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## REVISIÓN / REVIEW

### **HYPOXIC EXPOSURE AS A MEANS OF INCREASING SPORTING PERFORMANCE: FACT OR FICTION?**

### **LA EXPOSICIÓN HIPÓXICA COMO MEDIO PARA AUMENTAR EL RENDIMIENTO DEPORTIVO: ¿MITO O REALIDAD?**

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## ABSTRACT

The increasing demands of elite sports have led to continuing research into various methods for improving the sporting performance of their participants. One of the most widely discussed in the past few years, especially in the field of endurance sports, is altitude training, or *hypoxic exposure*. However, despite its increasing popularity amongst athletes and coaches worldwide, a great deal of controversy remains regarding its supposed benefits. As such, the aim of this review was to attempt to clarify the role of hypoxic exposure on improved sporting performance by analysing the various methodologies, tools and research available. The key conclusion is that hypoxic exposure currently lacks sufficient scientific evidence to validate its efficacy as literature results tend to be contradictory.

**KEYWORDS:** physical training and conditioning, anoxaemia, altitude.

## RESUMEN

Las crecientes exigencias del deporte de élite han propiciado la continua investigación de diversos métodos para aumentar el rendimiento deportivo de los deportistas. Uno de los que más se ha hablado en los últimos años, especialmente en los deportes de resistencia, es el entrenamiento en altitud o *exposición hipóxica*. No obstante, a pesar de la popularidad que ha cobrado entre atletas y entrenadores de todo el mundo, existe una gran controversia sobre sus supuestas bondades. De esta forma, el objetivo de esta revisión es tratar de clarificar el papel de la exposición hipóxica en el aumento del rendimiento deportivo, analizando las distintas metodologías, herramientas e investigaciones al respecto. Se concluye que la exposición hipóxica carece en la actualidad de suficientes evidencias científicas que validen su efectividad, pues los resultados de la literatura son contradictorios.

**PALABRAS CLAVE:** entrenamiento físico y acondicionamiento, anoxemia, altitud.

## INTRODUCTION

The increasing performance demands of high-level sports have led to the development of numerous methods, models and tools designed to optimise the form of sportspeople in a wide range of specialities. In the specific case of endurance sports, the physiological parameters related to maximum oxygen consumption have been widely studied due to their well-known influence on sporting performance (Earle and Baechle, 2007; López, 2008). Thus, different methods to increase  $VO_2$ Max in long-distance sportspeople, especially athletes and cyclists, have been studied for various decades (Billat, 2002; López, 2008).

It was only in the late 1960s, when the Olympic Games were held in Mexico City (1968), that athletes, coaches and other people involved in the sports world began to consider how best to prepare sportspeople in the geographically high regions of the host country in order to achieve maximum performance (Wilber, 2001). As a result, altitude training began to gain prominence amongst elite sportspeople, and the scientific community began to study the effects of hypoxia on athletes' bodies, with blood parameters such as red blood cell concentration, being the main subject for study (Levine and Stray-Gundersen, 2005; Vogt and Hoppeler, 2010).

The possible effects of altitude training on various sporting performance-related variables, especially the oxygen supply system, have been widely studied and used by both researchers and sportspeople (Wilber, 2001; Billat, 2002; Gore, Clark and Saunders, 2007; López, 2008; Vogt and Hoppeler, 2010).

