has been ascribed to greater peripheral adaptations, but in a recent LLTH study mitochondrial biogenesis was similar to that occurring in the normoxic control group, whereas exercise performances tended to be elevated in hypoxia (but not in normoxia) in the LLTH group (Robach *et al.* 2014). This could suggest that the observed peripheral adaptations in the earlier studies may indeed not be the mechanisms responsible for augmenting hypoxic exercise performance.

It has been proposed that the hypoxia-induced decrease in $\dot{V}_{O_2\,max}$ will not allow athletes to train at the same high absolute workloads in a hypoxic environment and that this could be the reason for LLTH not to superimpose the training effects, regardless of the greater peripheral adaptations. This led the team of Peter Hespel (Puype *et al.* 2013) to test the hypothesis that 30 s sprint interval exercise training might overcome this obstacle, as this type of exercise may not be as strongly affected by the reduction in $\dot{V}_{O_2\,max}$. They found, however, no improvements in $\dot{V}_{O_2\,max}$ or time trial performance following interval sprint training in hypoxia [6 weeks; three sessions per week at a fractional inspired oxygen (F_{I,O_2}) of 14.4%]. As such, these results are not very surprising, because high-intensity exercise (but not sprint exercise) in combination with hypoxia has been tested on several occasions over the last 15 years, with studies showing no superior performance gains ($\dot{V}_{O_2\,max}$, time trial, lactate metabolism and performance tests; Terrados *et al.* 1988; Truijens *et al.* 2003; Lecoultre *et al.* 2010). We added to this body of evidence recently (Robach *et al.* 2014). Thus, it should be clear that even despite maintaining a high training intensity, hypoxic training is not effective in potentiating endurance parameters.

At the same time, Millet's research group (Faiss *et al.* 2013) speculated that although the adaptations associated with hypoxic training may not be favourable for endurance parameters, they could perhaps increase the ability to perform repeated sprints (repeated sprint ability; RSA). In their initial study, they observed no improvements in average power outputs during the sprints but very large improvements (>40%) in the number of sprints that the subjects could perform following the hypoxic sprint training (4 weeks; two sessions per week at an F_{I,O_2} of 13.8%). The conclusions drawn seem hasty, however, because the criteria for fatigue were different between groups. The hypoxic group conducted sprints until a 55% reduction in peak sprint power was achieved while the number was only 68% in the normoxic group, whereas at the same relative reduction in performance the number of sprints was equal (69 and 68% reduction in hypoxia and normoxia after the ninth sprint, respectively).

In 2013, Galvin and co-workers tested the idea that interval sprints performed in hypoxia (4 weeks; three sessions per week at 3000 m) may improve exercise performance (Galvin *et al.* 2013). In their study, the Yo-Yo Intermittent Recovery Level 1 test (which can be used as an estimate of $\dot{V}_{O_2\,max}$) was improved to a greater extent in well-trained rugby players following hypoxic (33%) than normoxic training (14%), whereas repeated sprint ability remained unchanged. A 33% increase in an estimate of aerobic power should be of interest to many athletes, but unfortunately this single-blinded study is at odds with the study of Puype *et al.* (2013), in which performance was improved by 0.5%, and years later we found a 0.8% gain in $\dot{V}_{O_2 \max}$ with this type of training (Montero & Lundby, 2016); however, both improvements were not different from those observed in the respective control groups.

Since the first publications on sprint interval training in hypoxia (Faiss *et al.* 2013; Galvin *et al.* 2013; Puype *et al.* 2013), several others have followed.

The Australians have a strong tradition for altitude training studies, and it is no surprise that, based on the initial studies, they became interested in the potential of sprint interval training in hypoxia. Goods *et al.* (2015) conducted a study including 30 subjects who were randomized and blinded towards hypoxic or normoxic sprint training (5 weeks; three sessions per week at 3000 m altitude). In their study, cycling and running RSA mean and peak power were equally improved with hypoxic and normoxic training. Also, 20 m shuttle run improved equally regardless of group allocation. The authors speculate that the number of sprints following hypoxic sprint training will not be improved in their study any more than with normoxic sprint training, i.e. in contrast to Faiss *et al.* (2013, 2015*b*) but in agreement with Galvin *et al.* (2013) and Montero & Lundby (2016), because higher power outputs were found with normoxic in comparison to hypoxic training in the final two sprint sets (Goods *et al.* 2015).

