Combining hypoxic methods to maximize physical performance

From endurance athletes… to team sport players… and patients
Altitude/Hypoxic Training

LHTH

1960-
Altitude/Hypoxic Training

LHTH

1960-

LLTH

URSS ? 1950
2000 -

Altitude/Hypoxic Training

- LHTH
- LHTL
- LHTLH
- LLTH

- Natural/Terrestrial
- Nitrogen dilution
- Supplemental Oxygen
- Oxygen filtration
- IHE
- IHT
- IHIT


Altitude/Hypoxic Training

LHTH

Natural/Terrestrial

Nitrogen dilution

Supplemental Oxygen

Oxygen filtration

LHTL

LHTLH

LLTH

IHE

CHT

IHT

RSH

IHIT

(HH / NH)


Altitude/Hypoxic Training

- LHTH (HH)
- LHTL (HH / NH)
- LHTLH (HH / NH)
- LLTH (HH / NH)

Subcategories:
- Natural/Terrestrial (HH)
- Nitrogen dilution (NH)
- Supplemental Oxygen (HH)
- Oxygen filtration (NH)

References:
Why ?

Underlying mechanisms
Erythropoiesis vs. non-hematological factors

How ?

LHTH vs. LHTL vs. IHE/IHT  (IHIT and LHTLH)
Altitude x duration / intensity

HH (terrestrial) vs NH (simulated)

for Who ?

Endurance vs. “lactic” vs. intermittent sports

When ?

Periodization in the yearly program
From endurance athletes...
% Change in Red Cell Mass

- Control: -0.5%
- 1 wk N₂ house: 1.5%
- 1 wk N₂ + 2 wk alt: 2.2%

Levine and Stray-Gundersen, 2006
% Change in Red Cell Mass

- Control: -0.5%
- 1 wk N₂: 1.5%
- 1 wk N₂ house: 2.2%
- 3 wks N₂: 4.3%
- 3 wk Alt: 4.3%
- 4 wk 1800-3000m: *
- 4 wks 2500m: *
- low dose EPO: *

Levine and Stray-Gundersen, 2006
% Change in Red Cell Mass

- Control: -0.5%
- 1 wk N2 house: 2.2%
- 1 wk N2 + 2 wk alt: 4.3%
- 3 wk N2: 4.3%
- 3 wk Alt: 7.1%
- 4 wk 1800-3000m: 7.9%
- 4 wks 2500m: 8.7%
- Low dose EPO: * (statistically significant)

* Levine and Stray-Gundersen, 2006
LHTH - Optimal altitude for erythropoiesis?

Owing to the flat shape of the oxyhemoglobin dissociation curve above 60 mmHg, changes in $P_\text{a}O_2$ may not have much effect on $S\text{a}O_2$.

$P_\text{a}O_2$ values below 60 mmHg are reached from altitudes of about 2500 m (Anchisi et al., 2001)

Optimal altitude for LHTH are therefore slightly below this altitude (2200-2500 m) due to the combined effect of altitude- and exercise-induced desaturation (Woorons et al. 2007)
LHTH - Return to sea-level

1. a *positive* phase (2 to 4 days)
   - hemodilution
   - ventilatory adaptations

2. a *negative* phase (5-12/15 days) of progressive reestablishment of sea-level training volume and intensity.
   - altered energy cost
   - neuromuscular loss of adaptation

3. a third *positive* phase (after 15 to 21 days) characterized by a *plateau in fitness*.
   - increase in O$_2$ transport
   - delayed HVR benefits
   - increased economy

4. A *FOURTH* *negative* phase (30-35 days)?
   (Bonetti and Hopkins 2009; Issurin 2007)
Why ?  
Erythropoiesis  
Increase in Hb and red blood cell mass

How ?  
Altitude : > 1800 - 2200 – 2500 m  
Duration : min 3-weeks.  
Up to 4 weeks

for Who ?  
Endurance : 2-4 times a year  
“lactic” : once during winter training  
Intermittent: LMTM for general fitness

When ?
Altitude/Hypoxic Training

- LHTH (HH)
- LHTL (HH / NH)
- LHTLH (HH / NH)
- LLTH (HH / NH)

- Natural/Terrestrial (HH)
- Nitrogen dilution (NH)
- Supplemental Oxygen (HH)
- Oxygen filtration (NH)

IHE
CHT
IHT
RSH
IHIT (HH / NH)
LHTL - Increased VO$_{2\text{max}}$ / Improved performance

(Levine & Stray-Gundersen, 1997)
(Levine & Stray-Gundersen, 1997)
### LHTL – HH vs NH

**NH: Prémanon**
- 1200m
- $F_iO_2$: 15.8 ± 0.8%
- BP: 664.9 ± 6.7 mmHg
- $P_iO_2 = 121.4 ± 4.9$

**HH: Fiescheralp**
- 2250m
- $F_iO_2$: 20.93 ± 0.03%
- BP: 579.7 ± 23.4 mmHg
- $P_iO_2 = 121.3 ± 4.8$

*Same $P_iO_2$*
LHTL – HH vs NH

Legend:
- 3km running test
- Pre- and Post-test

- 2250m
- 1200m
- Sea level

Training loads quantification
- Lead-in
- LHTL
- Lead-out

(Saugy et al., 2014)
Sleep quality (questionnaire) higher in HH (Saugy et al., 2014)
Performance

(Saugy et al., 2014)
Augmented red cell volume vs non-hematological factors

**Why?**

- Economy *(Schmitt et al., 2006)*
- Muscle buffering capacity *(Gore et al., 2001)*
- Hypoxic ventilatory response *(Townsend et al., 2002)*

Performance increase by 1-3% vs. similar sea-level training.

