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# Inter-effort recovery hypoxia: a new paradigm in sport science?

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## ABSTRACT

High-intensity interval training (HIIT) is a popular method for optimising sports performance and, more recently, improving health-related parameters. The inclusion of hypoxia during HIIT can promote additional gains compared with normoxia. However, reductions in the effort intensities compared with the same training performed in normoxia have been reported. Studies have reported that adding hypoxia during periods of inter-effort recovery (IEH) enables maintenance of the intensity of efforts. It also promotes additional gains from exposure to hypoxia. Our call is for researchers to consider IEH in experiments involving different models of HIIT. Additionally, we consider the need to answer the following questions: What is the clinically relevant minimum dose of exposure to hypoxia during the recovery periods between efforts so that favourable adaptations of parameters are associated with health and sports performance? How does the intensity of exertion influence the responses to hypoxia exposure during recovery periods? What are the chronic effects of different models of HIIT and hypoxia recovery on sports performance?

### WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ In many training models, but not all, the benefits of integrating hypoxia into performance training sessions, compared with conducting the same training in normoxic conditions, seem to be apparent only when the absolute intensity of the training is preserved.

### WHAT THIS STUDY ADDS

⇒ We hypothesise that with inter-effort recovery hypoxia, it will be possible to obtain the benefits of exposure to intermittent hypoxia without reducing the absolute intensity of sessions.

### HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Due to the maintenance of the absolute intensity of the intermittent training sessions, the inter-effort recovery hypoxia will promote superior performance gains compared with the same training performed exclusively in normoxia or exclusively in hypoxia.

⇒ The inter-effort recovery hypoxia will promote a greater effect for stabilising hypoxia-inducible factor-1 due to changes between periods of normoxia and hypoxia compared with continuous exposure to hypoxia.

⇒ It will be possible to implement hypoxia as an additional stimulus to the training in different exercise modalities and environments without complex infrastructure.

## INTRODUCTION

Interval training is a popular method for optimising sports performance and, more recently, improving health-related parameters. Generally, this training method is defined as repeated sets of exercise completed at an intensity greater than the anaerobic threshold interspersed with recovery periods. Practically, interval training can be characterised as high-intensity interval training (HIIT) and sprint inrterval training (SIT).[1]

Studies have shown that the inclusion of hypoxia during interval training promotes additional gains compared with normoxia, possibly due to stabilisation of the hypoxia-inducible factor 1α (HIF-1α),[2] which regulates molecular responses related to cellular homeostasis, among which angiogenesis, erythropoietin (EPO), increases expression of glucose transporters and expression of key enzymes glycolytic.[3 4]

This training in hypoxia has been called 'Live Low and Train High' (LLTH)[5] and is characterised by brief periods of exposure to hypoxia (<2 hours) at rest or during training, two to five times a week and has received great attention from the scientific community, especially due to technological development, such as hypoxia-generating devices, has favoured interventions using the LLTH paradigm.[5]

Although adding hypoxia during interval training may result in greater performance gains compared with the same training performed in normoxia,[6 7] reductions in the intensities compared with the same training performed in normoxia have been reported during aerobic interval training in altitude.[8] Although, in general, interval training in hypoxia improves $VO_2max$ more than interval training in normoxia,[9] contradictory responses to the addition of hypoxia have been demonstrated depending on the



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variation of the interval training,[5] which may[6 7] or not[10 11] improve performance.

The main benefits of interval training on performance seem to be evidenced when the mechanical work or power of the training is preserved.[12] Furthermore, hypoxia has recently been shown to impair repeated sprint in hypoxia when the oxidative but not glycolytic contribution is substantial.[13] Thus, unlike interventions in the health area, in which obtaining similar physiological responses with a lower absolute workload may present some advantages[14] when the objective is to maximise performance, the 'challenge' is to increase metabolic stress by hypoxia without compromising the exercise intensity into training sessions.

An interesting approach between hypoxia and training refers to the addition of hypoxia during the inter-effort recovery (IEH) period through local blood flow restriction (local inter-effort recovery hypoxia (L-IEH))[15 16] or by systemic hypoxia (systemic inter-effort recovery hypoxia (S-IEH)).[17 18]

## LOCAL INTER-EFFORT RECOVERY HYPOXIA

Performing exercises with blood flow restriction has been a growing approach in clinical conditions for musculoskeletal rehabilitation[19] and improving athletic performance.[20] However, similar to what happens with some models of interval training performed with systemic hypoxia, the absolute intensity of the exercise has been substantially reduced. Thus, a way to obtain the benefits promoted by local hypoxia and maintain absolute training intensity has been the L-IEH approach.

Taylor *et al*[16] found that, after 4 weeks, the addition of L-IEH during SIT sessions, consisting of 4 to 7 maximal efforts lasting 30 s with 4.5 min of recovery, promoted a significant 4.5% increase in $VO_2$max compared with the same model of training performed in normoxia. These authors found significant increases in the expression of HIF-1α only in the L-IEH group. Ienaga *et al*[15] investigated the effects of L-IEH during an SIT training consisting of three sets of 6 s maximum sprints with 24 s rest between sprints and 5 min rest between sets. They found higher deoxyhaemoglobin and lower tissue saturation index ($StO_2$) in L-IEH. However, blood lactate concentrations ([La]), pH and workload in the L-IEH did not differ from the normoxia.