In addition to their first study, Faiss and co-workers published yet another study (Faiss *et al.* 2015*b*) suggesting that sprint interval training in hypoxia greatly improves the total number of repeated sprints that subjects are able to perform before fatiguing. After a mere six training sessions conducted over 3 weeks, they reported that cross-country skiers increased the number of arm double-poling sprints with hypoxic training from 10.9 to 17.1, i.e. a 55% increase in performance, but that this was not the case after normoxic training (11.6 *versus* 11.7). At the same time, the peak power output and the average power output during three 3 min all-out sprints with 3 min rest in between was improved in a similar manner in both groups. We have previously questioned the reported increase in the number of sprints completed following the hypoxic training in that study (Montero & Lundby, 2016), whereto the authors have also replied (Faiss *et al.* 2015*a*). The authors state that task failure (i.e. the ability to perform sprints) was set to 70% of peak sprint power output. Sprint peak power was assessed in an isolated trial, i.e. without subsequent sprint exercise to avoid 'any pacing strategy', which makes sense and was 528 and 532 W for the hypoxic and normoxic group, respectively. The peak powers used for their performance analysis, however, are based on the repeated sprint tests, which may be subjected to pacing strategies and, accordingly, the hypoxic group in particular had a lower peak power output (now 500 W, hence 28 W lower than in the isolated trial), whereas the normoxic group had a similar peak power output (525 W, hence only 7 W lower than in the isolated trial) when compared with the isolated trial. One could therefore argue that the hypoxic group in particular adjusted the 'pace' somewhat lower in the light of the coming repeated sprints. If using the peak power outputs from the isolated trials (assumed true because these are higher) then there is no superimposing effect of adding hypoxia to interval sprint training, i.e. a 69% reduction in power is observed after the 12th sprint in the normoxic group and an equal 69% reduction is observed after the 13th sprint in the hypoxic group.

Two studies were published by Brocherie (Brocherie *et al.* 2015*a*,*b*). The first demonstrated that Repeated Sprints in Hypoxia (RSH) (5 weeks; two sessions per week at an F_{I,O_2} of 14.3%) in young footballers had no effects on RSA (Brocherie *et al.* 2015*a*). In the second study (Brocherie *et al.* 2015*b*), six sessions of sprint interval training in hypoxia (equivalent to '3000 m altitude') were added to an ongoing 14 days of LHTL (≥14 h day^{-1} at 2800–3000 m 'altitude'). It appears that RSA (eight 20 m sprints), Yo-Yo Intermittent Recovery Level 2 performance and vertical jump height were not different from the control LHTL group, whereas these were improved in comparison to a control group training and living at sea level. From this study, however, it is impossible to identify by which stimulus RSA should be improved, and as such, we would recommend not mixing too many exotic training strategies at once.

Gatterer and colleagues join the list of authors not finding any additional effect of hypoxic sprint interval training when compared with normoxic sprint training. In an initial pilot study (Gatterer *et al.* 2014), the sum of sprints and fastest sprints were unchanged following hypoxic sprint training, whereas the fatigue slope became somewhat reduced. Later, they demonstrated that eight sessions (conducted within 12 days) of hypoxic sprint interval training had no additional effect on the Yo-Yo Intermittent Recovery test performance and the RSA fatigue slope (Gatterer *et al.* 2015).

Finally, in a double-blinded, placebo-controlled, cross-over-designed study applying 4 weeks of sprint interval training (at an F_{I,O_2} of 13.8 or 20.93%) with three sessions per week (i.e. 12 sessions in total), we found no effects on peak power (Fig. 1), average power, number of sprints, $\dot{V}_{O_2 \max}$ or time trial performance, when tested in either normoxia or hypoxia, at two time points (3–5 and 10–12 days after the last training session; Montero

& Lundby, 2016). It should be highlighted that RSA was tested without a prior exercise challenge as well as immediately after a $\dot{V}_{O_2\,max}$, and separately again after a time trial test. Thus, in a total of 12 RSA tests conducted after sprint interval training in hypoxia, none of these parameters was improved any more than with sprint interval training conducted in normoxia.

Thus, some studies show huge improvements in performance after hypoxic sprint interval training, whereas others show 'nothing'. Where does this leave us? We would recommend the reader to assess critically the strengths and weaknesses of the different studies by him or herself, but based on the available literature we are of the opinion that hypoxic sprint interval training cannot be recommended to athletes.

From a practical point of view, it also needs to be considered whether an improved ability to perform repeated sprints in the way they are performed in the above studies following any intervention will result in better match performance.

