

Interval-Hypoxia- Hyperoxia and sports

Dr. med. Egor Egorov

Hypoxia is a fundamental stimulus that impacts cells, tissues, organs, and physiological systems.

Oxygen is a two-faced Janus, both **necessary and **treacherous**.**

Two main aspects of this problem are hotly discussed:

the **destructive and the **constructive** action of hypoxia.**



J. Barcroft (Cardiff, 1920):

"Hypoxia not only intercepts the machine, but also damages the mechanism"

R. Roach (Hypoxia into the next millenium, 2000):

"Hypoxia is a constant threat throughout life"

N. Sirotinin's school (Kiev, 1939-2012): «Hypoxia (even severe but brief and intermittent) causes beneficial effects on an organism»



Joseph Barcroft
(1872-1947)



Nikolai Sirotinin
(1896-1977)

Paul Bert described the method of rebreathing for the receipt of hypoxic gas mixtures in his book «Barometric pressure: experimental physiological researches» (1878).

The concept of repeated hypoxic training arose before the Second World War because of the need for altitude acclimatization of Soviet pilots, who flew in open cockpits to altitudes of five to six thousand meters

In the 1930's the following basic methods were utilized:

- staying at high-mountain camps for several weeks;
- regular high-altitude flights in planes;
- training in barometric chambers;
- training by inhalation of low oxygen gas mixtures.

Hypoxie

Chronical,
unregulated

Coronainfarkt

Cerebralinfarkt

COPD

Sleepapnoe
(increased the risk
of CHD, CVI,
Hypertension)