Sportspeople traditionally spent their entire stay at altitude, where they both trained and lived. However, during the 1990s, a new altitude training regime known as "living high-training low", or simply "high-low", in which the

sportspeople live at altitude but train under normal conditions, was proposed. This altitude training regime is based on the suggestion that, although living at altitude appears to increase erythropoietin (EPO) production, haematocrit and haemoglobin levels, training at such hypobaric levels does not improve sporting performance as the low partial oxygen pressure in the environment ( $FiO_2$ ) does not allow a sufficiently high training intensity to achieve the desired adaptations to be reached (Levine and Stray-Gundersen, 2005; Wilber, 2001). Furthermore, according to Billat (2002), altitude training should be at least 10% less intense than that at sea level in order to avoid the appearance of overtraining syndrome. Indeed, in this respect, Terrados, Mizuno and Andersen (1985) showed that oxygen consumption on a cycloergometer decreased significantly in elite sportspeople above an altitude of 900 metres. It therefore appears clear that the scientific community considers prolonged stays at altitude to actually diminish sporting performance (Billat, 2002; Earle and Baechle, 2007). As a result, the “high-low” training paradigm was proposed as a more effective means of improving sporting performance (Wilber, 2001).

Levine and Stray-Gundersen (1997) were the first authors to evaluate the “high-low” methodology in a study involving 26 sportspeople (13 males and 13 females) divided into two different training groups, one based on the “living high-training low” method, in which the subjects lived at 2500 metres and trained at 1250 m, and a control group, whose subjects lived and trained at sea level. Three days after completing the four-week training period, the “high-low” group presented a 5% higher haematocrit and 9% higher haemoglobin levels ( $p < 0.05$ ), whereas the control group exhibited no significant improvements. Furthermore, the former showed a significantly higher  $VO_2$ Max and better performance in a 5-km race for up to three weeks after completing altitude training, thereby demonstrating the marked stability of the benefits of “high-low” training.

Unfortunately, the stays and daily journeys inherent to this training methodology are expensive. As a result, and in light of recent technological advances, various methods that attempt to recreate these high-altitude conditions under normobaric conditions have been developed, with hypobaric chambers being perhaps the best known. These simulated-altitude devices allow access to hypoxic conditions without the need to be continually travelling or staying away from the normal residence, and sportspeople can even have one installed in their own home.

The benefits provided by hypobaric chambers and rooms allow the use of a training methodology, namely Intermittent Hypoxia Exposure (IHE), that was previously difficult to achieve due to logistical problems. IHE is based on the fact that the concentration of EPO in blood increases after a hypoxia of between 90 and 120 minutes (Wilber, 2001; López, 2008), thus meaning that daily sessions of between 1.5 and 2 hours may result in the sought-after adaptations. IHE has two modes: at rest and whilst training. As its name suggests, intermittent hypoxia exposure at rest (IHEAR) is based on exposure to hypoxia under resting conditions irrespective of any training carried out under normal

conditions, whereas intermittent hypoxia exposure during training (IHET) involves inducing hypoxia whilst the sportsperson is training, something which, as noted above, does not appear to result in adaptations due to the poor quality of the training that can be performed under such conditions. However, these methods remain controversial, with some studies finding them to be beneficial (Bonetti, Hopkins, Lowe and Kilding, 2009; Burtscher, Gatterer, Faulhaber, Gerstgrasser and Schenk, 2010; Frese and Friedmann-Bette, 2010), but others finding no significant benefit in terms of any relevant parameters (Feriche et al, 2007; Beidleman et al, 2009; Faulhaber, Gatterer, Haider, Patterson and Burtscher, 2010; Hamlin, Marshall, Hellemans and Ainslie, 2010).

Despite this controversy, hypoxic exposure is currently widely used during sports training. Furthermore, although it has traditionally been considered to be a good means of increasing aerobic performance (Wilber, 2001), an increasing number of studies have considered its effects on several other variables, including strength (Nishimura et al, 2010), lipid profile (Minvaleev, 2011), the body composition of obese subjects (Wiesner et al, 2010), arterial rigidity in menopausal women (Nishiwaki et al, 2011), antioxidants (Pialoux et al, 2009a; Pialoux et al, 2009b; Pialoux et al, 2010), or altitude sickness in pilots (Debevec et al, 2010; Moniaga and Griswold, 2009). This interest in hypoxic exposure has also led to research in animals (Wenjun, Xudong, Xiaogang, Zheng and Zhenxi, 2010; Martinez-Bello et al, 2011). However, despite the current enthusiasm for training under hypoxic conditions, it is still not possible to unequivocally state that hypoxic exposure, of whatever type, is clearly beneficial for sporting performance.