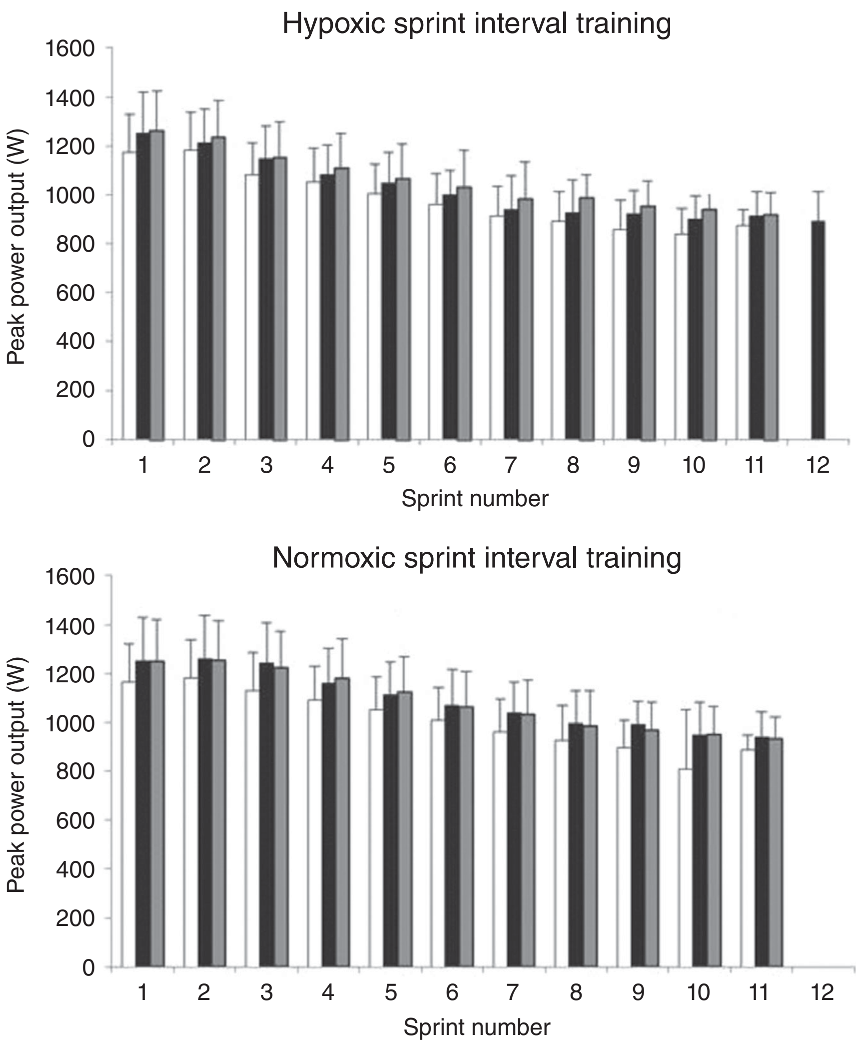

Figure 1. Peak power outputs during repeated 10 s all-out sprints separated by 20 s of rest before (open bars) and 3–5 (filled bars) and 10–12 days (grey bars) after 4 weeks of hypoxic (upper panel) or normoxic sprint interval training (lower panel) performed in a double-blinded, cross-over manner

In this study, the addition of hypoxia provided no additional effect on any of the determined parameters. Besides being tested in normoxia (the data shown in the figure), all subjects were also tested in hypoxic conditions, in which no additional effect was observed after the hypoxic training. Furthermore, the ability of all subjects to perform repeated sprints tested immediately after the completion of a maximal oxygen uptake test and a time trial test (both tested in normoxia and hypoxia) proved similar following both training regimens. The figure is adapted from Montero & Lundby (2016).

Conclusions

Altitude training does not convincingly increase exercise performance and should not be recommended to elite athletes unless there is a firm belief by the given athlete that this might genuinely be beneficial when considering the pros and cons of the various approaches (placebo may work wonders), which is unfortunate for science but great for sport performance.

In contrast to our conclusions, recent reviews by others supporting positive effects of altitude training are available (Gore *et al.* 2013).

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Additional information

Competing interests

None declared.

Author contributions

Both authors contributed equally to this work. Both authors approved the final version of the manuscript and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All persons designated as authors qualify for authorship, and all those who qualify for authorship are listed.

Funding

No specific funding was obtained for this work.