Regulated training

Vasoprotection

Neuroprotection

Cardioprotektion

Anti-Stressdefense

Improvement of
general und specific
performance

Oxygen- und carbon dioxide concentration in the atmosphere during the evolution

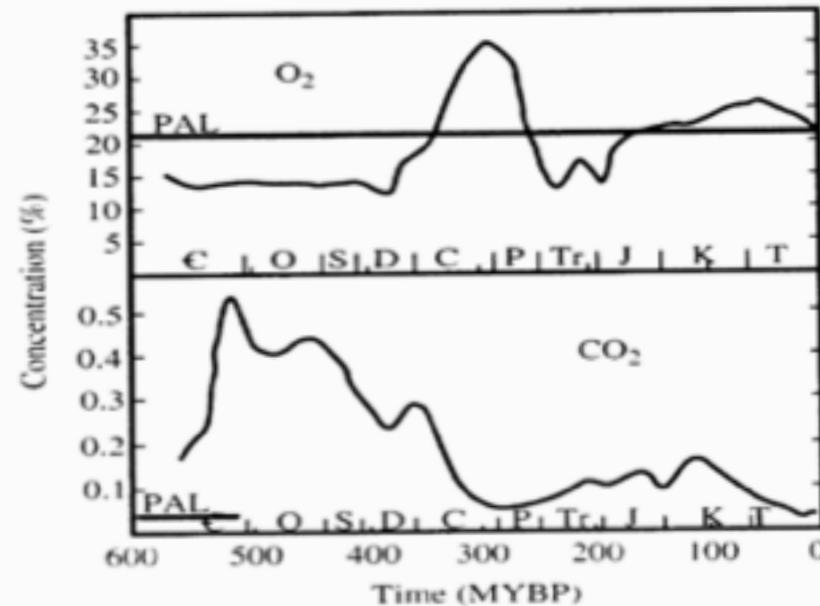
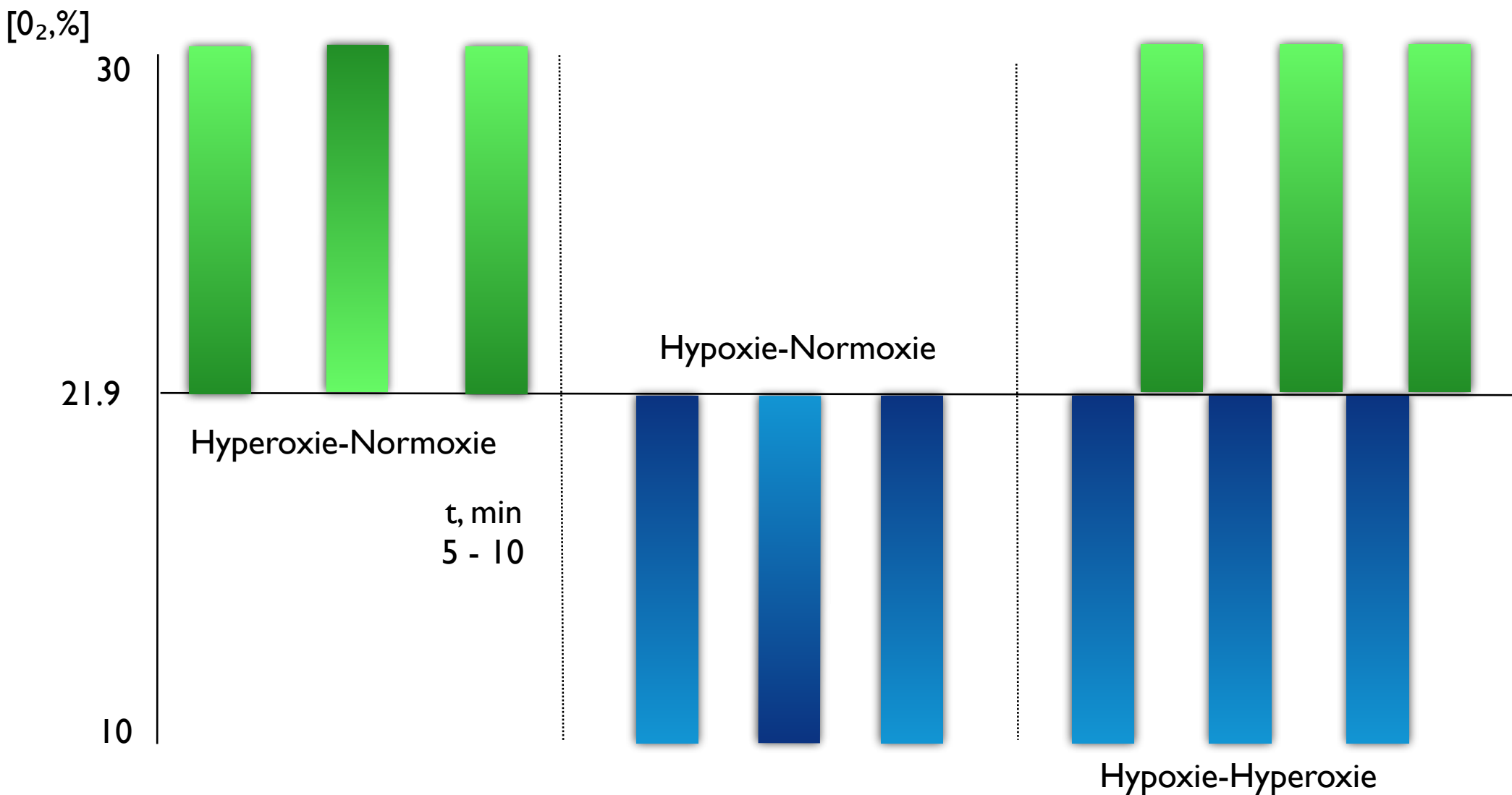
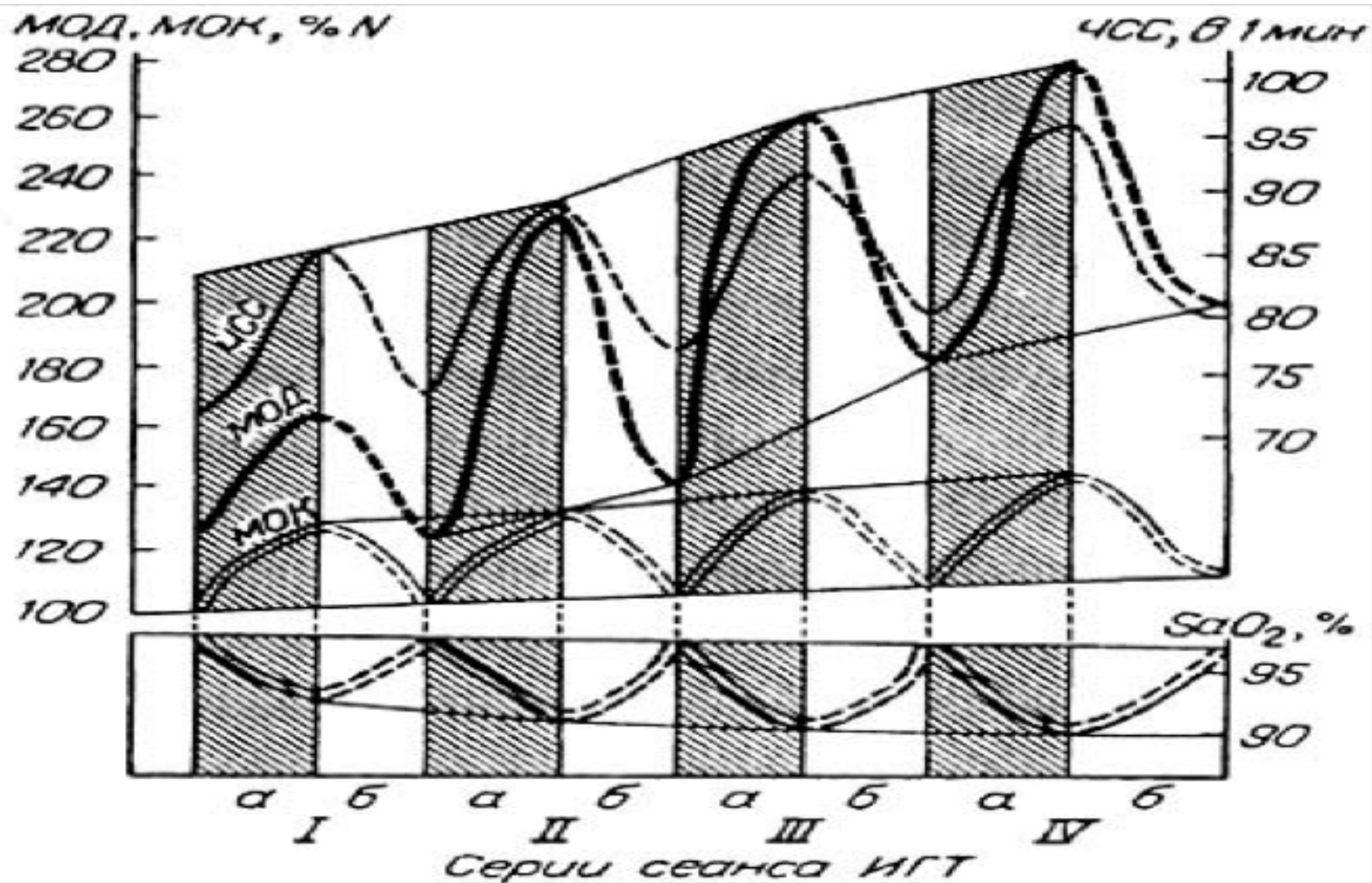