As a result, the aim of this paper is to attempt to determine whether hypoxic exposure improves sporting performance or not. This task will be undertaken using a scientific yet didactic approach using the most recent and relevant research in this field. To this end, two specific objectives have been established, namely to describe the main altitude simulators cited in the scientific literature and to present the state of the art.

## METHOD

A literature review of the SPORTDiscus and MedLine databases was performed in September 2011, in order to attempt to obtain a summary of the use of hypoxic exposure during cardiovascular endurance training, using the keywords *hypoxic training*, *hypobaric chamber*, *normobaric hypoxia* and *intermittent hypoxia*, matching the results against *training*, *exercise* and *adaptation (physiology)*. No restrictions were placed on publication year, and the criteria for including an article in this review were as follows:

- The article must cover the fields of physical activity and sports science
- It must be in the top 20 articles according to the EbscoHost relevance classification.

This search allowed us to collect some of the most relevant papers concerning hypoxic exposure from the past 30 years. If we had been more specific (for example searching only for papers concerning the beneficial effects of intermittent hypoxic exposure in sportspeople), we would have compromised the global review nature of this paper. Furthermore, our decision to take the relevance classification into account allowed us to select various of the most well-known articles from a list containing several hundred references, all of which, given the nature of this review, could not be included.

Finally, web pages for some of the most relevant companies in the hypoxia-based training industry, such as CAT, Biolaster, Go2Altitud or Altitrainer, were also reviewed to gain more up-to-date information regarding the devices currently used.

## RESULTS

### Main altitude-simulating devices

#### *Hypobaric rooms using diluted nitrogen*

These apartments, which were designed in Finland in the early 1990s, simulate the hypoxic conditions found at an altitude of approximately 2000–3000 metres whilst maintaining an atmospheric pressure similar to that found at sea level ( $\approx 760$  mm Hg), hence they are known as *normobaric hypoxic apartments* (Wilber, 2001).

To achieve this, 100% compressed  $N_2$  gas is introduced into the room via a ventilation system (under normal conditions, air contains approximately 20.9%  $O_2$  and 78%  $N_2$ ), thus reducing the oxygen content to around 15% and therefore the desired degree of hypoxia.

#### *Hypobaric chambers*

Hypobaric chambers simulate hypobaric conditions up to an altitude of around 6000 metres. They make use of a device that extracts and filters  $O_2$  from the air in the chamber and then reintroduces it with the desired reduced partial oxygen pressure. They are also known as hypoxic sleeping devices due to their ease of assembly, with no building work required, and small size.

#### *Inhaler devices*

These modern devices allow the inhalation of air with a lower oxygen content, depending on the altitude to be simulated, at any time and without installation. As a result, the sportsperson can be exposed to hypoxia at home, whether simply sat on the sofa or whilst exercising on an ergometer.

## State-of-the-art: the hypoxia controversy

Numerous authors have studied the effectiveness of training under hypoxic exposure conditions (Wilber, 2001; Böning, 2002; Gore, Clark & Saunders, 2007; Bonetti & Hopkins, 2009). To date, although high-low (Levine & Stray-Gundersen, 1997; Levine & Stray-Gundersen, 2005), low-high (Mori et al, 1996; Katayama, Sato, Ishida, Mori & Miyamura, 1998; Meeuwsen et al, 2001; Hendricksen & Meeuwsen, 2003), and even mixed protocols have been used (Millets, Roels, Schmitt, Woorons & Richalet, 2010; Robertson, Saunders, Pyne, Gore, & Anson, 2010), the majority of studies have concerned intermittent hypoxic exposure at rest (Beidleman et al, 2008, cited in Faria, 2009).