**How?**

- **Altitude** - HH (terrestrial) > NH (simulated)
  - 2200 – 2500 m for erythropoietic effect (terrestrial)
  - Up to 3000 m for non-hematological factors *(Brugniaux et al. 2006)*
- **Duration**
  - 4 wks for inducing accelerated erythropoiesis *(Ge et al., 2002)*
  - 2 wks enough for non-hematological factors *(Gore et al., 2001)*
- **Hypoxic daily dose**
  - Beyond 16 h.day for erythropoietic effect *(Wilber, 2007)*
  - Shorter (?) for non-hematological changes.

**For Who?**

- All

**When?**

- Prior the major competitions
## Variability of responses

<table>
<thead>
<tr>
<th></th>
<th>Physiological Adaptations</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$H_b_{mass}$</td>
<td>4mM speed</td>
</tr>
<tr>
<td><strong>Multiple 2-wk altitude</strong></td>
<td>0.9%</td>
<td>0.9%</td>
</tr>
<tr>
<td>(swimmers, &lt;10h·d$^{-1}$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Repeated 3-wk LHTL</strong></td>
<td>2.8%</td>
<td>6.5%</td>
</tr>
<tr>
<td>(runners, 14h·d$^{-1}$)</td>
<td>1st</td>
<td>2nd</td>
</tr>
<tr>
<td><strong>Extended 6-wk LHTL</strong></td>
<td>4.0%</td>
<td>1.2%</td>
</tr>
<tr>
<td>(runners, 14h·d$^{-1}$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Combined LHTL+TH</strong></td>
<td>3.6%</td>
<td>2.8%</td>
</tr>
<tr>
<td>(runners, 14h·d$^{-1}$ +TH)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>3-wk TH</strong></td>
<td>-0.7%</td>
<td>0.4%</td>
</tr>
<tr>
<td>(runners, TH 4·wk$^{-1}$)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Garvican et al.
to team sport players...
Altitude/Hypoxic Training

- LHTH (HH)
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  - Natural/Terrestrial (HH)
  - Nitrogen dilution (NH)
  - Supplemental Oxygen (HH)
    - Oxygen filtration (NH)
... and patients...
**Adipose Tissu Hypoxia**

Reduced oxygen tension in tissue in obese patients (Ye 2009)

HIF-1α is increased in the adipose tissue of obese patients and its expression was reduced after surgery-induced weight loss (Semenza 2002)

Angiogenesis deficient in adipose tissue of obese mice: VEGF expression not increased (Ye 2004).

**H-induced inflammation**

Obesity induces a chronic low-grade inflammatory state.

H induces gene expression in adipocytes and macrophages (Wood 2009)
## Compensatory adaptations to Hypoxic exposure or exercise

<table>
<thead>
<tr>
<th>Respiratory system</th>
<th>Cardiovascular system</th>
<th>Cellular and metabolic</th>
<th>Regulation of body weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyperventilation</td>
<td>↑ basal and max HR</td>
<td>↑ HIF-1 and VEGF</td>
<td>↓ basal leptin levels</td>
</tr>
<tr>
<td>↑ lung diffusion capacity</td>
<td>↑ peripheral vasodilation</td>
<td>↑ Angiogenesis</td>
<td>↑ adrenergic system</td>
</tr>
<tr>
<td>↑ CO₂ reserve in sleeping</td>
<td>↑ VO₂max</td>
<td>↑ diameter of arterioles</td>
<td>Basal noradrenaline remains high post-treatment</td>
</tr>
<tr>
<td>↓ Sleep desaturation</td>
<td>↓ Pro-inflammatory factors</td>
<td>↑ angiogenesis</td>
<td>↑ blood serotonin levels</td>
</tr>
<tr>
<td>↑ ventilatory response during exercise</td>
<td><strong>Cardiovascular protection</strong></td>
<td>↑ glycolytic enzymes &amp; mitochondria</td>
<td>↓ Appetite</td>
</tr>
<tr>
<td><strong>Improves respiratory function</strong></td>
<td></td>
<td>↑ Hb–O₂ affinity</td>
<td><strong>↑ body weight loss</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>↑ O₂, Fe and glucose conveyors</td>
<td></td>
</tr>
</tbody>
</table>
### Compensatory adaptations to Hypoxic exposure or exercise

<table>
<thead>
<tr>
<th>Brain</th>
<th>Cardiovascular system</th>
</tr>
</thead>
<tbody>
<tr>
<td>↑ vasoreactivity</td>
<td>↓ hypertension  NO inactivation</td>
</tr>
<tr>
<td>↑ cerebral blood flow and oxygenation</td>
<td>↑ release vasodilators (NO/NOS pathway)</td>
</tr>
<tr>
<td>↓ desaturation</td>
<td>↑ circulating angiogenic factors</td>
</tr>
<tr>
<td><strong>Implements cerebral function</strong></td>
<td>↑ peripheral <strong>vasodilation</strong></td>
</tr>
<tr>
<td></td>
<td>↓ Arterial stiffness</td>
</tr>
<tr>
<td></td>
<td>↓ Pro-inflammatory factors</td>
</tr>
<tr>
<td></td>
<td>Oxidative stress modulation</td>
</tr>
<tr>
<td></td>
<td>↑ exercise-induced Hypoxemia –</td>
</tr>
<tr>
<td></td>
<td>compensatory vasodilation</td>
</tr>
<tr>
<td></td>
<td><strong>Normalises blood pressure</strong></td>
</tr>
</tbody>
</table>
Thank you

Any Questions?
Few steps beyond..

La préparation physique.
D. Legallais & G. Millet
2007, Masson

S’entraîner en altitude
G. Millet & L. Schmitt
2011, deBoeck Univ

L’endurance.
Millet G. (ed), 2006
Edition EPS