Fig. 1. Estimates of Phanerozoic oxygen and carbon dioxide atmospheric concentrations from Berner (1990, 1994) and Berner and Canfield (1989); see Berner (1997) for a summary of independent geochemical estimates of Proterozoic carbon dioxide concentrations. PAL, present atmospheric level (20.9% O₂; 0.036% CO₂); MYBP, million years before present; C, Cambrian; O, Ordovician; S, Silurian; D, Devonian; C, Carboniferous; P, Permian; Tr, Triassic; J, Jurassic; K, Cretaceous; T, Tertiary.

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 geochemical estimates of Proterozoic carbon dioxide concentrations.

Verschiedene Möglichkeiten der Intervall-Sauerstoff-Therapie





Mechanisms of IHT action

An impressive amount of scientific information has been gathered with regard to the responses to hypoxia, from the integrative systems level to the molecular and genomic level, such as:

- 1. The regulation of respiration and circulation**
- 2. Free radical production**
- 3. Mitochondrial respiration**
- 4. The role of genetic factors (HIFs, MTF-1, NF- κ β , c-Fos, c-Jun etc)**
- 5. Epigenetic mechanisms of adaptation to IHT**

HOW IHT WORKS?

Numerous modern studies collectively show that IHT stimulates regeneration via several mechanisms:

- (1) elicits upregulation of cytoglobins** (myoglobin and neuroglobin), which constitute intracellular O₂ buffer and provide protection against ROS and RNS [*Li, 2006; Esteva, 2009*];
- (2) stimulates insulin-independent glucose transport** and accumulation of glycogen in the oxygen-sensitive cells (cardiomyocytes and neurons), thus increasing instantly available intracellular energy reserves [*Zhang, 1999; Mackenzie, 2009*];
- (3) incites activator protein-1 and HIFs**, the master proteins responsible for numerous adaptational pathways [*Prabhakar, 2001; Kirova, 2014; Nanduri, 2015*];

HOW IHT WORKS?

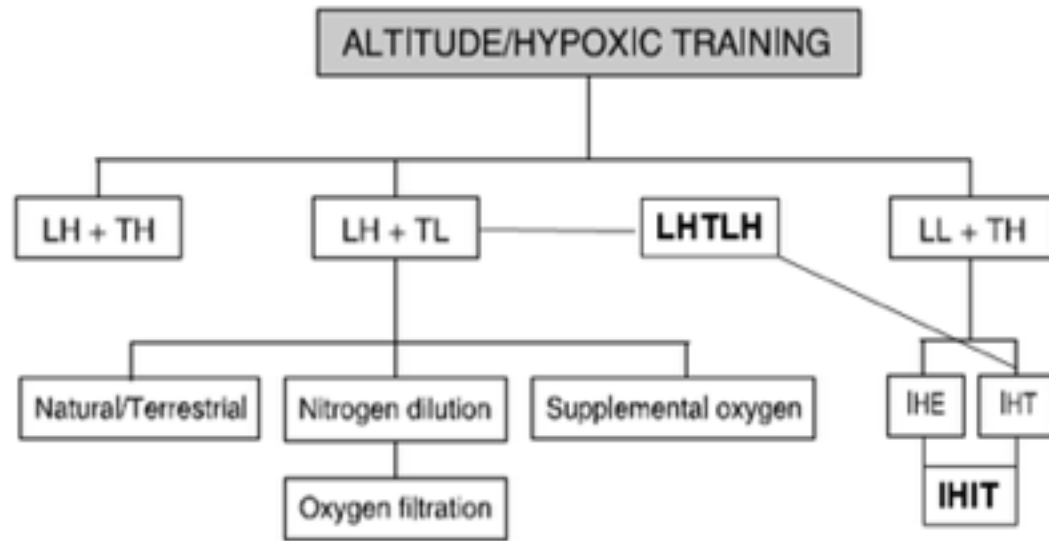
- (4) stimulates erythropoietin (EPO) production having multiple protective and neuroregenerative effects [*Brugniaux, 2011; Dale, 2013*];
- (5) stimulates HSP70, one of the key members in the chaperons family providing protection against injury and facilitating successful recovery after damage [*Zhong, 2000; Sazontova, 2007; Yeh, 2010*];
- (6) incites growth hormone and insulin-like growth factor-1 (IGF-1) release [*Xinghe, 2004; Wang, 2011*];
- (7) enhances antioxidant defense system and increases the resistance of Na⁺-K⁺ ATPase to oxidative stress [*Steshenko, 2010; Mankovska, 2014*];
- (8) stimulates endothelial NO production provoking vasodilation, opening of reserve capillaries and preventing Ca²⁺ overload, which has multiple protective and adaptogenic effects [*Manukhina, 2012*];

HOW IHT WORKS?