However, despite the increasing popularity of altitude training (either real or simulated), the widely differing results obtained make it difficult to reach a consensus regarding the methodologies to be used with sportspeople. Thus, whereas some authors have reported that hypoxia during exercise is detrimental to performance (Terrados, Mizuno and Andersen, 1985; Billat, 2002; Levine and Stray-Gundersen, 2005), others have found the opposite using very similar protocols (Terrados, Melichna, Sylven, Jansson and Kaijser, 1988; Katayama et al, 1998; Hendriksen and Meeuwsen, 2003).

Meeuwsen, Hendriksen and Holwijn (2001), for example, performed a study with an experimental and a control group in which eight elite triathletes trained for two hours a day on a cycloergometer in a hypobaric chamber simulating an altitude of 2500 metres whereas a further eight performed the same training at sea level. After training for 10 days under hypoxic conditions, the experimental group had a significantly improved  $VO_{2max}$  (7%), mean power, total power developed and peak power in the Wingate Anaerobic Test. These findings suggest that training under hypoxic conditions produces benefits in terms of both aerobic and anaerobic systems. Similar improvements in anaerobic performance have been reported by other authors (Aughey et al, 2005).

However, as noted above, intermittent hypoxic exposure at rest has been by far the most studied in the past few years (Rodríguez et al, 1999; Casas et al, 2000; Villa et al, 2005; Hamlin and Hellemans, 2007; Bonetti et al, 2009; Burtscher et al, 2010; Brugniaux et al, 2011), although widely differing results have been obtained here as well. Thus, some authors have found that intermittent hypoxia at rest improves the performance of sportspeople as well as certain blood parameters, such as erythropoiesis (Bonetti et al, 2009; Burtscher, et al, 2010; Frese & Friedmann-Bette, 2010). The study of Burtscher et al (2010), for example, showed that the running economy of male and female middle-distance runners improved significantly after two hours of hypoxic exposure three times a week for five weeks. This suggests that these sportspeople decreased their maximum oxygen consumption to a given sub-maximum intensity. Likewise, Bonetti et al (2009) showed that 60 minutes of intermittent hypoxia (3 minutes of exposure followed by a further 3 minutes of normoxia) improved the performance of cyclists and triathletes in a specific cycloergometer test, although this improvement had disappeared after 14 days.

In contrast, numerous other authors have found no beneficial effects after a period of intermittent hypoxic exposure (Beidleman et al, 2009; Faulhaber et al, 2010; Feriche et al, 2007; Hamlin et al, 2010). For example, Trujiens et al (2008), found no significant improvement after a program of intermittent hypoxia exposure at rest. These authors separated 23 participants into two equivalent groups, an experimental group whose members rested in a hypobaric chamber simulating an altitude of 4000–5000 metres, and a control group whose members rested in the same chamber but at sea level. This latter group acted as the placebo in this double-blind study. The rest periods for each group were three hours a day, five days a week for a month. Furthermore, each participant continued to train normally, with the differences between these training regimes being minimal as all had the same performance level and even trained at the same club or with the same coach. After four weeks of intermittent hypoxia exposure, the experimental group showed no significant improvement in terms of sub-maximal work economy, as measured by heart rate, lactic acid concentration in blood, ventilation and maximal aerobic speed.

In a related double-blind study, Faulhaber et al (2010) found no significant differences in a time-trial test between two groups of cyclists (an experimental and a control group) after seven sessions of intermittent hypoxic exposure lasting one hour each at a simulated altitude of 4500 metres. Hamlin et al (2010) found very similar results in a group of cyclists. Numerous other studies have also found no significant improvement in sportspeople when using different intermittent hypoxic exposure protocols (Hoppeler, Vogt, Weibel & Flück, 2003; Aughey et al, 2005; Hinckson, Hopkins, Downey & Smith; Rodríguez et al, 2007).