Kojima *et al*[19] aimed to examine the effect of L-IEH during SIT in cycling (5×10 s maximal efforts with 40 s performed in normoxia) on muscle oxygenation. They found that L-IEH showed lower oxyhaemoglobin (oxy-Hb) and $StO_2$ levels than normoxia. However, power output and [La] did not differ between conditions, and it concluded that L-IEH decreased muscle oxygenation of active musculature without interfering with power output. In addition, Wang *et al*[20] tested the effects of including local hypoxia through blood flow restriction (ie, L-IHE) in a session of repeated sprint exercise performed in hypoxia consisting of five sets of 10 s maximal sprint with a 60 s rest. Although absolute exercise intensity was not altered with the inclusion of L-IEH, the authors found that an elevated neuromuscular activity was seen in response to the L-IEH, especially during conditions of systemic hypoxia.

The above results suggest that L-IEH is a promising approach for generating local hypoxia and maintaining absolute exercise intensity.

## SYSTEMIC INTER-EFFORT RECOVERY HYPOXIA

To the best of our knowledge, the first study with S-IEH was carried out by Roels *et al*.[18] The rationale used by the authors for using intermittent hypoxic interval training (ie, S-IEH) is that bouts of exercise in normoxia would result in neuromuscular adaptations resulting from high-intensity exercise (ie, mechanical power in cycling). At the same time, adding hypoxia during recovery periods would stimulate haematopoiesis.

Roels *et al*[18] when comparing the effects of a 7-week training programme (two interval training at 100% or 90% of the maximum relative power) of S-IRH, with the same training programme performed in normoxia and exclusively in hypoxia, it found that the $VO_2$max increased only in the S-IRH (pre=4.62±0.33 vs post=5.02±0.42 L.min$^{-1}$). However, they did not find any changes in haematological $O_2$ transport that were justified as being due to the reduced time of exposure to hypoxia (~114 min.wk$^{-1}$ and $FiO_2$ equivalent to ~3000 m). In addition, the authors concluded that short-term exposure to hypoxia did not cause a greater increase in performance and haematological parameters.

In contradiction, Tobin *et al*[21] investigated the haematological responses after 5 days of exposure to continuous hypoxia (CH) or intermittent hypoxia (IH). These authors found that only IH significantly increased red blood cell count, haemoglobin concentration, haematocrit, percentage of reticulocytes, secretory immunoglobulin A, cortisol, cardiac troponin T and the Off-score compared with baseline. Wojan *et al*[22] observed that eight cycles of IH increased EPO levels to a similar extent as 120 min of CH and concluded that eight 4 min cycles of IH represent the shortest protocol to increase serum EPO levels in healthy subjects. Recently, Tobin *et al*,[23] when comparing the effects of IH and CH in young adults, showed that IH but not CH significantly increased key adaptive haematological responses. It concluded that the hypoxic pattern of IH would be the best method to boost haematological profiles before the ascent to altitude. Collectively, these studies did not support the hypothesis proposed by Roels *et al*[18] who did not find any significant changes in haematological parameters due to the low dose of hypoxia.

Recently, Dellavechia de Carvalho *et al*[17] compared the acute physiological responses of S-IEH ($FiO_2$=13.6%) during HIIT, consisting of 10 efforts at 120% of the peak velocity running, separated by 2 min of passive recovery. Despite the lower peripheral oxygen saturation ($SpO_2$) (86.2±3.5% vs 96.9±1.0%) and heart rate, the rating of perceived exertion,

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and [La] were not different. Furtherore, all participants of both studies completed 10 efforts, despite reductions in oxygen concentration during recovery between efforts. In this way, these results suggest that the addition of S-IEH can be an additional stimulus to training without impairing the quality (ie, intensity) of training.

## PERSPECTIVES

The body of knowledge to date suggests that the addition of IEH hypoxia (local or systemic) may be a more interesting paradigm than LLTH for improving haematological parameters related to $O_2$ transport and improving performance. Although longitudinal studies are necessary, from our point of view, the IEH has four advantages compared with the LLTH paradigm.

The first refers to maintaining the absolute intensity of the intermittent training sessions, regardless of the interval training model adopted. The second comprises an additive effect for stabilising HIF-1 because the repetitive changes between periods of normoxia and hypoxia (ie, IH) are more powerful stressor stimulus for accumulation of HIF-1 in the cells,[24] increasing EPO[21] and key adaptative haematological responses (ie, erythropoietic stimulation index) than continuous exposure to hypoxia stress.[23] The third corresponds to the possibility of the athlete reaching a higher aerobic contribution due to improved haemoglobin $O_2$ dissociation or increased tissue availability of $O_2$ from IH.[25] Finally, the fourth comprises the ease of implementing hypoxia as an additional stimulus for training in different exercise modalities and training environments, without the need for complex infrastructure. Thus, with IEH efforts can be performed freely, in normoxia, so that hypoxia is only added during recovery intervals.

Our call is for researchers to consider IEH in experiments involving different models of interval training. Additionally, we consider the need to answer the following questions: What is the minimum dose of exposure to hypoxia during the recovery periods between efforts so that favourable adaptations of parameters are associated with health and sports performance? How the intensity of exercise influences the responses to hypoxia exposure during recovery periods? What are the chronic effects of different models of interval training and hypoxia recovery on aerobic and anaerobic parameters and performance?

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