- (9) modulates humoral and cellular immunity [Serebrovskaya, 2011; Shi, 2015];**
- (10) stimulates brain-derived growth factor (BDGF) and glial cell-derived growth factor (GDNF) that provide neuronal protection and stimulate neuroregeneration [Wang, 2006];**
- (11) supports mitochondrial biogenesis and induces selection of non-mutated mtDNA [Zhong, 2000; Rozova, 2012];**
- (12) induces changes within mitochondria increasing the O₂ utilization efficiency of ATP production [Lukyanova, 2012];**
- (13) stimulates activity of natural mesenchimal and hematopoietic stem-cells responsible for repair [Serebrovskaya, 2011; Muscari, 2013; Lane, 2014; Miyamoto, 2015].**

Intermittent Hypoxia in Sports: Methods

Several methods of hypoxic training and/or altitude exposure are currently performed by elite athletes:



modified from Wilber, 2007

- traditional “live high-train high” (LHTH),
- “live low-train high” (LLTH),
- “live high-train low” (LHTL) or by using supplemental O₂ when training in altitude (LH + TLO₂),
- “intermittent hypoxic exposure”, IHE (staying passively in hypoxic rooms or breathing hypoxic gas)

- “intermittent hypoxic training”, IHT
- “intermittent hypoxic-hyperoxic training”, IHHT
- “intermittent hypoxic interval-training”, IHIT (combining normoxic and hypoxic exposure during the same interval-training session)
- combining LHTL and IHT (“live high-train low and high”, LHTLH)

USE OF INTERMITTENT HYPOXIC TRAINING IN DIFFERENT SPORTS

Pavel Radziewski and Maria Radziewska
Shchecin University, Poland; Kiev Pedagogical University, Ukraine

In: Intermittent Hypoxia: From Molecular Mechanisms to Clinical Applications.
Eds: Lei Xi & T.Serebrovskaya, Nova Science Publishers, 2009, chapter 24.



IHT IN CYCLIC KINDS OF SPORTS

- Kayak Rowing
- Boat-Racing
- Cycling (Highway)
- Skiing
- IHT in Horse Sport

IHT IN SPORTS GAMES (ACYCLIC SPORTS)

- Volleyball (Women)
- Volleyball (Men)
- Ice Hockey
- European Football (Soccer)

SPORT DISCIPLINES WITH EXTENSIVE INVOLVEMENT OF ANAEROBIC ENERGY-GENERATING PROCESSES

- Short Distance Running (Sprint)
- Short-Track
- Swimming

Summarized data about the use and effectiveness of IHT in various sports

Radziewski & Radziewska, 2009

Regimens:

Kayak paddling (men) [*Bakanichev, 1996; Yugai, 1992*]

15 sessions, 5'x5' - with 11 % O₂ (1 to 5 sessions),
- with 10.5 % O₂ (6 to 9 sessions),
- with 10 % O₂ (10 to 15sessions), alternating with 5' breaks

Boat racing (women) [*Khotochkina, 1993*]

18 sessions, 5'x5' - with 11 % O₂ (1 to 6 sessions),
- with 10.5 % O₂ (7 to 12 sessions),
- with 10 % O₂ (13 to 18sessions), alternating with 5' breaks

Athletics [*Volkov, 2000*]

2-week use: I - 5' x 5' 12 % O₂, number of series per one session - 6;
II – 30'' x 30'' 10 % O₂, number of series per one session - 60;
III - 1' x 1' 10 % O₂, number of series per one session- 30

Summarized data about the use and effectiveness of IHT in various sports

Radziewski & Radziewska, 2009

CONCLUSION

- IHT is a safe and effective method to improve training outcomes in different sport disciplines.
- IHT does not interfere with the traditional training. Moreover, IHT can be even more effective in comparison with the training at high altitudes.
- The method is beneficial not only during the **period of intensive training**, but also during all the **other periods of training cycle**, and even as the partial training substitute for athletes whose physical activity is **limited by trauma**.
- IHT regimes per se are very flexible, and can be easily selected depending on the **type of sport discipline and even individually**.
- The method is reproducible and the discovered positive effects of IHT in elite athletes are real.