In short, as can be seen from Table 1, there is still no consensus in the scientific community regarding the suitability of hypoxic exposure as a means of improving the performance of sportspeople.

**Table 1.** Summary of various studies that support or reject the benefits of hypoxic exposure.

Improved sporting performance after hypoxic exposure				
	Study	Population	HE Program	Results*
Favourable studies	Katayama et al (1998)	13 healthy adults	4500 m simulated, 6 days	Improved ventilatory response
	Meeuwssen et al (2001)	16 elite male athletes	2500 m simulated, 10 days	Improvement in aerobic and anaerobic tests
	Hendriksen and Meeuwssen (2003)	16 elite male athletes	2500 m simulated, 10 days	Improvement in aerobic and anaerobic tests
	Beidleman et al (2008), in Faria (2009)	10 healthy adults	4300 m simulated, 7 non-consecutive days	Improvements in time taken to perform a cycloergometer test

	Hamlin and Hellemans (2007)	22 sportspeople from different disciplines	8% O <sub>2</sub> in air breathed in chamber, 5 days/week, 3 weeks	Improved times to run 3 km and higher reticulocyte levels
	Terrados et al (1988)	8 competition cyclists	2300 m simulated, 4 days/week, 4 weeks	Lower lactate concentration, increased capillarity, lower anaerobic enzyme levels
	Casas et al (2000)	23 elite mountaineers	4000–5500 m simulated, 9–17 sessions	Increased haemoglobin, red blood cell and reticulocyte levels
	Rodríguez et al (1999)	17 elite mountaineers	4000-5000 m simulated, 9 sessions	Increased exercise time in maximal stress test, and higher haemoglobin, reticulocyte and red blood cell levels
	Villa et al (2005)	6 elite cyclists	4000 m simulated, 3 consecutive weeks	Higher EPO levels
	Frese and Friedmann-Bette (2010)	8 elite runners	2000 m, more than 3 consecutive weeks	Higher EPO levels
	Burschter et al (2010)	11 middle-distance runners	15% oxygen in inhaled air, 3 times/week, 10 weeks	Increased running economy and total exercise time in maximal test
	Mori et al (1996)	6 mountaineers	4000–6000 m simulated, 2 sessions/week, 3 weeks	Increased power production on cycloergometer, decreased lactate production
Unfavourable studies	Trujiens et al (2008)	13 swimmers, 10 runners	4000-5500 m simulated, 5 days/week, 4 weeks	No changes in running economy, heart rate or maximal aerobic speed
	Rodríguez et al (2007)	13 swimmers, 10 runners	4000-5500 m simulated, 5 days/week, 4 weeks	No improvements in VO <sub>2</sub> Max, heart rate or running test performance
	Hinckson et al (2006)	7 elite rowers	Oxygen saturation of 80–90%, every	No significant improvement in time taken to run

		day for 3 weeks	5 km or power generated over 500 m
Aughey et al (2005)	13 athletes	3000 m simulated, 23 consecutive days	Peak oxygen consumption reduced
Hamlin et al (2010)	9 elite athletes	O <sub>2</sub> saturation of 80%, 10 sessions	No significant improvements in a 20 km test on a cycloergometer
Faulhaber et al (2010)	11 cyclists	4500 m simulated, 7 sessions	Mean power in a cycloergometer test decreased
Beidleman et al (2009)	17 healthy adults	4300 m simulated, 7 sessions	No improvements in any variable in a cycloergometer test

\* All improvements are statistically significant at a level of 0.05 or 0.001, depending on the study.

Furthermore, despite finding significant increases in various blood markers, some of the studies that favour hypoxic exposure as a means of improving training (Mounier et al, 2009; Hamlin, et al, 2010) were unable to prove that this resulted in an increased sporting performance, which is the main objective of training.