EFFECTS OF INTERMITTENT HYPOXIA TRAINING ON PEAK PERFORMANCE IN ELITE ATHLETES

G. P. Millet, X. Woorons, B. Roels

Doha, Qatar; Bobigny, France; London, UK

In: Intermittent Hypoxia: From Molecular Mechanisms to Clinical Applications. Eds: Lei Xi & T.Serebrovskaya, Nova Science Publishers, 2009, chapter 23.

The benefits of IH methods in elite athletes is discussed, such as:

- intermittent hypoxic exposure by staying passively in hypoxic rooms;
- breathing hypoxic gas (“intermittent hypoxic exposure”, IHE);
- hypoxic training during continuous or interval-training session (“intermittent hypoxic training”, IHT).

Conclusions

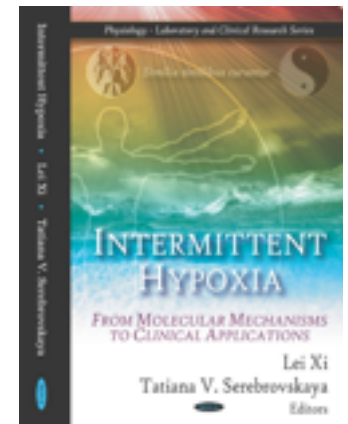
- IHT seems more beneficial than IHE in performance enhancement
- The intensity of the exercise in hypoxia *per se* could play a role in adaptations at the molecular level in skeletal muscle tissue.
- It is unlikely that IHT induce any improvement in VO₂max due to the altitude dose. However, improvement in athletic performance is likely to happen with high-intensity (above ventilatory threshold) due to increase in mitochondrial efficiency and pH / lactate regulation.

Millet et al, 2009

IHT: Summary and proposals for athletes

Just before the competitive phase, athletes engaged in endurance sports should include to their training program two training sessions a week at a simulated altitude of 2500-3000 m.

After warming at low intensity, they should perform 30 to 45 minutes of high intensity exercises (in series of 10 to 20 minutes), around their anaerobic threshold measured in under hypoxia. The athletes could also spend, in addition of to IHT, three hours in hypoxia at rest, 4-5 times a week to obtain a greater improvement in aerobic capacity.



The effects of intermittent hypoxic training on aerobic capacity and endurance performance in cyclists

Czuba et al., *Journal of Sports Science and Medicine* (2011) 10, 175-183 (Poland)

The aim of the present study was to evaluate the efficacy of IHT with 95 % of lactate threshold workload (WR_{LT}) on aerobic capacity and endurance performance in well-trained cyclists.

For three weeks, the subjects performed **3 training sessions per week in normobaric hypoxia environment ($O_2 = 15.2\%$)**.

The results indicate **a significant increase in VO_{2max} , VO_{2LT} , WR_{max} , WR_{LT} and change in lactate concentration (ΔLA) during incremental test in H group.**

Also **a significant decrease in time of the time trial** was seen, associated with a significant increase in average generated power (P_{avg}) and average speed (V_{avg}) during the time trial.

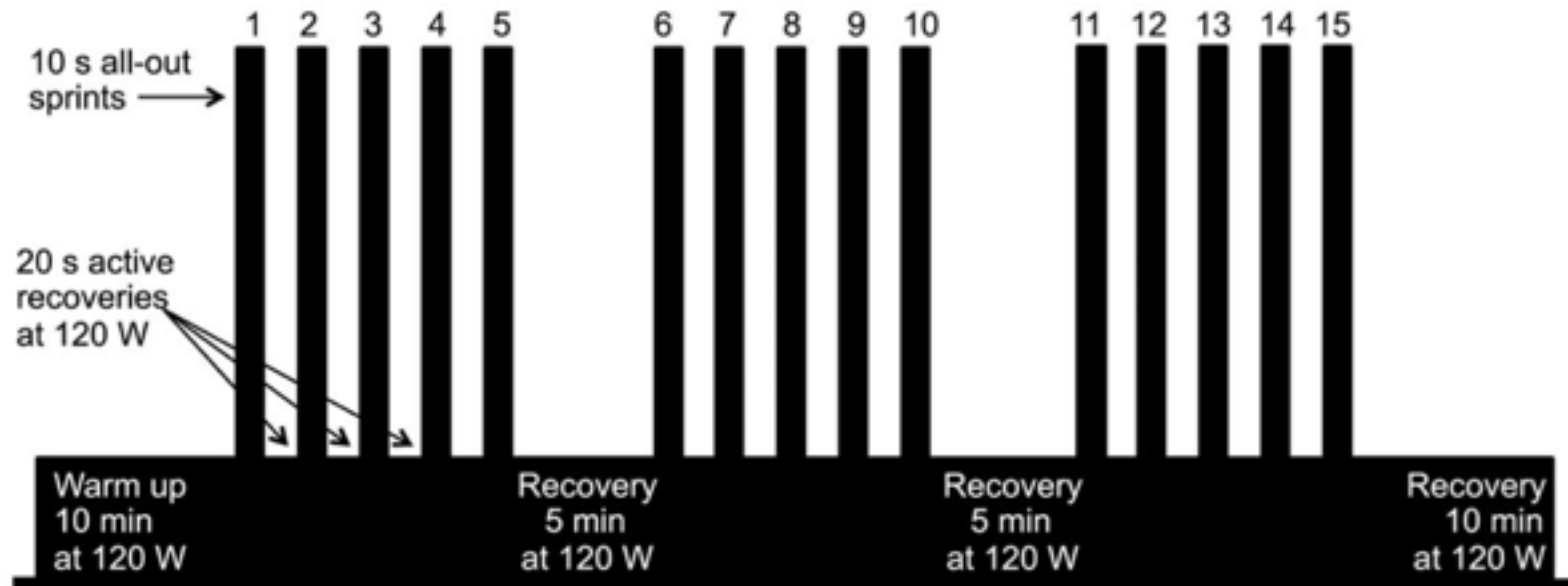
The intermittent hypoxic training (IHT) applied in this research **did not significantly affect the hematological variables** considered: number of erythrocytes (RBC), hemoglobin concentration (HGB) and haematocrit value (HCT).

This data suggests that **IHT at lactate threshold intensity and medium duration (30-40min) is an effective training means** for improving aerobic capacity and endurance performance at sea level.

Significant Molecular and Systemic Adaptations after Repeated Sprint Training in Hypoxia

Faiss et al., PLoS ONE 8(2), 2013

40 trained subjects completed 8 cycling repeated sprint sessions in hypoxia (RSH, 3000 m) or normoxia (RSN, 485 m), 3 sets of 5x10 s all-out repeated sprints with a 5 min recovery period at 120 W between sprints.



Larger performance improvement after repeated sprint training in hypoxia than for to the same training in normoxia was observed.

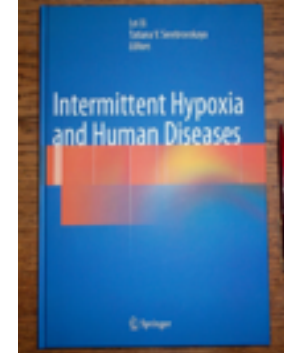
Repeated sprint training in hypoxia leads to:

- i) increased variations of blood perfusion possibly delaying fatigue during a repeated sprint ability (RSA) test;
- ii) specific molecular adaptations large enough for inducing further improvement in systemic RSA performance.

Adaptation to Intermittent Hypoxia/Hyperoxia Enhances Efficiency of Exercise Training

Sazontova et al, 2012

In: Lei Xi & T. Serebrovskaya (Eds). Intermittent Hypoxia and Human Diseases / Springer, UK, 2012



In experiments on rats it was shown that:

Adaptation to physical load and its combination with adaptation to variable oxygen levels increased the resistance of membrane structures to **free radical oxidation** at the expense of excessive activation of **antioxidant defense enzymes** in the course of physical training, which was partly compensated by adaptation to **hypoxia/normoxia** and was **fully prevented** by adaptation to **hypoxia/hyperoxia**.

A positive effect of IHT can be attained through the use of a novel technique **combining interval hypoxia with hyperoxia**.

Intermittent Hypoxia and doping ???