## DISCUSSION AND CONCLUSIONS

As has been seen throughout this paper, significant scientific progress still needs to be made in order to clearly establish hypoxic exposure protocols that improve sporting performance. There is currently a great deal of controversy surrounding hypoxia as a means of improving the physical abilities of athletes even though altitude training has become increasingly popular amongst athletes and coaches worldwide in the past few years.

Despite this, all the studies considered herein have certain common traits that demonstrate the favourable effects of intermittent hypoxic exposure on the performance of athletes. Although these traits are very general in nature, they may nevertheless serve as a guide to give the reader some idea of the protocols that may prove useful during training. These common elements are as follows (Beidleman et al (2008), in Faria (2009); Bonetti et al, 2009; Burschter et al, 2010; Casas et al, 2000; Frese and Friedmann-Bette (2010); Hamlin and Hellemans (2007); Hamlin and Hellemans (2007); Katayama et al, 1998; Meeuwssen et al (2001); Rodríguez et al, 1999; Terrados et al (1988); Villa et al (2005):

- In terms of altitude: The studies include altitudes of between slightly less than 2000 m and 5500–6000 m;

- In terms of number of sessions received: The studies cover treatment periods of between 6 days and 4 weeks;
- In terms of weekly exposure frequency: The studies tend to include 4 or 5 sessions a week;
- In terms of the length of each session: The studies cover lengths of between 20 minutes and 5 hours, with a mode of 2 hours, a mean of 2 h 15 min and a standard deviation of 1 h 26 min.

However, not all studies whose variables lie within these ranges provided satisfactory results (Faulhaber et al, 2010; Hamlin et al, 2010). Indeed, in an interesting meta-analysis, Bonetti and Hopkins (2009) concluded that the best means of improving sporting performance in elite sportspeople is the “living high-training low” method in natural surroundings, in other words without the use of an altitude simulator.

These marked contradictions between the findings of research studies from all over the world may be due to the inherent variability of the work published in terms of exposure frequency and length, altitude simulated, type of training used and the characteristics of the participants. Likewise, the majority of studies fail to adequately describe the intensity and level of the training undertaken (the term “elite” is far too imprecise in our opinion). Furthermore, as noted by various authors (Chapman, Stray-Gundersen and Levine, 1998; Chapman, Stray-Gundersen, & Levine, 2010), the ability to adapt to hypoxia depends on the individual concerned and, in their opinion, sportspeople can be classified as either “responders” or “non-responders”, in other words those for whom hypoxia results in improved performance and those who do not show a favourable response to such stimuli.

In light of the above, we are still some way from reaching a consensus regarding the optimal characteristics of simulated altitude training. As such, an in-depth understanding of each sportsperson, and their response to hypoxia, is essential when it comes to deciding whether to commence an exposure program or not. In this sense, Lozano (2008) notes that a personalised program should be designed for each individual on the basis of his/her characteristics and physiological responses in order to obtain a benefit from hypoxia-based training. The hypoxia session should thus be considered as one more load to which the sportsperson is subjected and should therefore form part of the programming and overall evaluation of the training load. The coach must take note of the sportsperson's reaction to the hypoxia sessions when it comes to programming the remaining training loads.

Despite this, the leading companies in the altitude-simulator sector appear very confident as regards the benefits of using their hypoxia exposure devices either during training or whilst resting. It is logical that these companies attempt to

support their products scientifically as, as we have seen above, some authors have indeed found promising results as regards simulated altitude and sporting performance. However, the marked difference between the various findings regarding the effects of hypoxia on sporting performance published in the scientific literature prevent us from sharing their enthusiasm.

As a result, we believe that there is still some way to go as far as our scientific understanding of this process is concerned before a set of uniform criteria that can be used to plan hypoxia-based training programs can be established. Indeed, the choice of simulated altitude, type of exposure (LHTL, IHEAR, etc.), its frequency and duration, the type of training undertaken and other relevant parameters remains highly controversial. Thus, hypoxic exposure should currently be used with care and its results cannot be guaranteed.

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