Sanchis-Gomar et al. (2009) performed an interesting experiments on rats, who had received **500 IU of** recombinant human erythropoietin **rHuEPO-alpha** three times a week for 2 weeks. These rats were then divided into two groups: one group was exposed intermittently to hypoxia (equivalent altitude of 4,000 m, 12 h per day), the other was not.

The authors conclude, IHT after rHuEPO-alpha administration can significantly modify the main haematological parameters tested by the anti-doping authorities. So, IHT should be banned as a doping procedure.

Guido Ferretti (Eur J Appl Physiol, 2010) made an objection:

Intermittent hypoxia exposure does not improve performance per se, is not harmful to health, is not contrary to the spirit of sport more than altitude acclimatization.

IHT in sport practice: benefits and disadvantages

Only the dose makes the poison

Paracelsus, 1538



Galvin et al, Br J Sports Med 2013 :

Athletes and teams in intermittent sports could confidently choose to implement repeated sprint training sessions in hypoxia to improve sports specific endurance in a relatively short period of time.

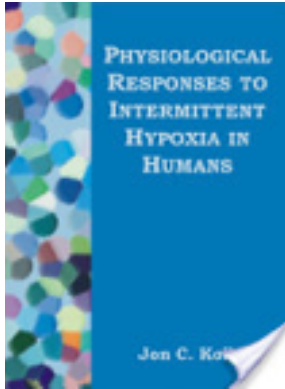
Gatterer et al., Journal of Sports Science and Medicine, 2014:

Hypoxia sprint training, in comparison to normoxia training, might lead to better running speed maintenance during the repeated sprint ability test.

Conclusions

The proper choice of the hypoxic dosage depending on individual's reactivity and the kind of sport must be titrated for each sportsman to avoid negative effects of hypoxia and to augment the favorable properties.

Kolb JC.

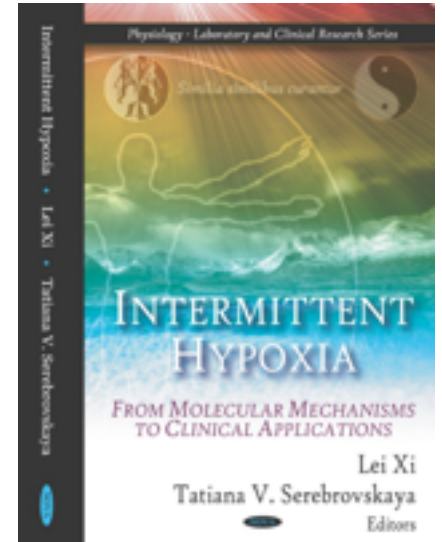


Physiological responses to intermittent hypoxia in humans.

Boca Raton, Florida (USA), 2004

Lei Xi & Tatiana V. Serebrovskaya (Eds)

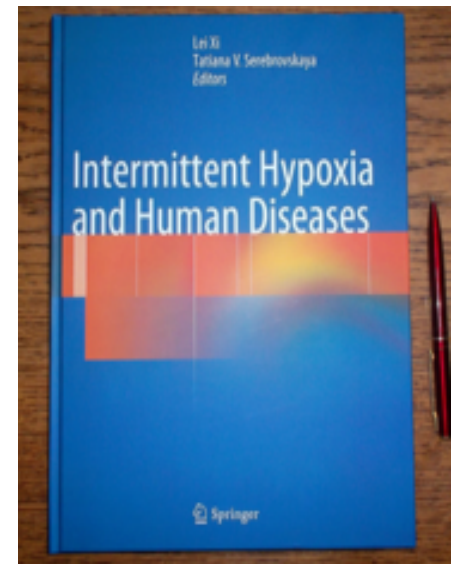
Intermittent Hypoxia: From Molecular Mechanisms to Clinical Applications



Nova Science, 2009

Lei Xi & Tatiana V. Serebrovskaya (Eds)

Intermittent Hypoxia and Human Diseases



Springer, UK, 2012

S.B. Singh et al. (eds.)

Translational Research in Environmental and Occupational Stress, *Springer India 2014*

Thank You very much for your attention!